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Research on Models for Evaluating Comprehensive Efficiency of Warehousing

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Abstract

Aiming at evaluating the comprehensive efficiency of warehousing, the article first analyzes factors that affect warehousing efficiency and construct an index system of efficiency evaluation in AHP method. Then, the article puts forward a method to determine weight of evaluation index hierarchically and constructs an efficiency evaluation model of warehousing operation and management. Methods such as expert assessment method, ADC method and fuzzy assessment study are used to evaluate efficiency of different layers in accordance with the characteristics of each index system. Combined with examplary analysis, the article verifies the feasibility and effectiveness of the evaluation methods.

Key words: Efficiency evaluation; AHP method; ADC method; Fuzzy evaluation

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INTRODUCTION

Despite rapid development of management concepts such as e-commerce, supply chain integration, efficiency customer response, quick response and just-in-time delivery, the supply chain that connects manufacturers and customers will never coordinate or reach the point where warehousing can be completely abandoned (Freds, 2004). The rapid development of modern science and technology will inevitably lead to changes in the warehouse management system, management methods, management personnel and management mediums. How to evaluate the effectiveness of modern warehousing is a very important issue in planning, construction, management and operation of warehouse. Starting with analyzing factors that influence efficiency of the warehousing operation and management, the article sets up an efficiency evaluation model of modern warehousing operation and management. It provides a theoretical basis for scientific decision-making and helps warehousing management development efficiently.

1. DEFINITION OF EFFICIENCY AND EFFICIENCY EVALUATION

Efficiency is defined as capacity of a system to meet requirements of a set of tasks or capability of a system to reach the predetermined targets under specified conditions (Guo, Zhi, & Yang, 2005; Ning & Liu, 2003). Warehousing efficiency refers to probability that a warehousing system is expected to accomplish planned tasks and reach possible targets under specified conditions. The structure of modern warehousing system is complicated. It does not only involve the traditional elements such as personnel, finance and material management but also the application of modern techniques such as environment, equipment and information At present few studies and application of efficiency evaluation are about warehousing system. Methods for efficiency evaluation of weapon system can be used for reference. They mainly involve integrating application of expert assessment method, index method, ADC method, AHP analysis method and fuzzy evaluation method (Guo, Zhi, & Yang, 2005; Ning & Liu, 2003).

2. WAREHOUSING COMPREHENSIVE EFFICIENCY EVALUATION

2.1 Analysis of Major Factors Affecting Warehousing Comprehensive Efficiency

Factors that affect the comprehensive efficiency of modern warehousing mainly include support efficiency of warehouse facilities, management efficiency of warehousing and environmental efficiency of warehousing. Factors affecting efficiency of warehousing facilities involve platform efficiency of material handling, efficiency of transportation vehicles, warehousing efficiency of warehouse, automation efficiency of warehousing, etc.; warehouse management efficiency includes personnel management efficiency, warehouse facilities management efficiency, financial management efficiency and safety management efficiency; the geographical environment of warehousing system has relatively great impact on warehousing efficiency, among which the traffic environment has the greatest impact, including highways, railways, waterways and air transport. Analyze major factors that affect modern warehousing operation and management efficiency. Apply AHP analysis method. Construction efficiency evaluation index system, shown in Figure 1.

