Research on Multi-objective Storage Planning without Fixed Storage Space in Multi-warehouse

Xiaokang Zhang*, Kaizhen Geng1, Lei Zhang1, Jianjun Yang1

1 713th Research Institute of China Shipbuilding Industry Corporation, Zhengzhou, Henan, 450015, China
*Corresponding author’s e-mail: zxk0819@yeah.net

Abstract: This paper takes multi-objective storage planning with multiple warehouses without fixed positions as the research object, and proposes a solution to this type of problem. The mathematical model of research problem environment is established, and further through the abstract analysis of system environment and storage and transportation rules, the research is carried out from the maximum storage and transportation capacity of storage and transportation system, the balance of the occupancy rate of each warehouse, etc., so as to improve the transportation efficiency of goods in and out of the port. The actual multiple requirements are abstracted into specific mathematical expressions that can be analyzed and calculated according to environmental parameters and rule knowledge bases, and a multi-objective function for system optimization is obtained, which lays a foundation for the subsequent optimization and solution using intelligent optimization algorithms.

1. Introduction
In the context of rapid domestic economic development and economic transformation, the warehousing and logistics industry continues to grow and expand. However, while the scale is rapidly expanding, some complex links have low operational efficiency due to the lack of scientific management and guidance. Goods storage planning is one of the important links. In the warehousing and logistics industry, reasonable storage planning can not only improve the storage capacity of the warehouse and the efficiency of the goods in and out of the warehouse, but also is the basis of a series of subsequent logistics processes. It seems very important.

At present, the research on storage planning mainly focuses on the space arrangement of a single type of goods (or simplifying the goods into a cuboid with the same structural size) in a warehouse with fixed storage positions or shelves. The storage layout in the article considers the efficiency of the goods in and out of the warehouse, the relevance of the goods, etc., and obtains a better solution in the established model [1,2,5]. Due to the increasing complexity of the goods to be stored and the warehouse environment, this relatively simple storage plan for fixed warehouses or single warehouses with shelves has been unable to meet the actual needs in many scenarios. In reality, in most cases, it is necessary to provide storage planning for large warehouses composed of multiple storage areas, and due to the variety and uncertainty of goods, there may not be fixed shelves in the warehouse or planned locations in advance. However, at present, there are very few materials available for research on this kind of problem, so this paper chooses to take multi-target storage with multiple warehouses without fixed positions as the research and analysis direction.
2. Problem Description and Analysis of Solutions

Compared with the more mature single-warehouse fixed-storage storage planning currently studied, multi-warehouse storage planning without fixed-storage is more complicated. Single warehouse fixed location storage only needs to consider the allocation problem once, that is, the goods to be stored are allocated to known cargo locations, and the results of the cargo location allocation are realized through the designed algorithm program to achieve the stability of cargo storage and the efficiency of transshipment access and other optimization goals[3,4]. For the problem of unfixed storage in multiple warehouses, at least two key links must be considered. One is to distribute a variety of goods to be stored to warehouses connected by different channels, and the other is to target the types of goods allocated to each warehouse and the quantity is planned for the location. Moreover, the two links are coupled with each other [6,7]. When allocating the amount of goods to be stored to each warehouse, the upper limit of the storage volume affected by the layout planning of the warehouses and the rules of the storage arrangement in the warehouse should be considered at the same time. In the second link, there is a great probability that the result will not be able to continue to run or the ideal solution cannot be obtained.

Aiming at this problem, this paper explores a feasible solution, the solution process is shown in the Figure 1.

![Flow chart of problem solving process](image)

Figure 1. Flow chart of problem solving process

Step 1: Collect and record the environmental parameters of the storage system and the parameters of the goods to be stored;

Step 2: According to the knowledge base of the storage rules in the warehouse, combining the storage system environment and the size parameters and characteristics of the goods to obtain the storage plan of the single goods in each warehouse;

Step 3: Use the group intelligence optimization algorithm according to the data result of the previous step to obtain a cargo distribution plan for multiple cargo storage;

Step 4: According to the distribution plan and the knowledge base of the goods arrangement rules in the warehouse, the goods of a certain type and quantity allocated by each warehouse are arranged in the warehouse to obtain the final storage planning result.

