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Research on Optimization of Warehousing System Based on Analytic Hierarchy Process and Order Index Method

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Abstract: *This paper discusses the issues of how to improve the systematic problems such as unreasonable warehouse layout, non-standard warehousing operation, incorrect inventory counting method, and imperfect warehousing information. The Analytic Hierarchy Process is adopted to analyze the factors affecting the picking efficiency, while the Cube-Order Index (COI) is for optimizing the storage location, which is planned according to the turnover rate of the goods. It tries to figure out the future development trend of the warehouse management and how to improve the efficiency of the warehouse operation for improving the competitiveness of enterprises.*

Keywords: *Warehouse management; Analytic Hierarchy Process; Order index method; System optimization*

1. Foreword

With the rapid development of science and technology and economy, all walks of life have encountered great opportunities and challenges. Logistics is an important link between production and sales, while the efficiency and speed are the essential requirements for the logistics enterprises. Warehousing is a necessary and essential part of the logistics process. The warehousing management plays a significant role in improving the quality of logistics service and the customer's satisfaction with the experience. Gradually, the managers of the enterprise have realized the importance of warehouse management[1]. Currently, few people have carried out the detailed research on the warehousing management of logistics. By analyzing the current situation of logistics warehousing management, this paper tries to explore a more scientific and efficient warehousing process, reduce the repetition of warehousing operations and cut down the warehousing costs.

2. Specifications of Warehouse Management

2.1 Standardize design for the warehouse

The building and structure of the warehouse shall comply with the construction standards and adjustment requirements of the relevant local laws and regulations. A perfect warehouse shall be a single-layer structure, easy to access and handle the products. It shall be equipped with the loading and unloading platform, operation monitoring system, smoke detector, spray device, emergency escape device and fire escape in the warehouse. It is recommended that the warehouse should have a loading and unloading platform (1.3m) as high as the container, which is convenient for the containers and trucks to conduct the loading and unloading (A fixed lifting platform shall be purchased, if the platform fails to reach that height). Canopy shall be set above the loading and unloading platform or between the parallel warehouse. And there shall be an independent canopy on both sides of the gate or above the loading and unloading operation area. There shall be no potential hazards, such the holes, the debris or uneven surface on the ground, the construction defects, the water and the oil that may cause slipping and falling[2]. The safe bearing capacity of each floor of the temporary or permanent workplace or storage area, should meet the standard of the maximum bearing capacity of the shelf. It should be decorated with the thermal insulation layer (material), and consideration should be taken to prevent the water or snow accumulation from causing roof leakage, collapse or other accidents.

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2.2 Reasonable division of storage areas

Different functional divisions in the storage area can greatly improve the efficiency of storage operations and the utilization rate of the warehouse. For example, the warehousing, it is necessary to set up a temporary storage area for the newly received goods, which should be near the door and platform of the warehouse, and convenient for counting before they are put on the shelf by the forklift. It shall set the special storage areas for the forklifts and hydraulic trucks, because most of such kind of tools are made of metal and take much room, and any random parking will occupy the passage. The charging area of the forklift should be set outside the warehouse. As the high-power electronic devices may cause fire, the charging area should be far away from the inventory area[3]. And it is necessary to set a packing area. After the picking is completed, the personnel shall place the goods in this area. In addition, a Quality Inspection Department should be set up to carry out the spot check, weighing and acceptance on the picked goods, which will reduce the error rate of delivery. The delivery staging area should be set near the exit of the warehouse. All goods to be delivered are temporarily stored here and delivered when the delivery personnel finish the counting.

