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Design Study on Intelligent Storage and Dispensing System for Ship Outfitting Parts

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Abstract: Since the storage allocation and inventory management of outfitting parts have always been a difficult problem for shipyards, an intelligent storage allocation system for ship outfitting parts is developed considering the characteristics of outfitting parts with complex shapes, special structures, short response cycles and high flush requirements. Firstly, to address the problems of ship outfittings with many types, non-uniform dimensions and large weight differences, three key factors are proposed, namely, item relevance, turnover timeliness and storage stability. Secondly, a heuristic algorithm-based optimization method for storage location is proposed for the characteristics of item relevance and turnaround timeliness. Then, considering the characteristics of storage stability, a storage shelf location allocation method based on adaptive differential evolution algorithm is proposed. Finally, an intelligent storage location allocation system for outfitting parts is developed. For this purpose, software testing and trial are conducted based on nearly half a year of real data from shipyards to verify the effectiveness of the model and method.

1. Introduction

With the continuous advancement in shipbuilding technology, the construction cycle of ships is gradually shortening, which puts higher demands on the ship outfitting process. Outfitting, as a key part of the shipbuilding process, involves a large number of outfitting components, the management and storage of which directly affects the construction schedule and cost control. Therefore, the process of outfitting outfitting outfitting outlets management and cargo distribution has become particularly important. Due to the wide variety of outfittings, large quantity, non-uniform dimensions, and large weight differences, it poses many challenges to inbound and outbound outfittings management (Sui et al., 2022)[1]. The large amount of data in the outfitting documents often makes information management and data tracking complex and inefficient. At the same time, the lack of effective planning of outfitting stacking area, often using simple empirical sorting and stacking principles(Fang et al.,2023)[2], leading to the waste of storage space and operational inefficiency. In addition, the allocation of cargo space usually relies on the experience of the management personnel, which lacks scientific basis and reasonable optimization strategy, thus failing to meet the needs of efficient cargo space management(Lei et al.,2021)[3]and material inventory management.

The existence of these problems not only increases the workload of shipyards in the management of outfitting parts, but also leads to a decline in operational efficiency and underutilization of storage space. Outfitting weighing (Li et al., 2019)[4] is also an important part of the construction process of luxury cruise ships. Ship outfitting components usually have large weight, especially in the construction of some large cruise ships. In order to ensure that the outfitting components are not damaged during transportation and storage, it is necessary to weigh each and every outfitting component accurately. To do this, outfitting teams need to use specialized equipment and tools to measure and record the weight of each outfitting component. However, the wide variation in the weight of outfits places high demands on the stability of the racks (Zhang et al., 2019)[5]. In order to avoid tilting or damage to the racks due to uneven weight bearing, the load carrying capacity and stability of the racks need to be considered to ensure safe storage of the outfittings.

In this paper, three characteristics of item association, turnover timeliness and shelf stability are considered. Firstly, heuristic algorithm is used to find the optimal storage space for inbound storage; secondly, adaptive difference algorithm is proposed for space allocation; finally, based on the above, an intelligent storage space allocation system for outfitting parts is developed to verify the feasibility of the algorithm, which improves the stability of the storage.

2. Outline

Due to the characteristics of ship outfittings such as large quantity, non-uniform size, and large weight difference, there are problems such as difficult group distribution, short storage cycle, and difficult storage management, etc. The following three key factors are proposed: item relevance, turnover timeliness, and storage stability.

(1) Item relevance

Item relevance refers to the principle of correlation and flushness between outfittings, i.e. outfittings with high correlation are more likely to be present in the same order at the same time, outfitted at the same time, or stored in a uniform manner due to the similarity in nature and structure of the outfittings.

(2) Turnaround timeliness

The timeliness of turnover mainly refers to the frequency of clothing, that is, based on the order of goods entering and leaving the warehouse, the turnover frequency of goods is similar, and they are stored in a location close to the priority for exports, in order to reduce the distance between high-frequency exports entering and leaving the warehouse, reduce operating time, improve operational efficiency, and reduce operating costs.

(3) Shelf stability

Shelf stability refers to the vertical and horizontal stability of the shelf according to the volume, quality, structure and other factors of the outfitting parts.

