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RESEARCH ARTICLE

# Multi-Type Equipment Selection and Quantity Decision Optimization in Intelligent Warehouse

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**ABSTRACT** The distribution warehouse in the field of trade express is still dominated by manual operation, which has disadvantages in terms of accuracy, timeliness and economy. Choosing intelligent logistics equipment that can meet different operation links and reasonably setting the number of logistics equipment will help to improve the warehouse operation efficiency and reduce the warehouse operation cost. This paper proposes a multi-objective optimization method to solve this problem. We build a collaborative optimization model of multi-type logistics equipment selection and quantity decision to meet the whole process of intelligent distribution warehouse. The model takes the total equipment cost, return on investment and warehouse operation efficiency as the optimization objectives, and considers the constraints of workload satisfaction, equipment utilization, area occupation and selection rules. We use genetic algorithm combined with penalty function to solve the model. The example shows that this method can meet the requirements of intelligent warehouse operation, and realize the economic selection and quantity decision of logistics equipment for loading and unloading, storage, sorting, palletizing and film winding. And furthermore, it is concluded that the shelf access operation can be completed by both loading and unloading equipment, and the total cost is better.

**INDEX TERMS** Intelligent warehouse, equipment selection, equipment technical parameters, quantity decision, model configuration, genetic algorithm.

## I. INTRODUCTION

Smart logistics is the only way for the development and transformation of logistics industry. Under the traditional manual operation mode, the logistics industry is a labor-intensive industry, and the shortage of labor has become a common problem in the industry. Fewer and fewer school-age laborers are willing to engage in labor-intensive and low-tech jobs such as loading and unloading and handling in the logistics industry. In addition, the manual operation mode also has a series of problems in terms of operation accuracy and timeliness. Taking the picking operation as an example, according to the research, at present, the manpower for handling the picking operation is over 50%, and the time for picking operation accounts for 30%-40% of the whole delivery time. Moreover, long-term repetitive work is easy to make people feel tired and boring, which leads to high picking error rate and low picking efficiency. For express goods with relatively large volume and weight, it is necessary to carry the goods many times by manual picking, which is of great work intensity.

More and more logistics enterprises begin to apply new technologies and intelligent equipment to replace manual operations. The complexity of express distribution operation scene is one of the important and difficult points to be overcome in the process of realizing express distribution automation. At present, there are many types of transport vehicles, such as flatbed trucks and vans, in the actual operation scene serving the distribution of express goods. There are many kinds of transportation modes in cargo transportation, such as pallet transportation, container cage transportation and parts transportation. There are many types of goods

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**FIGURE 1. Common intelligent logistics equipment in warehouse.**

packaging, such as cartons and woven bags. Goods categories include hardware, household appliances, grain and oil and other categories. Therefore, it is the premise and foundation to analyze the operation mode and process of intelligent express distribution for different goods categories to solve the current difficulties in express distribution.

At the same time, under the trend of intelligent logistics development, more diverse and mature automated and intelligent logistics equipment has been continuously developed and applied, such as: unmanned forklift, automated guided vehicle (AGV), automatic mechanical arm, automatic sorting line, stacker, automatic packaging equipment and so on. Common intelligent logistics equipment is shown in Figure 1. These different types of automation equipment have various models, different functions and different efficiencies. As far as the model is concerned, only unmanned forklifts can be divided into forward-moving, counterweight, stacking, three-way fork, side fork, etc. As far as functions are concerned, all kinds of equipment can be divided into handling equipment, sorting equipment, storage equipment, etc. As far as efficiency is concerned, there are differences in the efficiency of various types of equipment in handling a single piece of goods. It is necessary to consider the efficiency matching of the equipment needed to connect the operation links in order to ensure the smooth and orderly operation process.

To sum up, how to combine the characteristics of express logistics distribution operation, select intelligent logistics equipment to meet different operation links, and reasonably set the technical parameters and quantity of logistics equipment to ensure smooth and efficient operation process is an urgent practical development problem. Therefore, we propose a collaborative optimization method of multi-type logistics equipment selection and quantity decision to meet the whole process of intelligent distribution warehouse. Our main contributions and novelties are as follows:

(1) We consider the interaction between various equipment selection and quantity decision in intelligent distribution warehouse, and analyze the equipment types required in each operation link.

(2) We established and solved the optimization model of equipment selection and quantity decision in intelligent distribution warehouse. To the best of our knowledge, this problem has not been studied or solved in the relevant equipment configuration literature.

(3) We design a genetic algorithm with penalty function to solve the model. Through the calculation of an example, we analyze the influence of different mixing rules of loading and unloading equipment on the economic selection and quantity decision of logistics equipment.

The article is organized as follows: Section II introduces the latest literature review of related issues in detail, analyzes the shortcomings of existing research and puts forward the research focus of this paper; Section III describes the problem and constructs the optimization model of various equipment selection and quantity decision. Section IV introduces the solution algorithm; Section V provides a case study; Finally, Section VI introduces the conclusion and future work.

## II. RELATED WORK

This part mainly summarizes the research status quo from three aspects: equipment selection, quantity decision-making and their coordination.

### A. SELECTION OF WAREHOUSE EQUIPMENT

Equipment selection refers to the selection of equipment needed for various operations in the warehouse for all kinds of goods. The selection process is limited by the applicable fields, functions and performance characteristics, the workload and working environment requirements of all kinds of equipment.

From the perspective of the scope of the equipment studied, most of the existing studies are aimed at making selection decisions for material handling equipment. Chan et al. [1] studied the selection of material handling equipment such as conveyors, industrial trucks, automatic guided vehicles, hanging conveyors, cranes, etc. Chakraborty and Prasad [2] studied the selection of industrial trucks in manufacturing organizations, taking into account 11 customer requirements and 12 equipment technical specifications. Hornáková et al. [3] studied the selection of a forklift used for material handling in an industrial tire production enterprise. In addition, in recent years, some scholars have also studied the selection of storage systems, sorting systems and other equipment. Zaerpour et al. [4] studied the selection of manual and automatic storage systems, taking into account factors such as shelf investment cost, operating cost, storage capacity and throughput. Calzavara et al. [5] studied the equipment selection of vertical lifting module in small item order sorting, and compared it with manual sorting system equipped with carton rack considering technical and cost factors.