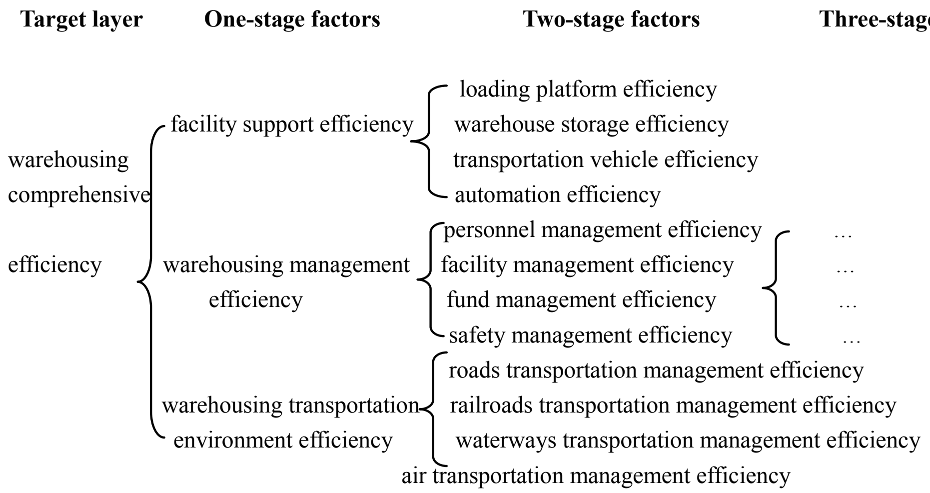

Figure 1
Warehousing Comprehensive Efficiency Evaluation Index System

2.2 Determining Index Weight in AHP Method

Weight plays an important role in synthesizing efficiency of individual targets. AHP method is adopted in the article to determine efficiency weight of factors at different stages. First, construct judgment matrix at various stages $W=(a_{ij})$, then, normalize it:

$$\beta_i = \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}, \quad i = 1,2,\cdots,n, \tag{1}$$

$$w_j = \frac{\beta_j}{\sum_{i=1}^{n}\beta_i}, \qquad j = 1,2,\cdots,n. \tag{2}$$

Work out the maximum characteristic root of W $\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Ww)_i}{w_i}$. Uniformity index is $C.I. = \frac{\lambda_{\max} - n}{n-1}$. If $C.R. = \frac{C.I.}{R.I.}$ <0.1, W has the desired uniformity. $w=(w_1, w_2,\cdots,w_n)^T$ is the determined weight (Ning & Liu, 2003; Han, Cao, & Zhang, 2012)

2.3 Efficiency Evaluation Model

Let efficiency value of facility support, warehouse management and transportation environment at one-stage be E_1, E_2, E_3. Suppose efficiency value of No.j sub-system affiliated to No.i system at one-stage is E_{ij}, i=1, 2, 3; j=1, 2, 3, 4. Let w_{ij} be the corresponding efficiency weight, then $E_i = \sum_{j=1}^{4} w_{ij}E_{ij}$, i=1, 2, 3 and warehousing comprehensive efficiency is $E = \sum_{i=1}^{3} w_i E_i$, among which w_1, w_2, w_3 is weight of facility support, warehouse management and objective environmental efficiency respectively.

2.3.1 Facility Support Efficiency

Facility support efficiency is determined by loading platform efficiency, warehousing efficiency of warehouse, efficiency of loading and unloading vehicles and automation efficiency of warehousing. This system is similar to equipment system. So ADC method is adopted to evaluate efficiency (Guo, Zhi, & Yang, 2005).

Suppose an individual facility is in the state of "function" or "malfunction" when tasks begin to be performed, system efficiency vector can be expressed as $A=(a_1, a_2)$, where a_1=MTBF(MTBF+MTTR). a_1 is probability of "function" state; a_2 is the probability of "malfunction" state; MTBF is facility mean time between failures; MTTR is mean time to repair (Huang, & Wang, 2013).

Credibility matrix of system is

$$D=\begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix},\ \sum_{i=1}^{n} d_{ij}=1,\ \ j=1,2,\cdots,n\ .$$

Where d_{ij} is probable that the facility is in the state of No.i at the beginning and in the state of No. j during performance of task. Suppose malfunction and repair of facility are exponentially distributed, task performance time is T and malfunction can not be repaired during performance time, then

$$d_{11}=\exp(-T/MTBF),\ d_{21}=0,$$
$$d_{12}=1-d_{11},\ d_{22}=1-d_{21}=1. \quad (3)$$