In this paper, we focus on three aspects to optimize the allocation of storage space: item relevance, turnover timeliness and shelf stability.

Considering the principles of stable center of gravity of shelves, balanced operation of aisle and shortest operation path, the cargo space allocation based on adaptive difference algorithm is carried out for shelf stability; Stage 3: Developing an intelligent storage space allocation system for outfitting parts and verifying the feasibility of the algorithm by taking a shipyard as an example.

The framework of this paper is shown in Figure 1 below.

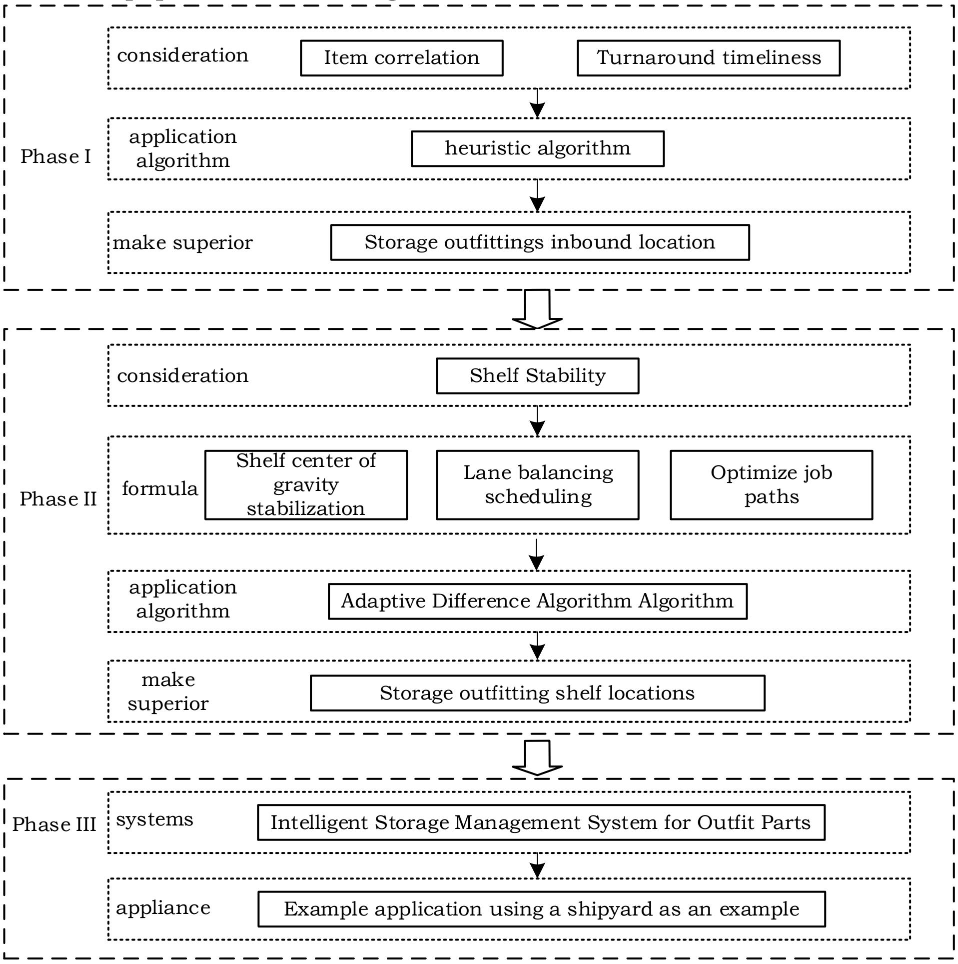

Figure 1: Framework diagram

3. Optimization of outfitting outlets storage and warehousing locations

3.1. Description of the problem

In order to reduce costs and improve the efficiency of warehouse operations, outfitting outlets with high, medium and low turnover rates can be stored in three zones depending on the turnover rate of the material. Inventory turnover is the efficiency of inventory turnover over a period of time and is used to measure the rate of movement of a particular outfitting item in the warehouse. Depending on the stock turnover of outfittings in the warehouse, it is possible to reduce the time taken to move outfittings in and out of the warehouse.