From the point of view of selection method, almost all the existing research on equipment selection adopts multi-criteria decision-making method. Chakraborty and Banik [6] used analytic hierarchy process (AHP) to study the selection of the best material handling equipment in a specific processing environment, and determined the most critical and reliable criteria in the selection process through sensitivity analysis. Yazdani-Chamzini [7] proposed a handling equipment selection model based on fuzzy analytic hierarchy process and fuzzy technique for order preference by similarity to an ideal solution (TOPSIS). Hadi-Vencheh and Mohamadghasemi [8] studied the selection of material handling equipment by establishing a mixed fuzzy multi-criteria decision-making model. Nguyen et al. [9] proposed an integrated multi-criteria decision-making model based on fuzzy analytic hierarchy process and fuzzy additive ratio evaluation method to solve the problem of conveyor selection. Özceylan et al. [10] adopt a multi-criteria decision-making method based on fuzzy, and consider four indicators of cost, quality, flexibility and performance to give decision-making suggestions for equipment selection. Soufi et al. [11] proposed a multi-criteria decision-making technique based on AHP to realize the selection of materials and equipment in manufacturing plants. In addition, a few studies have adopted mathematical programming method to solve the problem of equipment selection. Sujono and Lashkari [12]; Mahdavi et al. [13] integrated the job assignment and material handling equipment selection model in flexible manufacturing system (FMS) into the 0-1 integer programming model to obtain the overall optimal solution.

### B. QUANTITY DECISION OF WAREHOUSE EQUIPMENT

Part of the research gives a solution to the problem of equipment quantity decision by constructing a single objective function model with the lowest cost or the least equipment. More commonly, the quantity decision of equipment is regarded as a multi-objective decision-making problem affected by multiple factors, that is, a multi-objective optimization problem. Then the mathematical programming model is established and solved by heuristic method. Yuan and Gong [14] established a queue network model for the scene of sorting system composed of automatic handling robots and movable shelves, and calculated the optimal number and speed of automatic handling robots. Liu et al. [15] studied the task scheduling and quantity decision-making of AGV, and optimized the task scheduling and quantity of AGV by constructing a multi-objective optimization model, considering the charging task and the variable speed of AGV. Jiang [16] studied the problem of multi-robot picking order batch processing and shelf number decision-making in warehouse, established a two-stage model with the objective function of maximizing the sum of average similarity of all picking stations and balancing the picking times of picking stations, and solved it by dynamic clustering algorithm. The results show that it can effectively reduce the number of shelves and improve the picking efficiency of multi-robot system in warehouse. Tang et al. [17] studied the equipment configuration quantity of AGV unmanned warehouse and the coordinated scheduling problem of AGV- picking station with two resources. In order to achieve the minimum equipment configuration and operation costs and the shortest order completion time, they established a two-stage mathematical model and designed a two-stage genetic algorithm to solve it. Polten and Emde [18] studied the task scheduling and quantity decision-making problem when AGV visited a very narrow channel in the warehouse, and solved it based on neighborhood search algorithm. Grznár et al. [19] combined genetic algorithm with commercial simulation software to study the optimal number of workers in warehouse sorting, so as to achieve the goal of improving sorting speed and optimizing the number of workers.

### C. COLLABORATIVE OPTIMIZATION OF WAREHOUSE EQUIPMENT SELECTION AND QUANTITY DECISION

Equipment selection and quantity decision affect each other, so it is necessary to consider equipment selection and quantity

**TABLE 1. Research on equipment selection and quantity decision-making.**

| literature | equipment selection | quantity decision of equipment | scene | equipment type | objective function | approach |
|---|---|---|---|---|---|---|
| Ulutas et al. [21] | √ | - | logistics system | stackers | price, capacity, lift height , warranty period, fork length | Multiple-Criteria Decision-Making approach |
| Zhang et al. [22] | √ | - | equipment system | multi-equipment | development cost | a hybrid method integrated network DEA and grey target model |
| Aghajari et al. [23] | √ | - | underground hard rock stopes | mining equipment | technical specifications, economic and environmental issues, stope conditions, management and operational issues | Multiple-Criteria Decision-Making approach |
| Zhou et al. [24] | √ | √ | manufacturing industry | machining devices | economy, energy consumption, technology, inter-enterprise collaboration | a fuzzy multi-objective decision-making approach |
| Liu et al. [25] | - | √ | logistics system | AGV | minimizing the maximum completion time | improved genetic algorithm with modified critical-path based searching |