This article mainly analyzes the key parts of the first three steps.
3. Definition of parameter symbols

![Figure 2. Model diagram of warehousing system](image)

The layout of multiple warehouses and aisles is shown in Figure 2. A total of 4 channels can be connected to the main road, and each channel is connected to 3 warehouses. The structural dimensions of each warehouse and the parameters of the transfer equipment in the warehouse are known. The structural dimensions of various goods to be stored are also known. The storage planning task is to find out the types and quantities of the goods to be stored in each warehouse, and to determine the specific placement of goods in each warehouse, given the types and quantities of the goods to be stored.

Refer to Table 1 for the description of model symbols.

**Table 1. Definition table of model parameter symbols**

| Model parameters | Symbol Description |
|------------------|--------------------|
| wh               | Warehousing system parameter matrix |
| A                | Net width in warehouse |
| B                | Net length in warehouse |
| a1               | The width of the mooring board in warehouse |
| b1               | Length of tether plate in warehouse |
| a2               | The width of the hoisting area in the warehouse |
| b2               | The length of the hoisting area in the warehouse |
| H                | Net height in warehouse |
| dl               | Safety distance in the longitudinal direction between cargoes |
| dw               | Safety distance in the width direction between cargoes |
| d2               | The distance of the tether plate boundary from the inner boundary of the reservoir |
| d3               | Sidewalk width |
| hc               | The minimum distance between the center of the traveling hanger and the surrounding cargo edge |
| gs               | Parameter matrix of goods to be stored |
| num              | Quantity of goods to be stored |
| l                | Cargo length |
| w                | Cargo width |
| h                | Cargo height |
| c                | Stackable storage layers |

**Information input:**

The entire storage system is composed of 12 warehouses distributed in 4 lanes, each warehouse has
its own structure size parameters and internal shipping equipment parameters. In order to facilitate
subsequent calculation and solution and improve the versatility of the program, a warehouse model and
goods to be stored are established separately. In the model, the basic information of the warehousing
system, the type of goods to be stored and the corresponding parameter information are collectively
expressed in the matrix \( \mathbf{wh} \) and \( \mathbf{gs} \). Set the column matrix \( \mathbf{wh} \) \(_{1-12}\) and matrix \( \mathbf{gs} \) \(_{1-8}\) to represent the
parameter information of the 1-12th warehouse and the 1-8th goods respectively.

\[
\mathbf{wh} = \begin{bmatrix}
    \text{wh}1 & \text{wh}2 & \text{wh}3 & \ldots & \ldots & \ldots & \text{wh}12
\end{bmatrix}
\]

\[
\mathbf{gs} = \begin{bmatrix}
    \text{gs}1 & \text{gs}2 & \text{gs}3 & \ldots & \ldots & \text{gs}8
\end{bmatrix}
\]

Information output:
1. Representation method of storage scheme for single goods:
   ① the matrix \( \mathbf{pa} \) represents the number of columns that can be stored in each warehouse for each
   single type of goods;
   ② the matrix \( \mathbf{pb} \) represents the number of stacks that can be stored in each column of each
   warehouse for each kind of goods;
   ③ the matrix \( \mathbf{pab} \) represents the total number of stacks that can be stored in each warehouse for
   each single type of goods.

\[
\mathbf{pa} = \begin{bmatrix}
    \text{pa}11 & \text{pa}12 & \ldots & \text{pa}112
\end{bmatrix}, \quad
\mathbf{pb} = \begin{bmatrix}
    \text{pb}11 & \text{pb}12 & \ldots & \text{pb}112
\end{bmatrix}, \quad
\mathbf{pab} = \begin{bmatrix}
    \text{pab}11 & \text{pab}12 & \ldots & \text{pab}112
\end{bmatrix}
\]