Outfits with an inventory turnover greater than 2 are classified as high turnover outfits, those with an inventory turnover between 1 and 2 are classified as medium turnover outfits, and those with a turnover of less than 1 are classified as low turnover outfits.

3.2. Assumptions of the problem

In response to the above problem description, the following problem assumptions are made:

Assumption 1: Each material has a corresponding inventory turnover value that allows it to be categorized into high, medium, and low turnover outfits.

Assumption 2: Warehouse storage space can be divided into three zones based on turnover rate, i.e. high, medium and low turnover outfitting storage zones for more effective management of outfitting in and out of the warehouse.

Hypothesis 3: The turnover rate of outlets is related to the outfitting and outfitting times, with high turnover outfits having a relatively short in and outfitting time and low turnover outfits having a relatively long in and outfitting time.

Assumption 4: The outfitting plan may need to be adjusted according to the material characteristics and operational requirements of the particular warehouse to optimize cost reduction and operational efficiency.

3.3. Model building

In order to achieve the shortest inbound and outbound operation times for a batch, an objective function can be created. The objective function considers the following factors:

Inbound operation time: shorten the inbound operation time by placing high turnover outfittings close to the inbound aisle where they can be easily removed.

Outfitting time: Reduce outfitting time by placing low turnover outfittings close to the outfitting aisle where they can be easily removed.

Turnover Balancing: Based on the turnover rate of outfittings, the outfittings are distributed to equalize the outfittings flow rate and access time in the warehouse.

The objective function is established as shown in equation (1).

$$f = Min\sum_{t=1}^{n} t_1 \tag{1}$$

where t1 denotes the time required for each entry or exit or entry.

3.4. Algorithmic process

The steps of the inbound outfitting algorithm (Jiang et al.,2020)[6]are as follows, and the flowchart is shown in Figure 2.

(1) When an outfitting piece arrives at the outfitting table, enter the outfitting piece number, obtain the outfitting piece's turnover rate, the outfitting piece's corresponding type, and the outfitting piece's partition code in the outfitting list table.

(2) Search for suitable outfittings according to the principle that outfittings of the same type and part of the outfittings should be together as much as possible. Firstly, cycle through the outfittings according to the outfittings number from the smallest to the largest, search for the outfittings that have not been utilized 100% of the time and the outfittings with the same zoning code, then mark the outfits with outfitting numbers. Finally, it will be put into the warehouse.

(3) If the warehouse cannot be found, according to the principle of high, medium, and low turnover rate of automatic warehouse space division, enter each partition to find suitable warehouse space for storage.