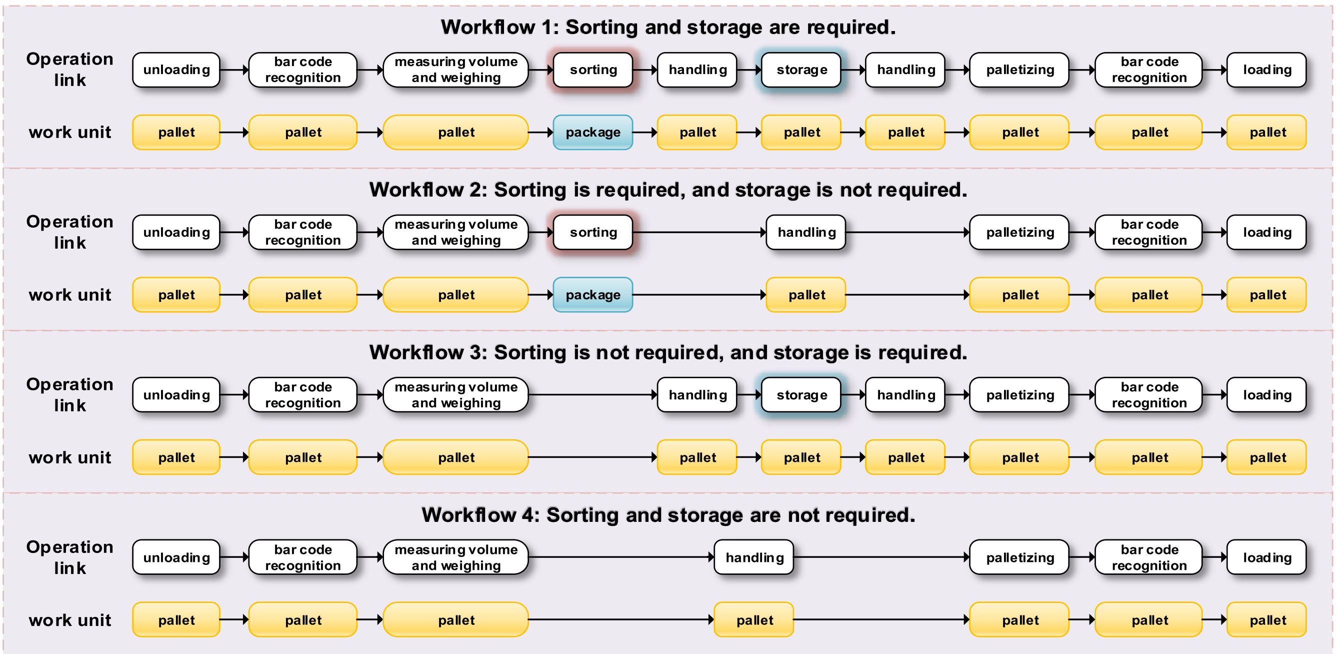


**FIGURE 2. Operation process of intelligent express distribution warehouse.**

decision as a whole. However, the research data in this field is still relatively lacking. The simulation of logistics warehouse can be helpful to the research of collaborative optimization of equipment selection and quantity decision. Kato and Kamoshida [20] proposed a multi-agent simulation environment for logistics warehouse, and modeled and simulated the warehouse to design and evaluate possible system configurations.

Generally speaking, although some research achievements have been made in the field of equipment selection and quantity decision-making, there are still some limitations, as shown in Table 1. The research methods mainly include multiple-criteria decision-making approach and genetic algorithm. Among them, the multi-criteria decision-making method needs to input many parameters, which is subjective and has poor performance in solving complex and large-scale equipment. Genetic algorithm is intelligent, and has good applicability to multi-type equipment selection and quantity decision. There are three main limitations in the research field. First, in the aspect of equipment selection, the research content is mostly single type or single equipment selection, and the range of equipment selected is mostly concentrated in material handling equipment. There is a lack of research on the selection of multi-type equipment on the basis of comprehensive consideration of the operation relevance between multi-equipment. Second, in the aspect of equipment quantity decision-making, there are many research documents on the quantity decision-making of loading and unloading equipment, few on the quantity decision-making of other types of equipment such as sorting equipment, and even less on the comprehensive optimization of various types of equipment quantity decision-making problems. And the research scenes are mostly manufacturing enterprises, factories, etc., and there is a lack of literature focusing on intelligent logistics warehouse scenes. Third, the research content in equipment selection and collaborative optimization of quantitative decision-making is insufficient. Most of the existing studies have divided equipment selection and quantity decision into two problems to solve in turn, and few studies have considered the interaction between equipment selection and quantity decision.

Therefore, in this paper, aiming at the scene of commercial logistics distribution warehouse, considering the total cost of equipment, return on investment and warehouse operation efficiency, a multi-objective programming model is constructed to realize the selection and quantity decision optimization of a variety of intelligent equipment in a less populated warehouse. The focus of this paper is to analyze the operation process of intelligent distribution warehouse, clarify the types of equipment required in each operation link, and summarize the common influencing factors of various equipment selection and quantity decision, which effectively supports the construction of optimization model. Genetic algorithm is used to solve the model, and the optimal configuration of equipment is obtained, so as to maximize the return on investment of intelligent equipment.

## III. EQUIPMENT SELECTION AND QUANTITY DECISION MODEL OF INTELLIGENT WAREHOUSE

### A. PROBLEM DESCRIPTION

The intelligent express distribution warehouse studied in this paper refers to the express distribution warehouse that can realize the whole process with fewer people by using intelligent logistics equipment. The work flow of intelligent distribution warehouse is shown in Figure 2. The work units include pallets and spare parts. The work flow of each work unit is different and the proportion of work volume is relatively fixed, including unloading, handling, sorting, storage, palletizing and loading.

According to the operation link, we divide the optional equipment into storage equipment, sorting equipment, loading and unloading equipment, palletizing equipment, film wrapping equipment and information technology equipment. According to the operation process of intelligent express distribution warehouse, we analyzed the equipment functions required by different operation links and operation units, and preliminarily determined the optional equipment types, as shown in Table 2.

**TABLE 2. Intelligent express distribution warehouse equipment requirements.**

| serial number | operation link | work unit | optional equipment type |
|---|---|---|---|
| 1 | unloading | pallet | handling equipment |
| 2 | access operations from shelves | pallet | handling equipment |
| 3 | horizontal handling in warehouse | pallet | handling equipment |
| 4 | loading | pallet | handling equipment |
| 5 | bar code recognition | pallet | information technology equipment |
| 6 | measuring volume and weighing | pallet | information technology equipment |
| 7 | supply and remove packages for sorting process, and palletizing | package | palletizing equipment |
| 8 | sorting | package | sorting equipment |
| 9 | storage | pallet | storage equipment |
| 10 | wrapping film | pallet | film wrapping equipment |

The problems studied in this paper include two sub-problems: equipment selection and quantity decision. The problem of equipment selection refers to the selection of appropriate logistics equipment for different operation links of different operation units, that is, different operation activities. First, determine the type of logistics equipment; The second is to determine the technical parameters of logistics equipment, that is, choose different types of logistics equipment. In the same operation activity, different types of equipment can be used jointly, that is, multiple models can be selected at the same time. The problem of quantity decision refers to the need to determine the configuration quantity of each type of equipment after equipment selection. The space occupied by the corresponding number of equipment needs to meet the requirements of warehouse space; The operation capacity of the equipment needs to meet the workload demand of the warehouse; The operation efficiency of equipment with sequential operation activities needs to be properly matched.

The research object of this paper is a planned intelligent distribution warehouse, and the facilities have been determined. It is necessary to determine the equipment models selected by the intelligent distribution warehouse and the configuration quantity of each type of equipment to ensure that the whole process of the warehouse can be completed, meet the workload and efficiency requirements of the warehouse, and minimize the total cost of equipment.