2. Representation of storage schemes for multiple goods:

\[
\mathbf{p} = \begin{bmatrix}
    \text{p}11 & \text{p}12 & \ldots & \text{p}112 \\
    \text{p}21 & \text{p}22 & \ldots & \text{p}212 \\
    \vdots & \vdots & \ddots & \vdots \\
    \text{p}81 & \text{p}82 & \ldots & \text{p}812
\end{bmatrix}
\]

Among them, the matrix element \( \text{p}_{ij} \) represents the number of stacks of the \( i \)-th goods stored in the
\( j \)-th warehouse.

4. Mathematical modeling and analysis

4.1. Single cargo storage planning

Under the set model parameters, the matrices \( \mathbf{pa}, \mathbf{pb}, \mathbf{pab} \) can be solved according to the storage rules
knowledge base, so as to obtain the storage information of each single type of goods in each warehouse.

1) Determine the number of storable columns

First determine the inequality: \( \frac{1}{2} + \text{dl} \geq \text{hc} \) whether it holds

If established, \( \text{dl} = \text{dl} \)

If it doesn't hold, \( \text{dl} = \text{hc} - \frac{1}{2} \)

\[
\text{pa} = \frac{a1 + 2 \cdot (\text{d2} - \text{d3}) + \text{dl}}{1 + \text{dl}}
\]

Judgment inequality: \( \text{pa} \cdot \text{a} + (\text{pa} - 1) \cdot \text{dl} - 1 \leq \text{a2} \) whether it holds

If established, \( \text{pa} = \text{pa} \)

If it doesn't hold, \( \text{pa} = \text{pa} - 1 \)

2) Determine the number of storable goods in each column
Judgment inequality: \[ \frac{w}{z} + dw \geq hc \] whether it holds
If established, \( dw = dw \)
If it doesn't hold, \( dw = hc - \frac{w}{z} \)

\[ pb = \left\lfloor \frac{b1 + dw}{w + dw} \right\rfloor \] 

3) Determine the number of storable stacks
\[ pab = pa.* pb \]

4.2. Multiple cargo storage planning
Through the description and analysis of the problem, and on the basis of the above-mentioned set environmental condition parameters, starting from the three principles of ensuring the maximum storage capacity of the warehousing system, the balance of the space occupancy rate of each warehouse, and the transportation efficiency of the goods in and out of the warehouse, the goods Storage allocation model.

1) Ensure the maximum capacity of the warehousing system
For a specific storage environment, there is an upper limit on the storage capacity. Only a reasonable warehouse and cargo space allocation for the goods to be stored and the existing environmental conditions can make our storage system reach or approach the maximum storage capacity [8].

a) Cargo stacking layers
In this model, there are many parameters that affect the storage capacity of the system. One of the main factors is the number of layers in which goods can be stacked in the warehouse. Due to the limitation of self-weight and pressure-bearing capacity, each cargo has a parameter index of the number of full layers "c". The number of layers that the goods can stack. For a warehouse, when a kind of goods is stored inside, the storable layers are:

\[ c' = \left\lfloor \frac{H}{h} \right\rfloor \]

Judging the relationship between the size of \( c \) and \( c' \), if \( c' \geq c \), it indicates that the warehouse space size satisfies the maximum stacking layer of the goods, if \( c' < c \), it indicates that the warehouse space size cannot satisfy the cargo reaching the maximum stacking layer number. When allocating the goods to be stored in the warehouse, it is preferred to select the warehouse whose space size meets the maximum stacking number of the goods.