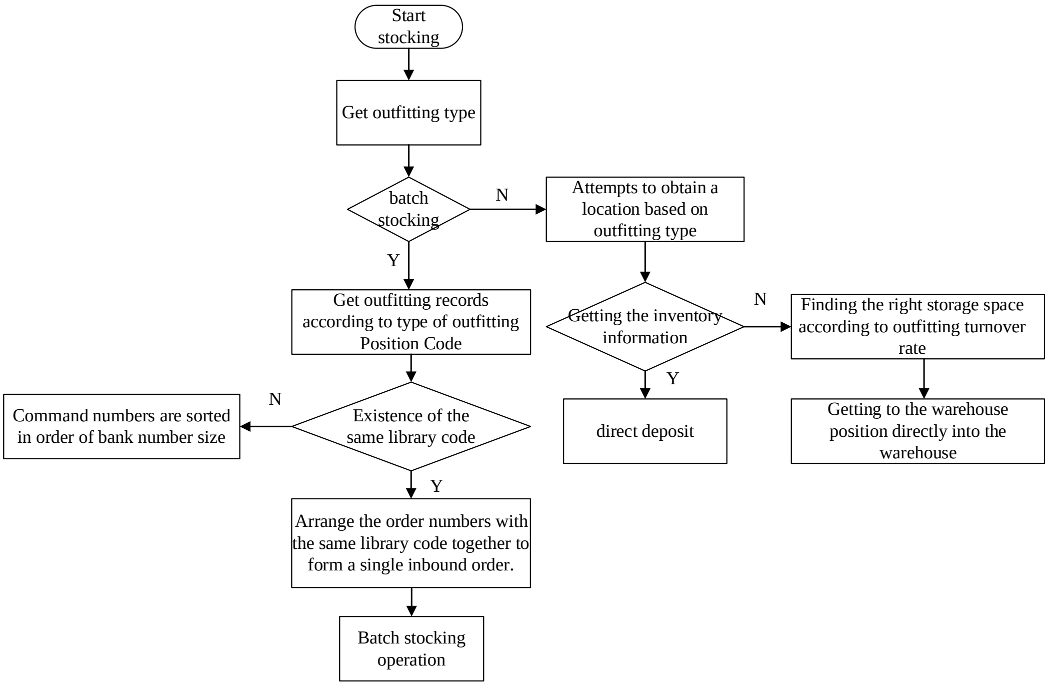

Figure 2: Warehousing Algorithm Process

The above process algorithm calculates the task number and shelf number to get an input for the following search for the specific location of the specific shelf for outfitting parts.

4. Allocation of outfitting storage racks

4.1. Description of the problem

A three-dimensional warehouse has N aisles, each of which is occupied by a stacker cranes, and the stacker cranes in each aisle can work at the same time when performing inbound operations. The shelves are assumed to be oriented horizontally in the x-direction and vertically in the y-direction.

With the type, quantity and size parameters of the outfits to be stored and the plant area known, specific racking spaces are planned for the outfits to be warehoused. The optimization of the racks is based on the principles of stable centre of gravity, balanced lane scheduling and optimized work paths.

4.2. Assumptions of the problem

It is assumed that each row of shelves is assigned to a dedicated stacker cranes for outfitting operations, i.e., when performing an outfitting operation, each shelf can be moved simultaneously, but for the same row of shelves, only one outfitting movement can be performed at a time (picking up or storing one type of outfitting). Production outfitting is characterised by a wide range of outfits with a low degree of standardisation, making the demand for individual outfits highly uncertain and difficult to predict accurately from historical data.

4.3. Model building

Considering the principles of automated three-dimensional warehouse racking center of gravity stability, aisle balance scheduling and optimization of operation paths, outfitting pieces of larger quality are placed in the lower level, and outfitting pieces of lighter quality are placed in the upper level to meet the complex constraints of dynamic changes in inventory, occupancy status of the cargo space and pallet use, and to establish a multi-objective optimization model.

(1) Ensure shelf stability

Considering the principle of high light and low weight, the outfittings with higher quality are placed in the bottom layer to ensure the stability of the center of gravity of the shelves; considering the position of the center of gravity of the outfittings to reduce the risk of tilting of the shelves, and determining the maximum load-bearing capacity of each shelf.

(2) Balanced lane scheduling

Determine the width and height of the aisle according to the size and placement of the outfittings to ensure that machinery and equipment can pass through smoothly; design suitable shelves on both sides of the aisle or on the track to improve operational efficiency; consider the frequency of outfittings entering and leaving the warehouse and place the more frequently used goods in easy-to-access locations to minimize operating time.

$$f_3(A)=\sqrt{\frac{1}{K-1}\sum_{k=1}^{K}(P_K-\overline{P})^2} \tag{2}$$

Where, Pk represents the number of occupied spaces in the kth row of shelves after allocation of spaces, and represents the average number of occupied spaces per shelf after optimized allocation.

(3) Optimize operation path

Considering the storage and pickup demand of outfits, the layout of shelves is optimized to make the operation path as short as possible; a reasonable storage strategy is designed according to the relevant attributes of the goods (e.g., outfitting types, weights, sizes, etc.) to reduce the pickup time; and the dynamic changes of outfits are considered, and dynamic adjustments are made through real-time monitoring of the inventory situation of the outfits and the occupation status of the goods spaces.

$$f_4(A)=\frac{1}{n}\sum_{q=1}^{n}\sqrt{r_q^2+c_q^2+k_q^2} \tag{3}$$

where n denotes the total number of jobs, and (rq,cq,kq) are the coordinates of the target cargo position corresponding to job q.

4.4. Algorithmic process

Based on the above three principles, adaptive difference algorithm (Xia et al.,2021)[7] is used, and the algorithm flow is shown in Figure 3 below.