2.3 Optimization of warehousing operation process

As the warehousing process is extremely important, it is necessary to develop the standard acceptance criteria for the goods, and the inspectors shall follow those provisions. The warehousing of goods should establish a standardized process. Firstly, the purchasing personnel of the company should send a purchase order to the supplier. After receiving the purchase order, the supplier should send an email of the warehousing reservation to the warehouse, which includes the quantity of goods sent and the time of arrival. It will reply to the supplier after receiving the reservation email from the warehouse system, and the supplier will deliver the goods to the warehouse at the agreed time. Only after the delivery personnel deliver the goods before the scheduled time and register them in the Loss Prevention Department of the warehouse, can the acceptance personnel accept the goods. The acceptance personnel shall require the carrier personnel to stack the goods orderly according to the types of goods without any mixing. Since the outer box of goods may be damaged, it should set the proportion of unpacking inspection and unpack the goods for inspection. At least one out of every 20 boxes should be unpacked for inspection. The acceptance personnel should ensure that the actual acceptance of goods is consistent with the information uploaded to the system. The goods that fail to pass the acceptance shall be sent back to the supplier. After the acceptance is completed, the quantity shall be checked on the system, and the receipt shall be signed and submitted to the system department. The warehousing process is optimized and managed by adopting the optimization method of ESIA, as shown in Table 1.

Table 1 ESIA Optimization in Warehousing

Means	Content
Eliminate(E)	1. Directly query the relevant information through the purchase order number to reduce the time for the acceptance personnel to check the quantity of order. 2. Carry out the unpacking inspection by sampling, which is conducted by the delivery personnel to avoid wasting the time of the acceptance personnel. 3. Reduce the time for the acceptance personnel waiting for the delivery personnel to unload the goods. If the goods fail to be delivered on time, the acceptance personnel can refuse to accept them, which will make the delivery personnel improve their punctuality rate.
Simply(S)	1. Simplify the process of handling the defective goods, shortage and other problems. The delivery personnel should pick out the defective goods in advance and inform the acceptance personnel. 2. Simplify the procedure of appearance inspection, submit it to the Loss Prevention Department for inspection, and ask the supplier to place the goods with appearance damage on the surface.
Integrate(I)	1. Integrate the purchase order information and receipt information to reduce the acceptance personnel's query time.
Automate(A)	1. Use RF equipment to scan the receipt number. The receipt includes the actual quantity information of goods. The acceptance personnel will view the actual quantity information after scanning the barcode of goods via RF equipment. The acceptance personnel can conduct the warehousing after checking. 2. The receiving system is associated with the inventory system, and the receiving quantity can be modified on the inventory quantity via WMS. 3. With the help of WMS automatically planning the location of the goods, there is no need for the acceptance personnel to plan the location again.

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3. Optimization Measures for the Warehouse

A special inventory department should be set up for the warehouse. With a virtual warehouse, it is convenient and quick to view the real-time inventory. The virtual warehouse should correspond to the actual inventory with being updated every day. The storage location of the goods shall be recorded in the system.

3.1 Adopt the Analytic Hierarchy Process to build the index system that affects the picking efficiency

Analytic Hierarchy Process is suitable for dealing with the optimization problems of multi-objective and multi-criteria decision. This method can deal with the problems in hierarchy that are complex and difficult to quantify. The weight of each factor is determined through qualitative analysis and quantitative calculation, which helps to obtain the optimal solution. It is mainly to calculate the maximum eigenvalue of the comparison matrix and characteristic $A = \{a_{ji}\}_{m\times n}$. And the assignment rules are shown in the table. If the element *i* is judged as *aij* element by comparing with *j*, and it is judged as $b_{ji} = 1/b_{ji}$ by comparing with *i*, calculate the maximum eigenvalueλ_{max} of A, which belongs to the normalized eigenvector $W = (\omega_1, \dots, \omega_n)^T$ of the eigenvalue, that is, the AHP weight of the index. The scale of judgment matrix is established according to the principle of Analytic Hierarchy Process (AHP), as shown in Table 2.