Capability matrix of the system is $C=[c_1,\ c_2]^T$, where c_1 is the capability magnitude of facility to perform task when in the state of "function" during performance of task; c_2 is the capability magnitude when facility is in the state of "malfunction", apparently $c_2=0$. Construction ADC evaluation model:

$$E=\mathrm{ADC}\ =(a_1,a_2)\begin{bmatrix} d_{11} & d_{12} \\ 0 & 1 \end{bmatrix}[c_1,0]^T=a_1d_{11}c_1 \quad (4)$$

a). Loading platform efficiency

$$E_{11}=a_1d_{11}c_1=a_1\exp(-T/MTBF_{zt})\cdot W'_{zt}/W_{zt} \quad (5)$$

W'_{zt} is the total amount of platform material handling; W_{zt} is the designed total amount of platform material handling.

b) Warehousing efficiency of warehouse

$$E_{12}=a_1d_{11}c_1=a_1\exp(-T/MTBF_{cc})\cdot W'_{cc}/W_{cc}. \quad (6)$$

W'_{cc} is the total amount of the stored materials; W_{cc} is the total amount of the materials that warehouse can store.

c) Efficiency of loading and unloading vehicles

$$E_{13}=a_1d_{11}c_1=a_1\exp(-T/MTBF_{cl})\cdot W'_{cl}/W_{cl}\ . \quad (7)$$

W'_{cl} is the actual vehicle load; W_{cl} is the designed vehicle load.

d) Efficiency of warehousing automation

Automation covers a variety of contents, including both equipment configuration like stereo shelves, stacking machines, forklifts, vans and information level of warehousing such as storage system, control system, networking and data picking system. Expert assessment method is used here to determine E_{14} (Guo, Zhi, & Yang, 2005).

2.3.2 Warehouse Management Efficiency

A method combining quantitative and qualitative analysis is used to evaluate warehouse management efficiency. Construct efficiency model: $E_{2i}=\sum_{j=1}^{n}k_jP_j$, where n is the number of factors; k_j is weight of index; P_j is capability index of factors.

a) Personnel management efficiency

Personnel management efficiency is mainly reflected in personnel quality and personnel training.

$$E_{21}=k_1\frac{w'_{ry}}{w_{ry}}+k_2\frac{n'_{ry}}{n_{ry}}\ . \quad (8)$$

Where W'_{ry} is the actual working capacity of staff; W_{ry} is the expected working capacity of staff; n'_{ry} is the number of qualified personnel training; n_{ry} is the number of personnel training.

b) Warehousing facility management efficiency

Warehousing facility management efficiency is mainly reflected in the intact rate of facility and the utilization rate of facility.

$$E_{22}=k_1\frac{n'_{sb}}{n_{sb}}+k_2\frac{w'_{sb}}{w_{sb}}\ . \quad (9)$$

Where n'_{sb} is the number of intact facilities; n_{sb} is the number of facilities; w'_{sb} is the actual workload of facilities; w_{sb} is the designed workload of facilities.

c) Fund management efficiency

Warehousing operation expenses can be divided into two categories: one is business expenses and the other is freight and miscellaneous charges.

$$E_{23}=k_1\left(1-\frac{|m'_{yz}-m_{yz}|}{m_{yz}}\right)+k_2\left(1-\frac{|m'_{yw}-m_{yw}|}{m_{yw}}\right). \quad (10)$$

Where m'_{yz} is the actual freight and miscellaneous charges; m_{yz} is the expected freight and miscellaneous charges; m'_{yw} is the actual business expenses; m_{yw} is the expected business expenses.

d) Safety management efficiency

Safety management is also reflected in two aspects: One is operational errors, such as errors in receiving and delivering goods and the other is losses on business caused by safety incidents.

$$E_{24}=k_1\left(1-\frac{n'_{sf}}{n_{sf}}\right)+k_2\left(1-\frac{n'_{sg}}{n_{sg}}\right). \quad (11)$$

Where n'_{sf} is the number of errors in receiving and delivering goods; n_{sf} is the total number of receiving and delivering goods; n'_{sg} is the number of losses caused by incidents; n_{sg} is the number of incidents.