Add a loop judgment statement in the program to record the degree of adaptation and matching when each warehouse stores each kind of goods,

Form a 12 * 8 order warehouse-goods fitness evaluation matrix \( assess1 \) [9]. Three values "0", "1", and "2" are used in matrix \( assess1 \) to indicate that the warehouse is not suitable for storing the goods, the warehouse is more suitable for storing the goods, and the warehouse is suitable for storing the goods. Then do the following calculation:

\[ ae1 = assess1 * p \]

\[ as1 = \sum_{i=1}^{12} ae1(i, i) \] 

\[ f_1 = \max \sum_{i=1}^{12} ae1(i, i) \]

b) Warehouse space occupancy
According to the single cargo storage solution obtained, using the data results in the matrix \( pab \), the number of stacks of various ammunition that can be stored in each warehouse can be obtained, and the proportion of space occupied by each stack of cargo in the warehouse can be easily obtained accordingly. Based on the data, a space proportion matrix can be constructed, which is multiplied by the cargo allocation plan expressed by the number of stored cargo stacks to obtain the space occupancy rate \( acl1-12 \) of each warehouse under the allocation plan. Add conditional judgment statements in the program to
control the space occupancy value of the warehouse. In the case that the warehouse can be put down, some allocation schemes with lower warehouse occupancy rates are eliminated.

\[ m \ll ac \ll n \ (n = 1, 2, 3, \ldots 12) \]  

(8)

2) The occupied space of each library is balanced

Since the type and quantity of the goods to be stored are constant, there are 12 warehouses in the set storage environment. Therefore, in order to avoid the imbalance of the task assigned to the warehouses, the individual warehouses are overloaded and the individual warehouses are almost empty. The quantity of the goods to be stored allocated by the warehouse is quantitatively expressed, and the average storage capacity of each warehouse is ensured by tending to average the value.

From the above analysis, the space occupancy rate of each warehouse \( ac_{1-12} \) can be used to quantify the amount of goods in the warehouse. By calculating the variance of this value, it indicates that the evaluation in this kind of goods to be stored for each warehouse plan, each whether the storage task volume of the library is average.

\[
u_{ac} = \frac{\sum_{i=1}^{12} ac_i}{12}
\]

(9)

\[ S_{ac}^2 = \frac{\sum_{k=1}^{12} (ac_k - u_{ac})^2}{12}
\]

(10)

\[ f_2 = \min \left( \sum_{k=1}^{12} (ac_k - u_{ac})^2 \right)
\]

(11)

4.3. Cargo transfer efficiency

a) When multiple goods are stored and allocated for each warehouse, some commonly used goods with a large quantity should be distributed to more channels;

Set in the 8 kinds of goods to be stored, the 6th and 7th kinds of goods have more quantities and the transshipment frequency is higher. In order to improve the transshipment efficiency of the warehousing system, these two kinds of goods must be distributed in as many transport lanes as possible, to avoid the situation that some transport lanes are occupied for a long time, which greatly affects the overall efficiency of the warehouse. The evaluation matrix \( \text{assess}_2 \) is now set to evaluate and screen the planning matrix \( p \) for the storage and distribution of multiple goods generated during the operation of the algorithm, so that the population evolution is proceeding in the direction we expect.

\[
\text{assess}_2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 1 & 0 \end{bmatrix}
\]

(12)

Through the loop statement in the program to obtain the 1 * 12 order matrix \( ae_2 \), starting from the beginning, three numbers as a group, divided into four groups of data. Among the four sets of data, the number of sets with non-zero numbers is set to as2.

\[ f_3 = \max (as2) \]

(13)

b) Goods with higher transshipment frequency are placed in warehouses closer to the main aisle;