### B. MODELING

According to the operation status of intelligent distribution warehouse, for the convenience and universality of research, we made the following seven assumptions:

(1) Assumption of facility elements: The facility conditions of the intelligent distribution warehouse have been determined, including the length, width and height of the warehouse, the ground bearing capacity, the height of the

platform, the number of parking spaces in and out of the warehouse, etc.

(2) Assumption of goods elements: The goods handled by the intelligent distribution warehouse are divided into various operation units according to the loaded container unit equipment, and the warehousing ratio of each operation unit is determined.

(3) Demand factor assumption: The average daily storage capacity of intelligent distribution warehouse is relatively stable, delivery vehicles arrive in different periods, and the maximum operation demand for simultaneous unloading in a certain period is determined.

(4) Assumption of process elements: The sequence of operation links of different operation units in the intelligent distribution warehouse is determined, and the proportion of operation demand of different operation units in each operation link is determined.

(5) Time factor hypothesis: The total duration of daily average operation of intelligent distribution warehouse is determined.

(6) Assumption of equipment elements: Each type of operation needs one type of equipment to complete, and at least one type of equipment can be selected to complete, and multiple types of equipment can be selected; Equipment for different types of job activities shall not be mixed.

(7) Cost factor assumption: The depreciation cost of equipment is calculated by the average life method.

On this basis, in the whole operation process of the warehouse, it is determined that there are n types of operation activities according to the operation units and operation links. One type of operation activities needs one type of equipment to complete, and there are m types of equipment to choose from. The symbols and variables are defined as shown in Table 3.

For the collaborative optimization of equipment selection and quantity decision of intelligent distribution warehouse with minimum total equipment cost, maximum return on investment and maximum operation efficiency of warehouse system, the following mathematical model is established.

**TABLE 3. List of symbols and variables defined.**

| sequence | symbols and variable | symbols and variable descriptions |
|---|---|---|
| 1 | $n$ | Number of job activity types |
| 2 | $E$ | A collection of all optional equipment, $E = \{E_1, E_2, \cdots, E_n\}$ |
| 3 | $E_i$ | Set of alternative equipment for Class $i$ operation activities, $E_i = \{e_{i1}, \cdots, e_{ij}, \cdots, e_{im}\}$ |
| 4 | $m$ | Model number of alternative equipment for each type of operation activity |
| 5 | $e_{ij}$ | Alternative equipment of model $j$ in Class $i$ operation activities |
| 6 | $I$ | Average annual income of warehouses |
| 7 | $b_{ij}$ | The purchase cost of each device $e_{ij}$ |
| 8 | $Nt_{ij}$ | Depreciation life of equipment $e_{ij}$ (estimated service life) |
| 9 | $p_{ij}$ | $p_{ij} = b_{ij}/Nt_{ij}$, Average annual fixed cost of each equipment $e_{ij}$ |
| 10 | $c_{fij}$ | Average annual energy consumption cost of each equipment $e_{ij}$ |
| 11 | $c_{mij}$ | Average annual maintenance cost of each equipment $e_{ij}$ |
| 13 | $c_{ij}$ | $c_{ij} = c_{fij} + c_{mij}$, Average annual variable cost of each equipment $e_{ij}$ |
| 14 | $Q_i$ | Maximum operation demand of Class $i$ operation activities in $t$ period |
| 15 | $t_{ij}$ | Time for equipment $e_{ij}$ to complete unit workload |
| 16 | $q_{ij}$ | $q_{ij} = t/t_{ij}$, The amount of work that equipment $e_{ij}$ can complete in $t$ period |
| 17 | $A$ | Maximum allowable area occupied by warehouse |
| 18 | $a_{ij}$ | Characteristic value of occupied area of equipment $e_{ij}$ |
| 19 | $UR_{ij1}$ | Upper utilization limit of device $e_{ij}$ |
| 20 | $UR_{ij2}$ | Lower utilization limit of equipment $e_{ij}$ |
| 21 | $x_{ij}$ | Decision variables that determine the number of equipment $e_{ij}$ configured |

### 1) OBJECTIVE FUNCTION

$$minZ_1 = \sum_{i=1}^{n}\sum_{j=1}^{m}\left(p_{ij} + c_{ij}\right)x_{ij} \tag{1}$$

$$maxZ_2 = \left(I - \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}x_{ij}\right) \Big/ \sum_{i=1}^{n}\sum_{j=1}^{m} p_{ij}x_{ij} \tag{2}$$

$$maxZ_3 = \sum\nolimits_{i=1}^{n}\sum\nolimits_{j=1}^{m} q_{ij}\cdot x_{ij} \tag{3}$$

Equation (1) represents the average annual total cost of all equipment is the smallest, that is, the sum of the average annual fixed cost and the average annual variable cost is the smallest. Equation (2) represents the average annual return on investment of equipment is the largest, that is, the ratio between the average annual profit of warehouse and the cost of fixed equipment in warehouse is the largest. Equation (3) represents the warehouse system has the highest operation efficiency, and the total amount of work that can be completed by the equipment configured for all operation activities is the largest in a period.

### 2) CONSTRAINTS

$$\sum_{j=1}^{m} q_{ij}\cdot x_{ij} \geq Q_i, \forall i \in \{1, n\} \tag{4}$$

$$UR_{ij1} \geq Q_i \Big/ \sum_{j=1}^{m} q_{ij}\cdot x_{ij} \geq UR_{ij2}, \forall i \in \{1, n\} \tag{5}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij}\cdot x_{ij} \leq A \tag{6}$$

$$\sum_{j=1}^{m} x_{ij} \geq 1, \forall i \in \{1, n\} \tag{7}$$

$$x_{ij} \in N+ \tag{8}$$

| equipment quantity | 2 | 0 | 0 | 1 | 0 | 6 | 0 | 0 | 0 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|

**FIGURE 3.** Chromosome coding model.

Equation (4) represents the workload satisfies the constraint, which means that the sum of the operating capacities of the equipment configured for Class $i$ operation activities is greater than or equal to the maximum operating demand in a period. Equation (5) represents the constraint of equipment utilization rate, which refers to the ratio of the actual workload of equipment to the maximum operating capacity. The upper limit is set to avoid shortening the service life of equipment due to excessive working intensity, and the lower limit is set to ensure the utilization rate of equipment reaches a certain level. Equation (6) represents an area occupation constraint, which means that the total area occupied by the equipment meets the requirements of the usable area of the warehouse. Equation (7) represents a constraint of selection rules, which means that at least one type of equipment is selected for each type of operation activity, and multiple types of equipment can be selected. Equation (8) indicates that the decision variable determining the number of equipment is a non-negative integer.