2.3.3 Efficiency of Warehousing Transportation Environment

Efficiency of warehousing transportation environment is difficult to be measured by a unified standard. Therefore, fuzzy evaluation method is used.

Let comment set be $V=\{v_1,\ v_2,\ v_3,\ v_4,\ v_5,\}=\{[10,9],(9,8],(8,7],(7,6],(6,0]\}$, representing evaluation result "excellent", "fair", "good", "average" and "poor". Let judgment factors set be $U=\{u_1,\ u_2,\ u_3,\ u_4\}$ and $u_i(i=1,2,3,4)$ in turn be roads, railways, waterways and air transport. Fuzzy relationship matrix is $\widetilde{R}=(r_{ij})_{4\times5}$, r_{ij} $(0\le r_{ij}\le 1)$ showing the degree of membership that factor parameter u_i is evaluated as v_j. If n experts among m experts evaluate u_i as v_j, then $r_{ij}=n/m$, and evaluation weight of roads, railways, waterways and air transport is

$\tilde{A}$=(w_1, w_2, w_3, w_4) (Ning & Liu, 2003; Huang & Wang, 2013; Ouyang et al., 2013).

Get by synthetic operation of $\tilde{A}$ and $\tilde{R}$

$$\tilde{B} = \tilde{A} \bullet \tilde{R} = (w_1, w_2, w_3, w_4)\begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} \\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35} \\ r_{41} & r_{42} & r_{43} & r_{44} & r_{45} \end{bmatrix} = (b_1, b_2, b_3, b_4, b_5)$$

To take full advantage of $\tilde{R}$ information and coordinate weight of factors, fuzzy operator $M(\circ,\oplus)$ is used to determine b, that is $b_j = \min\{1, \sum_{i=1}^{4} w_i r_{ij}\}$. In accordance with the principle of maximum membership, take $E_3 = \max_{1\le j\le 5}\{b_j\}$ as efficiency value of transportation environment (Guo, Zhi, & Yang, 2005).

3. EXAMPLE ANALYSIS

3.1 Weight Calculation

Take the target layer as an example. Work out the weight vector of one-stage factors relative to target layer by the use of formula (1) and (2). Results are shown in Table 1.

Table 1
Judgment Matrix and Normalization Results

W	Facility support	Management	Transportation environment	β_i	w_j	$(Ww)_i$
Facility Support	1	3	5	2.466	0.6268	1.9331
Management	1/3	1	4	1.1	0.2796	0.8625
Transportation Environment	1/5	1/4	1	0.368	0.0935	0.2891

Work out $\lambda_{\max}$=3.087, CI=0.0435, CR = 0.075 < 0.1. So one-stage index weight vector is (w_1,w_2,w_3)=(0.6268,0.2793,0.0935). Work out two-stage index weight vector in the same way (w_{11},w_{12},w_{13},w_{14},w_{21},w_{22},w_{23},w_{24})=(0.256, 0.1393, 0.3246, 0.2801; 0.351, 0.2283, 0.1194, 0.3011).

3.2 Efficiency Calculation

3.2.1 Facility Support Efficiency Calculation

Suppose system runs 10 hours. MTBF of material handling platform is 160 hours; MTTR is 4 hours. Warehouse MTBF is 500 hours; MTTR is 10 hours. MTBF of loading and unloading vehicles is 120 hours; MTTR is 5 hours. Use formula (5) - (7) to work out facility support efficiency.

Efficiency vector of material loading platform is A = (0.976, 0.024), credibility matrix is $D = \begin{bmatrix} 0.94 & 0.06 \\ 0 & 1 \end{bmatrix}$. The designed material loading of platform is 1000 tons. The actual amount of material loading is 700 tons. So C=(0.7,0)^T.

Then, material loading platform efficiency E_{11}=(0.976,0.024)$\begin{bmatrix} 0.94 & 0.06 \\ 0 & 1 \end{bmatrix}$(0.7, 0)^T=0.6419.