Set in 8 kinds of goods to be stored, the transfer frequency of the 1st, 2nd and 8th goods is lower, and they will not be transferred for a long time; the transfer frequency of the 6th and 7th goods is higher, and it will be frequent transshipment; the remaining 3, 4, and 5 cargoes are centered in transshipment frequency. In order to avoid the long-term congestion of the aisle affecting the efficiency of the goods out of the warehouse, the sixth and seventh kinds of goods should be stored in the warehouse close to the main aisle, and the first, second, and eighth kinds of goods should be stored in the warehouse away from the main aisle. In order to make the population evolution direction consistent with the expected effect, the evaluation matrix \( \text{assess}_3 \) is now set:

\[
\text{assess}_3 = \begin{bmatrix} -2 & -2 & 0 & 0 & 0 & 2 & 2 & -2 \\
-1 & gs(1,1) & gs(1,2) & 1 & 1 & 1 & gs(1,7) & gs(1,8) \\
-1 & gs(1,1) & gs(1,2) & gs(1,3) & gs(1,4) & gs(1,5) & -1 & -1 \\
gs(1,1) & gs(1,2) & 2 & 0 & 0 & 0 & gs(1,6) & gs(1,7) & gs(1,8) \end{bmatrix}
\]


\[ ae2 = assess \ast p \]  
\[ f_4 = \min(ae2(1,1) + ae2(1,4) + ae2(1,7) + ae2(1,10) + ae2(2,2) + ae2(2,5) + ae2(2,8) + ae2(2,11) + ae2(3,3) + ae2(3,6) + ae2(3,9) + ae2(3,12)) \]

c) In order to improve the transshipment efficiency and management convenience in the warehouse, the types of goods distributed in each warehouse should be as few as possible;

Due to the variety of goods and the large size difference, the arrangement of the warehouse also needs to consider the problem of tiered transportation, which is complicated and inconvenient for inventory management. In addition, when the crane spreader in the warehouse grabs different sizes of goods, it needs to repeatedly adjust the structure of the spreader to smoothly lift and transport. The process is relatively time-consuming and labor-intensive. The number of types of goods. Set 1 * 12 order matrix \( assess4 \), it is easy to get a variety of goods distribution scheme matrix \( p \) in the program, the number of non-zero values in 8 values in each column, and give the result of all 12 columns of statistics \( assess4 \) is assigned, so we have:

\[ f_5 = \min \sum_{j=1}^{12} assess4(1,j) \]  

4.4. Constraint and objective function

Through the analysis of the storage system environment and the rules of cargo storage and transshipment, the multi-objective function expressions and corresponding constraint functions for multi-objective storage planning problems with no fixed cargo space in multiple warehouses are obtained.

Constraint function:

\[ m \ll ac_i \ll n \ (n = 1,2,3,\ldots 12) \]

Multi-objective function:

\[ f_1 = \max \sum_{i=1}^{12} ae1(i,i) \]

\[ f_2 = \min \sum_{k=1}^{12} (ac_k - u_{ac}) / 12 \]

\[ f_3 = \max(asc2) \]

\[ f_4 = \min(ae2(1,1) + ae2(1,4) + ae2(1,7) + ae2(1,10) + ae2(2,2) + ae2(2,5) + ae2(2,8) + ae2(2,11) + ae2(3,3) + ae2(3,6) + ae2(3,9) + ae2(3,12)) \]

\[ f_5 = \min \sum_{j=1}^{12} assess4(1,j) \]  

5. Summary and Outlook

This paper takes multi-objective storage planning without fixed positions in multiple warehouses as the research object, and proposes a solution to this type of problem. After that, a general mathematical model representing the environmental parameters of the storage system and the information of the goods to be stored was established. Through the analysis of the knowledge base of the storage rules, the storage capacity of the storage system was maximized, the space occupancy rate of each warehouse was balanced, and the shipment of goods into and out of the warehouse was improved. Starting from the three principles, the multi-objective function of the system is obtained, which lays the foundation for the use of intelligent optimization algorithms to solve later. The next work will mainly focus on the algorithm design, select the appropriate intelligent optimization algorithm and improve it, and apply the research results of the text to the algorithm program, and finally obtain the relative optimal solution.
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