## IV. ALGORITHM DESIGN

The advantage of genetic algorithm is that it uses a population-based algorithm to solve problems, and it is suitable for the calculation of large-scale problems. At the same time, it does not have too many mathematical requirements for optimization problems and has strong expansibility. Therefore, we choose genetic algorithm to solve the problem.

### A. ENCODING AND DECODING

We use the real-value coding method. Assume that there are $n$ types of operation activities in the warehouse, and each type of operation activity has $m$ types of equipment to choose from. Taking $n = 2$ and $m = 5$ as an example, the alternative equipments are numbered according to the numbers 1-10. Equipment 1-5 is the alternative equipment for "Operation Activity 1" and equipment 6-10 is the alternative equipment for "Operation Activity 2". The gene sequence of chromosome is the number of equipment model, and the gene of chromosome is the selected number of this type of equipment, and one chromosome corresponds to a feasible solution. An example of chromosome model coding is shown in Figure 3.

The chromosome model code indicates that "Operation Activity 1" selects two "Equipment 1" and one "Equipment 4" to complete, and "Operation Activity 2" selects six "Equipment 6" to complete.

### B. POPULATION INITIALIZATION

The random generation method is used to initialize the population. Different population sizes will affect the search speed and final results of the algorithm. Too small population size will cause the genetic algorithm to fall into local convergence, while too large population size will increase the calculation of the genetic algorithm and make the convergence of the algorithm slow. Therefore, it is necessary to select the population size according to the characteristics of the research problem.

### C. SET FITNESS FUNCTION

Fitness function value can be used to measure the pros and cons of individuals, and it is the only evaluation index in the search process of genetic algorithm. Firstly, the objective function value needs to be transformed into evaluation index. Because the deviation function method can not consider whether the optimization direction of the original objective function is maximum or minimum, it can not only eliminate the dimension but also reflect the deviation degree of the current solution from the optimal solution, so the deviation function method is used to transform the multi-objectives in the equipment configuration model in this paper into the evaluation index of fitness function. According to the established equipment configuration model, only one of the three optimization objectives is considered in turn, and the optimal values of the objective function are $minZ_1$, $maxZ_2$ and $maxZ_3$, respectively. Therefore, the comprehensive function is selected as shown in Formula (9):

$$Z = \sqrt{(Z_1 - minZ_1)^2 + (Z_2 - maxZ_2)^2 + (Z_3 - maxZ_3)^2} \tag{9}$$

Among them, $Z_1$ is the average annual total cost index of all equipment, $Z_2$ is the average annual return on investment, and $Z_3$ is the operational efficiency index of warehouse system.

At the same time, genetic algorithm also involves the handling of constraints. For the new population produced after each crossover and mutation, judging whether the individuals meet the constraints increases the complexity of the algorithm, so penalty function can be used to make the fitness value of the infeasible solution very large, so that the infeasible solution is not selected in the iterative process, and the problem is transformed into unconstrained and then solved. Therefore, the fitness function can be obtained as formula (10):

$$fitness = Z + C, amongthem,$$
$$C = \begin{cases} 0, & Individual\ satisfaction\ constraint \\ 10^{10}, & Individual\ does\ not\ meet\ constraints \end{cases} \tag{10}$$

### D. SELECTION OPERATION

The binary tournament algorithm is used for selection operation. Two individuals are selected from the parent population at a time, and the individual with better fitness value is selected to enter the next generation population. And repeat the process, the number of repetitions is the size of the population, and finally select some individuals in the parent population to enter the evolutionary process.

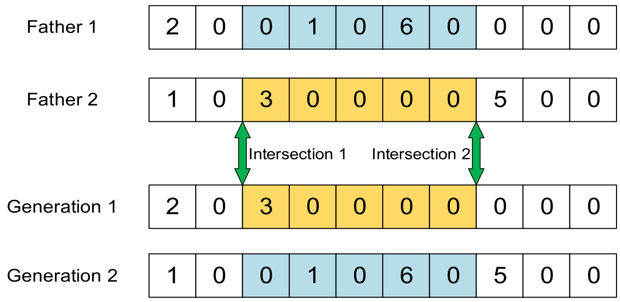


**FIGURE 4.** Cross operation diagram.

**TABLE 4.** Operation efficiency requirement table.

| Operation link | unloading | sorting | Stowage and palletizing |
|---|---|---|---|
| Operation efficiency (pallet/hour) | 75 | 58 | 150 |
| Operation link | Film wrapping | loading | - |
| Operation efficiency (pallet/hour) | 300 | 75 | - |

## E. INTERLACE OPERATION

The method of two-point crossing is adopted for crossover operation. The operation steps are as follows. Firstly, we set the crossover probability (Pc). Secondly, two parents are selected at a time, and the generated random number is compared with the crossover probability to determine whether the parents intersect. If the random number is greater than the crossover probability, the parents are not crossed, and the parents are kept; If the random number is less than or equal to the crossover probability, crossover will be carried out to randomly generate two crossover points, and the gene fragments between the two crossover points in two parents will be exchanged to generate two new offspring individuals. The schematic diagram of crossover operation is shown in Figure 4.

## F. MUTATION OPERATION

Reverse mutation is used for mutation operation. The mutation operation is also based on the set mutation probability (Pm). For each parent selected in the selection operation, a random number is generated and compared with the mutation probability to determine whether the parent is mutated. If the random number is greater than the mutation probability, the parent is not mutated, and the parent is kept. If the random number is less than or equal to the mutation probability, mutation will be carried out, and two mutation points will be randomly generated. The sequence of gene fragments between the mutation points will be reversed to generate new offspring individuals. The schematic diagram of mutation operation is shown in Figure 5.

## G. FORM A PROGENY POPULATION

This step is to ensure that the size of the offspring population is consistent with that of the parent population. The specific steps are to calculate the number of offspring individuals obtained after selection, crossover and mutation, and compare it with the size of the parent population. If the number is insufficient, take the corresponding number of individuals with the highest fitness value in the parent population and form a new offspring population together with the offspring individuals.