Table 2 Scale of Judgment Matrix

Scale	Definition	Interpretation
1	Equally important	Index i and j are equally important
3	Slightly important	Index i is slightly more important than j
5	Quite important	Index i is more important than j
7	Significantly important	Index i is much more important than j
9	Absolutely important	Index i is significantly more important than j
2,4,6,8	Relatively important between two levels	

In the Analytic Hierarchy Process, the negative mean value of the maximum characteristic and other roots of the judgment matrix is introduced as an index to measure the deviation from the consistency of the judgment matrix, namely:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1}$$

Examine the consistency of decision makers' thinking, including,

$$\lambda_{max} = \sum_i^n \frac{(AW)_i}{nW_i}$$

(AW)i refers to the *i*th element of vector *AW*. It is also necessary to introduce the average random index(*RI*) of the judgment matrix to measure whether the judgment matrix of different orders has the satisfactory consistency. For the Level 1-4 of judgment matrix[4], the values of *RI* are listed in Table 3.

Table 3 Average Random Index

1	2	3	4
0.00	0.00	0.58	0.90

When the order is larger than 2, the ratio of the consistency index (*CI*) of the judgment matrix to the average random index(*RI*) of the same order is called the consistency ratio, which is recorded as *CR*. When

$$CR = \frac{CI}{RI} < 0.10$$

The judgment matrix has the satisfactory consistency. And the eigenvector $W = (\omega_1, \omega_2, \dots, \omega_n)^T$of matrix A is the weight coefficient of each index, which is recorded as: $W^* = (\omega_1, \omega_2, \dots, \omega_n)^T$

Based on the field investigation of Jingdong warehouse, it is concluded that the main factors affect the efficiency of picking staff are as follows: the walking distance of operators, the utilization rate of storage location, the hit rate of goods and the waiting time of the operation. The index system affecting the picking efficiency was constructed by taking the picking efficiency as the criterion and the above factors as the plan, as shown in Table 4.

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Table 4 Index Affecting the Picking Efficiency

Criterion	Plan
Picking efficiency A_1	Walking distance of the operators B1
Picking efficiency A_2	Utilization rate of storage location B_2
Picking efficiency A_3	Hit rate of goods B_3
Picking efficiency A_4	Waiting time of the operation B_4

According to the relevant literature, the above factors are scored, as shown in Table 5.

Table 5 Scoring Index of the Plan

A	B_1	B_2	B_3	B_4
B_1	1	5	2	3
B_2	1/5	1	1/2	2/3
B_3	1/2	2	1	5
B_4	1/3	2/3	1/5	1

The judgment matrix is constructed according to the relevant knowledge of Analytic Hierarchy Process:

Construct the judgment matrix A=$\begin{pmatrix} 1 & 5 & 2 & 3 \\ 1/5 & 1 & 1/2 & 2/3 \\ 1/2 & 2 & 1 & 5 \\ 1/3 & 2/3 & 1/5 & 1 \end{pmatrix}$

Obtain the matrix Q by normalizing the column vector of the judgment matrix:

$$Q=\begin{pmatrix} 0.492 & 0.577 & 0.541 & 0.310 \\ 0.098 & 0.115 & 0.135 & 0.069 \\ 0.246 & 0.231 & 0.270 & 0.517 \\ 0.164 & 0.077 & 0.054 & 0.103 \end{pmatrix}$$

Add Q by row to obtain the matrix C=$\begin{pmatrix} 1.920 \\ 0.418 \\ 1.264 \\ 0.398 \end{pmatrix}$. Normalize matrix C to obtain eigenvector B=$\begin{pmatrix} 0.480 \\ 0.104 \\ 0.316 \\ 0.100 \end{pmatrix}$. Then according to the formula $W_i = W_i / \sum_{i=1}^{n} W_i$; w = $\begin{pmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ w_n \end{pmatrix}$ to get the weight vector P=$[0.477 \quad 0.104 \quad 0.305 \quad 0.115]^T$. Use formula $\lambda_{max} = \sum_i^n \frac{(AW)_i}{nW_i}$, $\mathrm{CI} = \frac{\lambda_{max}-n}{n-1}$ to obtain the maximum characteristic root λ =4.21, CI=0.07. Because CI<0.1, the judgment matrix passed the one-time test.