(1) Initialize parameters and population

Set the parameters of the adaptive difference algorithm, including the population size, the maximum number of iterations, the crossover probability, and the variance probability, and randomly generate the population of the initial cargo space allocation scheme, and each individual represents a possible cargo space allocation scheme.

(2) Determine whether the maximum number of iterations T is reached, if so, output the one with the highest fitness as the optimal solution; if not, proceed to the next step.

(3) Perform variation and crossover operations and calculate the fitness.

(4) Perform selection operation with iteration number t=t+1, merge the tth generation to obtain the optimal solution, and go to (2).

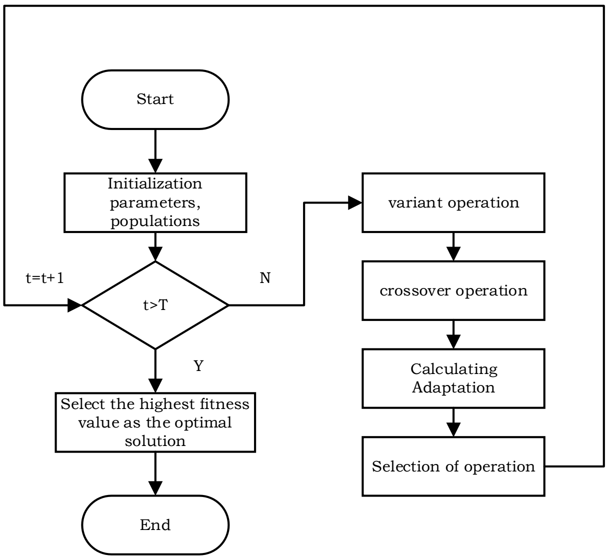

Figure 3: Adaptive Differential Algorithm

Based on the task number and shelf number obtained in the first stage, the optimal shelf space allocation is calculated by the above process algorithm.

5. Case Study

This article takes the actual production process of a shipyard as an example. Equipment warehousing is an important component of the shipyard manufacturing process. By deploying a warehouse management system, shipyards can dynamically query inventory and other information at any time, quickly and accurately grasp the operation of the three-dimensional warehouse, which is conducive to achieving efficient storage space, warehousing, and warehouse accommodation, effectively ensuring the safe and effective operation of warehousing, and achieving the goal of integrated and intelligent warehouse management.

5.1. Interface design

The development of the system for allocating and optimizing the cargo space in an automated three-dimensional warehouse is based on the Pycharm platform, which is implemented using the Python programming language and the MySQL database management system.

The system is mainly composed of three parts: hardware equipment, system software and database, which are divided into user interface, representation layer, business logic layer and data access layer. Each layer has different roles, and all the layers interact together to maintain the operation of the system, and the interactions between the layers are mainly realized through the internal interfaces, and the data transfer is carried out through the interfaces provided by each layer. The software structure of the outfitting intelligent storage management system designed in this paper is shown in Figure 4 below:

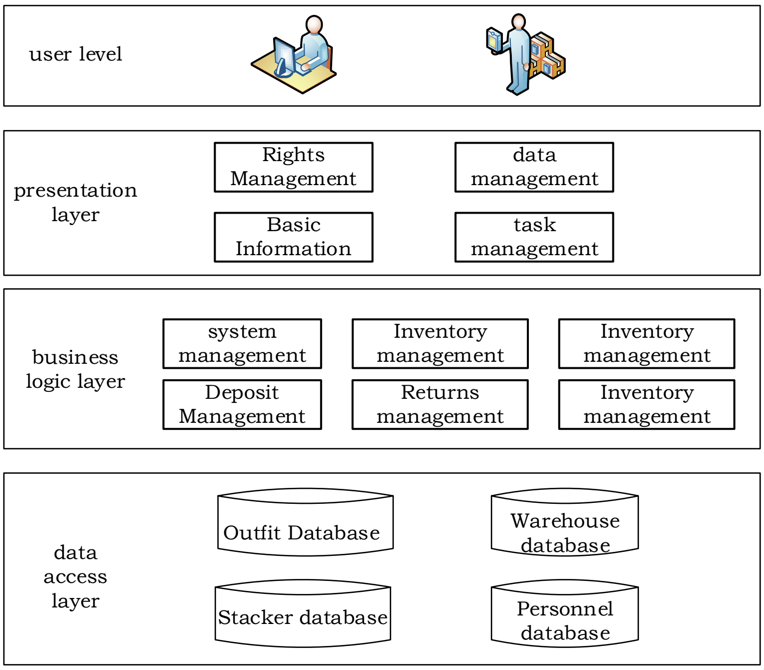

Figure 4: System Software Structure Diagram

For inbound cargo space allocation design software interface, the quality inspection after passing the inbound cargo list for cargo space allocation. Select the information for quality inspection of goods and submit it for warehouse allocation, as shown in Figure 5.