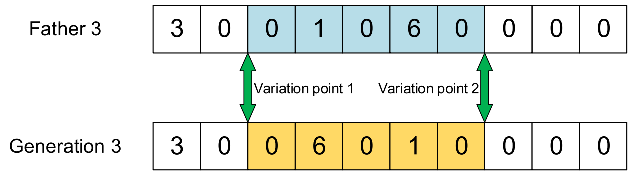


**FIGURE 5.** Operation diagram.

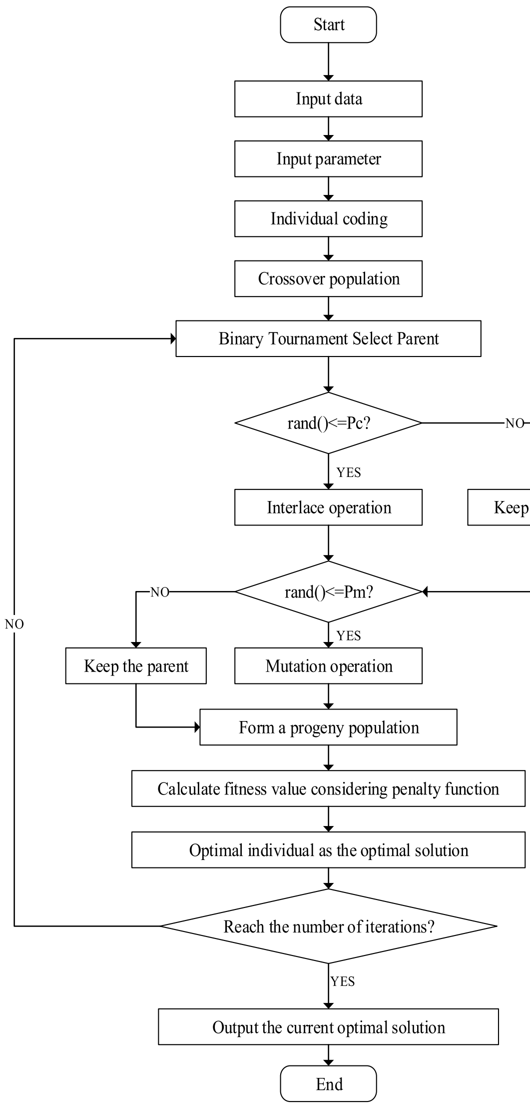


**FIGURE 6.** Overall flow chart of genetic algorithm.

## H. SET TERMINATION CONDITIONS

Taking the maximum number of iterations as the termination condition, when the genetic algorithm runs to the maximum

**TABLE 5. Storage equipment alternative set and single set of shelf parameters.**

| model | storage rack | fixed cost (ten thousand yuan per year) | variable cost (ten thousand yuan per year) | storage capacity (pallet) | occupied area ($m^2$) |
|---|---|---|---|---|---|
| 1 | Two-tier shelves (a group of 8 cargo spaces) | 0.027 | 0.005 | 8 | 18.2 |
| 2 | Three-tier shelves (a group of 12 cargo spaces) | 0.040 | 0.008 | 12 | 18.2 |

**TABLE 6. Alternative set of mechanical arm and single operation parameters.**

| model | mechanical arm | fixed cost (ten thousand yuan per year) | variable cost (ten thousand yuan per year) | operation efficiency (pallet/h) | occupied area ($m^2$) |
|---|---|---|---|---|---|
| 1 | Mechanical arm type 1 | 2.3 | 1.48 | 16 | 4 |
| 2 | Mechanical arm type 2 | 2.6 | 1.70 | 20 | 4 |
| 3 | Mechanical arm type 3 | 2.8 | 1.80 | 24 | 4 |

number of iterations, it will stop searching and output the optimal individual in the current population, that is, the optimal solution.

The overall flow of the genetic algorithm designed in this paper is shown in Figure 6.

## V. EXPERIMENTAL RESEARCH

Taking an intelligent distribution warehouse as an example, the equipment configuration scheme is put forward and the advantages of the scheme are analyzed under the condition that the facility conditions are determined, the operation process is determined and the operation requirements are known.

### A. SERVICE CATEGORY AND WORKLOAD DEMAND

The weight range of goods served in this intelligent distribution warehouse is 4kg-20kg, the volume range is 0.03$m^3$-0.1$m^3$, the length range is 0.20m-0.65m, the height range is 0.25m-0.36m, and the width range is 0.15m-0.59m. And the goods can be stored at room temperature, and there are no fragile goods. All warehouses are standardized, and goods are loaded and transported by pallets. According to the survey data, the pallet size is 1.2m*1.0m, and the stacking height is up to 1.5m. When the goods are piled up, the average number of stacked goods is 50 pieces, the maximum weight is 1000kg, the deadweight of the pallet is 12kg, and the height of the pallet is 150mm.

According to the investigation, the workflow and workload ratio of the intelligent distribution warehouse are shown in Figure 7. The operation links include unloading, sorting, storage, stowage, palletizing and loading. In addition, the handling operation is a necessary joint operation between any two links. The number marked in Figure 7 indicates that the goods that have passed the previous link operation enter the next link operation according to the proportion shown in the number. For example, after the goods have been sorted, 90% of the goods are stored and 10% of the goods are loaded with pallets.