Through the weight analysis, the walking distance the picking operators has the greatest impact on the picking efficiency, followed by the hit rate of the goods. Therefore, it can improve the storage location. Since the goods are currently placed on both sides of the warehouse passages, the picking personnel have to walk back and forth between the passages. Compared with walking back and forth to pick the goods on both sides of the passages, the walking distance of picking goods on one side of the passages is nearer. It can reduce the walking distance by adjusting the density of the storage location, as well as increasing the utilization rate.

3.2 Adopt Cube-Order Index (COI) to optimize the storage location

Cube-Order Index (COI) refers to the ratio between the storage space a for the goods and the daily average shipment volume b of the goods [5]. Cube-Order Index (COI)=a/b. According to the field survey, the relevant data of seven kinds of goods are obtained, and the value of COI is calculated, as shown in Table 6.

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Table 6 COI of Some Goods

Goods	Storage Space(m^3)*a*	Daily Average Shipment Volume *b*	Cube-Order Index (COI)=a/b
A	3	124	0.024
B	10	220	0.045
C	3.5	89	0.096
D	6	115	0.052
E	8.5	83	0.060
F	5	94	0.037
G	2.5	38	0.066

Reorder according to COI, as shown in Table 7.

Table 7 COI of Some Goods after Reordering

Goods	Storage Space(m^3)a	Daily Average Shipment Volume b	Cube-Order Index (COI)=a/b
A	3	124	0.024
F	5	94	0.037
B	10	220	0.045
D	6	115	0.052
E	8.5	83	0.060
G	2.5	38	0.066
C	3.5	89	0.096

According to the distribution principle of storage location, the goods with lower COI should be placed close to the shipping area, and A goods should be placed nearest to the shipping port to improve the storage efficiency and cut down the costs. The COI can be taken into consideration when planning the storage location in the warehouse.

3.3 Plan the storage location according to the turnover rate

The turnover rate of the goods (W) refers to the ratio between the annual average shipment volume of goods and the average inventory[6]. Average inventory (Y)=cargo storage location (a)/single cargo volume (c), cargo turnover rate (W)=365 * average daily shipment (b)/average inventory (Y). According to the survey results mentioned above, it can calculate the turnover rate of these seven goods, as shown in Table 8.

Table 8 Turnover Rate of Goods

Goods	Storage Space(m^3)a	Average Daily Shipment b	Single Cargo Volume (m^3)c	Average Inventory Y=a/c	Turnover Rate W=365*b/Y
A	3	124	0.001	3000	15.09
B	10	220	0.018	556	144.54
C	3.5	89	0.002	1750	18.56
D	6	115	0.006	1000	41.98
E	8.5	83	0.016	531	57.03
F	5	94	0.004	1250	27.45
G	2.5	38	0.0096	260	53.26

After sorting the turnover rate, the result is shown in Table 9.

Table 9 Turnover Rate of Goods after Sorting

Goods	Storage Space(m^3)a	Average Daily Shipment b	Single Cargo Volume (m^3)c	Average Inventory Y=a/c	Turnover Rate W=365*b/Y
A	3	124	0.001	3000	15.09
G	2.5	38	0.0096	260	53.26
E	3.5	89	0.002	1750	18.56
C	5	94	0.004	1250	27.45
D	6	115	0.006	1000	41.98
F	8.5	83	0.016	531	57.03
B	10	220	0.018	556	144.54

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According to the turnover rate of goods and its liquidity, the goods with high turnover rate and fast mobility are placed nearer to the shipping area, which can greatly cut down the handling cost as well as improving the efficiency.

4. Conclusion

The standard operation process of warehousing refers to that the acceptance personnel shall inspect the goods carefully, to avoid causing any inventory differences, which will affect the manager's judgment on the inventory, and make the false strategic planning. The inventory count is extremely important. It is necessary to adjust the method of inventory count. The inventory personnel should ensure that the goods stored in the storage location are consistent with the goods information. The stored goods must be unpacked for inspection to figure out the category, specification and quantity, which ensures the accuracy of the uploaded information, and avoids any losses caused by mistakes. The storage optimization scheme mentioned above in this paper aims to provide the reference for the relevant decision-makers.

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