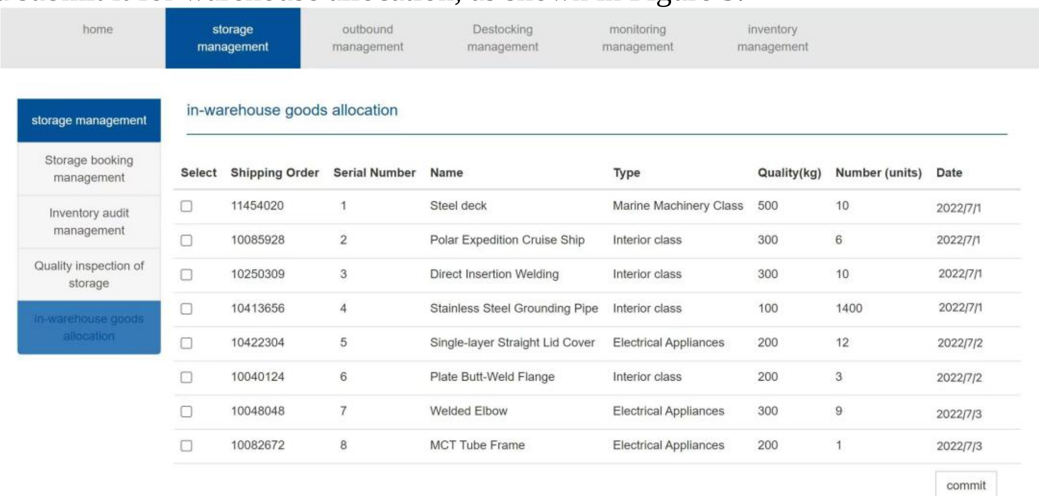

Figure 5: Warehouse Location Allocation Interface

5.2. Results

A specific example is used to verify the effectiveness of the above methods for optimizing the storage entry location and shelf position allocation for outfitting parts in a three-dimensional warehouse. In the example, data from a portion of the outfitting parts' shelves and storage locations is used for numerical validation. By calculating the turnover rate, each category of outfitting parts is placed on the shelves according to its turnover rate to optimize the entry location. Then, based on the adaptive differential algorithm, the optimal shelf position allocation is obtained. The results are shown in Table 1.

Table 1: Cargo Allocation Table

date	num	id	name	quality	assert	out_value	zone	location
2022/8/12	10108746	1	Non-tight lining ring	20	5	18223	A	A-1
2022/8/16	10081516	2	Needle terminal	44	500	10416	A	A-1
2022/8/16	10090295	3	Nylon tie	55	10000	84452	B	B-1
2022/8/16	10278681	4	silencer	50	1	11580	B	B-1
2022/8/17	10083125	5	ball float level switch	20	1	83933	C	C-1

6. Conclusions

Outfit warehousing is an important part of the manufacturing process in shipyards. Shipyards use warehouse management systems to achieve inventory monitoring, efficient operation, ensure the safety of outfitting warehousing, and achieve the goal of integrated and intelligent warehouse management. Firstly, based on the main factors such as item correlation, access frequency, shelf stability and so on, the principle of warehouse optimization is designed. Secondly, by calculating the inventory turnover rate of outfittings in the warehouse obtained, a heuristic algorithm is used to design the algorithmic process of warehousing. Then, consider the factors such as shelf stability, aisle balance scheduling and optimized operation paths to achieve the management objectives such as lean and intelligent warehouse management with high stability, high efficiency and high accuracy. Finally, develop intelligent storage space allocation system for outfitting parts. Based on the real data from the shipyard in the last six months, the software is tested and tried.

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