Work out in the same way E_{12}=(0.98,0.02)$\begin{bmatrix} 0.98 & 0.02 \\ 0 & 1 \end{bmatrix}$(0.6, 0)^T=0.576, E_{13}=(0.96,0.04)$\begin{bmatrix} 0.92 & 0.08 \\ 0 & 1 \end{bmatrix}$(0.8, 0)^T=0.706

Warehousing automation efficiency is decided by expert assessment method. Facility support efficiency is E_{14}=0.56, $E_1 = \sum_{i=1}^{4} w_{1i}E_{1i}$ =0.6306.

3.2.2 Warehouse Management Efficiency Calculation

Adopt quantitative analysis and qualitative analysis combination method. Use formula (8)-(10) to determine efficiency value of each subsystem, shown in Table 2.

Table 2
Calculation Results of Two-Stage Indices of Warehouse Management

Efficiency value of two-stage index	Three-stage INdex (weight)		Four-stage index	
Personnel management efficiency E_{21}=0.27	quality（0.6）	0.667	Actual work capacity	60
			Expected work capacity	90
	Training capacity（0.4）	0.875	Number of qualified training	70
			Number of training	80
Facility management efficiency E_{22}=0.724	Facility intact rate（0.6）	0.753	Intactness number	201
			Facility total	267
	Facility utility rate（0.4）	0.68	Actual workload	1360
			Designed workload	2000

To be continued

Continued

Efficiency value of two-stage index	Three-stage INdex (weight)		Four-stage index	
Fund management efficiency E_{23}=0.79	actual freight and miscellaneous charge index（0.3）	0.65	actual freight and miscellaneous charge	405
			expected freight and miscellaneous charge	300
	Business expense index 0.7)	0.85	Actual business expense	4670
			Expected business expense	5500
Safety management efficiency E_{24}=0.488	Delivery error rate（0.4）	0.877	Times of delivery error	312
			Total of delivery	2540
	Incident loss rate（0.6）	0.228	Times of incident loss	98
			Times of incident	127

Warehouse management efficiency is $E_2=\sum_{i=1}^{4} w_{2i}E_{2i}=0.67$.

3.2.3 Transportation Environment Efficiency Calculation

Count assessment results from 10 experts and get fuzzy relationship matrix

$$\widetilde{R}=\begin{bmatrix} 0.8 & 0.1 & 0.1 & 0 & 0 \\ 0.6 & 0.2 & 0.1 & 0.1 & 0 \\ 0.5 & 0.1 & 0.3 & 0.1 & 0 \\ 0.4 & 0.1 & 0.2 & 0.2 & 0.1 \end{bmatrix}$$

Use 4.1 to decide evaluation weight of roads, railways, waterways and air transportation

$\widetilde{A}$=(0.3,0.4,0.1,0.2) $\widetilde{B}=\widetilde{A}\cdot\widetilde{B}$=(0.61,0.14,0.14,0.09,0.02), so get E_3=0.61. Therefore, the overall efficiency evaluation value of the warehousing operation and management is $E=\sum_{i=1}^{3} w_iE_i=0.64$.

3.3 Result Analysis

The efficiency evaluation results show that the warehousing system efficiency can be increased dramatically. Measures can be taken on the warehouse facilities and warehousing management. In the investment and construction of facilities, improving the construction quality and level of treasury infrastructure, dispatching transportation vehicles with high reliability and stability and improving automation level of system can elevate efficiency of warehousing operation and management but may cause a substantial increase in the investment costs. Strengthening warehousing internal management has significant effect on the enhancing system efficiency.

CONCLUSION

Warehousing system is a complex system. The article selects major evaluation indices that can directly reflect warehousing comprehensive efficiency. Based on AHP analysis, the article constructs efficiency evaluation index system and establishes evaluation model in accordance with characteristics of each subsystem to strive to make evaluation results reflect the actual case with great practical value. Factors affecting evaluation of warehousing comprehensive efficiency may be significant or insignificant. Problems still need to be further explored in future research such as how to refine system capacity factors, how to determine state of system and how to use qualitative indices to weaken human factors.

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