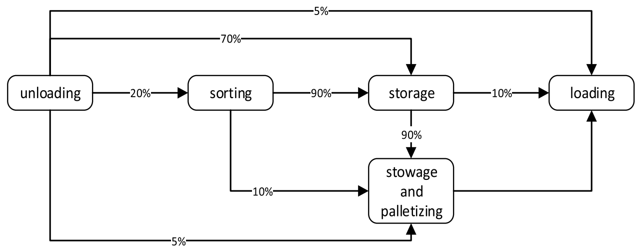


**FIGURE 7.** Operation diagram.

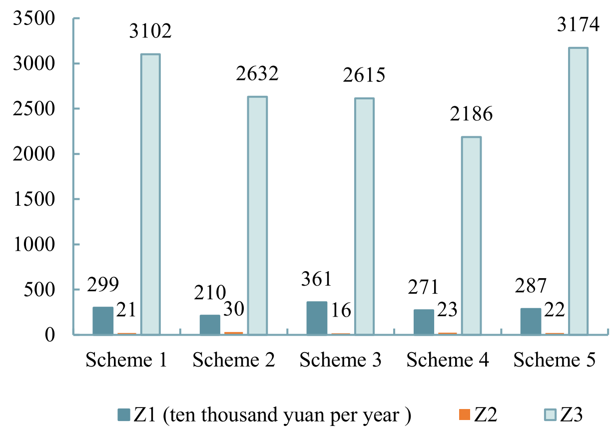


**FIGURE 8.** Equipment configuration target value of each scheme.

There is a sequential operation relationship between the operation links in the intelligent distribution warehouse. According to the survey data, the operation efficiency requirements of each operation link are shown in Table 4.

### B. ESTABLISH EQUIPMENT ALTERNATIVE SET

#### 1) ALTERNATIVE SET OF STORAGE EQUIPMENT

The intelligent warehouse has a large cargo weight and a fast turnover speed, and the operation mode of random access can better meet the demand, so the beam shelf is selected and divided into two models, as shown in Table 5.

**TABLE 7. Optional set of handling equipment and single operation parameters.**

| model | handling equipment | fixed cost (ten thousand yuan per year) | variable cost (ten thousand yuan per year) | working performance (pallet/h) | occupied area ($m^2$) | hoisting height (m) |
|---|---|---|---|---|---|---|
| 1 | Forward moving unmanned forklift | 4.38 | 1.35 | 30 | 5.4 | 4.5 |
| 2 | Trident unmanned forklift truck | 4.38 | 1.35 | 30 | 4.7 | 4.5 |
| 3 | Lifting AGV | 3.00 | 0.77 | 60 | 1.2 | 0.1 |
| 4 | Pallet-carrying AGV | 1.88 | 0.85 | 60 | 2.7 | 0.1 |
| 5 | Cattle AGV | 2.00 | 0.77 | 60 | 1.5 | 0.1 |
| 6 | Fork AGV | 6.00 | 0.97 | 60 | 1.2 | 0.1 |

**TABLE 8. Alternative set of film wrapping equipment and single operation parameters.**

| model | film wrapping equipment | fixed cost (ten thousand yuan per year) | variable cost (ten thousand yuan per year) | working performance (pallet/h) | occupied area ($m^2$) |
|---|---|---|---|---|---|
| 1 | Full-automatic pre-tension film winding machine | 0.66 | 0.57 | 20 | 5 |
| 2 | Full-automatic pressurizing intelligent film winding machine | 1.16 | 0.79 | 25 | 5 |
| 3 | Full-automatic tension-resisting stretching and winding machine | 0.53 | 0.43 | 25 | 5 |
| 4 | High speed online winding machine | 13.97 | 3.12 | 60 | 8 |
| 5 | Full-automatic online film winding machine | 2.66 | 1.41 | 30 | 5.5 |
| 6 | Full-automatic cantilever winding packaging machine | 3.99 | 1.12 | 30 | 11 |

**TABLE 9. Precondition setting of equipment configuration model operation.**

<table>
<tr><th>Setting factors</th><th colspan="2">Operation link</th><th>Scheme 1</th><th>Scheme 2</th><th>Scheme 3</th><th>Scheme 4</th><th>Scheme 5</th></tr>
<tr><td rowspan="4">Handling equipment mixing rules</td><td rowspan="4">Handling</td><td>Loading</td><td>Forward moving unmanned forklift</td><td>Forward moving unmanned forklift</td><td>Forward moving unmanned forklift</td><td rowspan="4">Forward moving unmanned forklift</td><td rowspan="4">① Forward-moving unmanned forklift truck<br>② Choose one of the other five kinds of loading and unloading equipment.</td></tr>
<tr><td>Unloading</td><td>Forward moving unmanned forklift</td><td>Forward moving unmanned forklift</td><td>Forward moving unmanned forklift</td></tr>
<tr><td>Access operations from shelves</td><td>Trident unmanned forklift truck</td><td>-</td><td>Trident unmanned forklift truck</td></tr>
<tr><td>Intra-warehouse transportation</td><td>Select a category from the four categories of AGV.</td><td>Select a category from the four categories of AGV.</td><td>-</td></tr>
<tr><td rowspan="5">Convenience of equipment procurement</td><td colspan="2">Storage</td><td colspan="5">Choose one of two storage racks.</td></tr>
<tr><td colspan="2">Supply packages for sorting process</td><td colspan="5">Choose one of the three mechanical arms.</td></tr>
<tr><td colspan="2">Remove packages from a pallet</td><td colspan="5">Choose one of the three mechanical arms.</td></tr>
<tr><td colspan="2">Load the packages on a pallet</td><td colspan="5">Choose one of the three mechanical arms.</td></tr>
<tr><td colspan="2">Wrapping film</td><td colspan="5">Choose one of six kinds of film wrapping equipment.</td></tr>
</table>

### 2) ALTERNATIVE SET OF SORTING AND STOWAGE PALLETIZING EQUIPMENT

In the sorting operation, the sorting and picking of packages are completed by the mechanical arm, and the conveying and sorting are completed by the automatic sorting line. In the stowage and palletizing operation, the disassembly and palletizing are completed by the mechanical arm, and the film is wrapped.

According to the mechanical arms commonly used in the warehouse, the alternative set of mechanical arms is selected

**TABLE 10. Results of equipment selection and quantity configuration.**

| Scheme | Handling | | | | Storage | Supply packages for sorting process | Remove packages from a pallet | Load the packages on a pallet | Wrapping film |
|---|---|---|---|---|---|---|---|---|---|
| | Loading | Unloading | Access operations from shelves | Intra-warehouse transportation | | | | | |
| 1 | Forward unmanned forklift<br>5 sets | Forward moving unmanned forklift<br>5 sets | Trigeminal type Unmanned forklift<br>11 set | Cattle AGV<br>18 sets | Three-tier shelves (a group of 12 cargo spaces)<br>44 sets | Mechanical arm type 1<br>4 sets | Mechanical arm type 3<br>7 Taiwan | Mechanical arm type 3<br>13 sets | Full-automatic pre-tension film winding machine<br>16 sets |
| 2 | Forward unmanned forklift<br>4 sets | Forward moving unmanned forklift<br>4 sets | -<br>- | Cattle AGV<br>18 sets | Three-tier shelves (a group of 12 cargo spaces)<br>40 sets | Mechanical arm type 2<br>4 sets | Mechanical arm type 1<br>12 sets | Mechanical arm type 2<br>8 sets | Full-automatic tension-resisting stretching and winding machine<br>16 sets |
| 3 | Forward unmanned forklift<br>12 sets | Forward moving unmanned forklift<br>12 sets | Trigeminal type Unmanned forklift<br>16 sets | -<br>- | Three-tier shelves (a group of 12 cargo spaces)<br>41 sets | Mechanical arm type 1<br>5 sets | Mechanical arm type 2<br>15 sets | Mechanical arm type 3<br>7 sets | Full-automatic tension-resisting stretching and winding machine<br>15 sets |
| 4 | Forward moving unmanned forklift<br>24 sets | | | | Three-tier shelves (a group of 12 cargo spaces)<br>38 sets | Mechanical arm type 2<br>3 sets | Mechanical arm type 3<br>10 sets | Mechanical arm type 2<br>13 sets | Full-automatic tension-resisting stretching and winding machine<br>18 sets |
| 5 | Forward moving unmanned forklift<br>15 sets | | | Cattle AGV<br>19 sets | Three-tier shelves (a group of 12 cargo spaces)<br>41 sets | Mechanical arm type 1<br>4 sets | Mechanical arm type 3<br>12 sets | Mechanical arm type 1<br>15 sets | Full-automatic tension-resisting stretching and winding machine<br>20 sets |

as shown in Table 6 under the condition that the rated lifting capacity and working scope meet the requirements.

The sorting efficiency of automatic sorting lines is generally high, and the price difference is not big. The selection is mainly determined according to the type of goods handled. The intelligent distribution warehouse has a wide range of goods weight and volume. According to the characteristics of common types of automatic sorting lines, the narrow-band sorting machine has a wide range of parts, which is suitable for both boxed and bagged goods. Easy to assemble, strong expansibility; The purchase cost is low, so narrow-band sorter is selected. In addition, the automatic sorting line is set to be annular, so that a plurality of package supply points can be set, and the goods do not need to be loaded and unloaded again when the goods are circulated for the second time. According to the investigation, the intelligent distribution warehouse delivers goods to 10 directions at most every day, so the number of sorting crossings with automatic sorting lines is 10. The number of robotic arms for sorting and picking bags is matched with the number of sorting crossings one by one, so 10 robotic arms are needed to complete the sorting and picking bags, and 10 robotic arms with the lowest annual cost are selected to work together, and the efficiency is higher than 160 Torr/h, which can meet the requirement of the maximum efficiency of sorting operation of 58 pallet/hour. Therefore, 10 robotic arms model 1 are selected to complete the sorting and picking bags.

### 3) ALTERNATIVE SET OF HANDLING EQUIPMENT

Under the condition that the rated lifting capacity meets the demand, the alternative set of loading and unloading equipment is shown in Table 7.

#### 4) ALTERNATIVE SET OF FILM WRAPPING EQUIPMENT

According to the common automatic film wrapping equipment in the warehouse, choose the alternative equipment as shown in Table 8.

### C. DESIGN THE OPERATION SCHEME OF EQUIPMENT CONFIGURATION MODEL

According to the operation process of the intelligent distribution warehouse and the alternative set of various types of equipment, the operation of loading and unloading equipment is special, and only the forward-moving unmanned forklift can complete the loading and unloading operations; Only the forward-moving unmanned forklift and the three-way forklift can complete the shelf access operation; All loading and unloading equipment can complete horizontal handling operations. Therefore, it is necessary to consider whether the loading and unloading equipment in each link is mixed or not, and a total of five operation models are designed, as shown in Table 9.

### D. USE GENETIC ALGORITHM TO SOLVE THE PROBLEM

In the genetic algorithm, the population size is set to 500, the number of iterations is set to 500, the crossover probability is set to 0.9, and the mutation probability is set to 0.08, and the above five schemes are solved respectively.

The equipment configuration results corresponding to the five schemes are as shown in Table 10.

According to the equipment configuration results from Scheme 1 to Scheme 5, the three objective function values in the equipment configuration model are obtained as shown in Figure 8. It can be seen that the average annual total cost of equipment configuration scheme 2 is the lowest, which is 2.1 million yuan per year, which can save 0.60 million yuan per year to 1.5 million yuan per year compared with other schemes, and the return on investment is the highest, and the operation efficiency can meet the requirements of warehouse operation. Therefore, equipment configuration scheme 2 is finally selected.

At the same time, we found that the average annual total cost of scheme 3 is the highest without mixing loading, unloading and equipment for accessing from the shelf, while the average annual total cost of scheme 2 is the lowest without mixing loading, unloading and Intra-warehouse transportation equipment. It can be seen that for this intelligent express distribution warehouse, loading, unloading and Intra-warehouse transportation are the bottleneck links, and the efficiency requirements of accessing from the shelf are low. Therefore, accessing from the shelf can be completed by loading and unloading equipment at the same time, and the total cost is better.

## VI. CONCLUSION

This paper takes the intelligent distribution warehouse as the research object, and divides the equipment into six types: storage equipment, sorting equipment, loading and unloading equipment, palletizing equipment, film wrapping equipment and information technology equipment. We established a multi-objective equipment selection and quantity decision model based on total equipment cost, return on investment and warehouse operation efficiency. Moreover, a genetic algorithm for equipment selection and quantity decision model is designed. The effectiveness of the model and method is verified by an example.

There is still something to be further studied in this paper. Due to the fact that the order fluctuates with time in the actual operation of the warehouse, the cost comparison between renting equipment and purchasing equipment can be considered in the process of equipment selection and quantity decision. At the same time, the optimization of automatic sorting process, the flexible setting of automatic sorting and the configuration of automatic sorting equipment on this basis deserve further study. In addition, the spatial arrangement of fixed equipment and the application rules of mobile equipment deserve further study.

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