Construction and Evaluation of D&A System Maturity Index System

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Abstract. Given the extreme importance of data, this paper investigates the maturity of the data and analysis (D&A) system using Intercontinental Cargo Services (ICM) as an example. In this paper, we first established indicators to assess the maturity of D&A system using hierarchical analysis and conducted consistency tests; then we analyzed the validity of the maturity of D&A system using fuzzy comprehensive evaluation method to discern the maturity level of D&A system, so that the test results have integrity and objectivity.

Keywords: D&A system maturity · hierarchical analysis method · fuzzy comprehensive evaluation method

1 Introduction

D&A system is a complex interconnected system of people management, information technology and business processes used to manage data and analyze information [1]. ICM operates a large seaport, it wants to assess the maturity of its current D&A system and come up with a strong action plan to optimize its D&A capabilities to instill trust and confidence in its customers [1].

Tao Hongfei mentioned in the China Electricity Journal that "previous assessment methods were limited to local, qualitative analysis basis, and the assessment results were unconvincing. The hierarchical analysis method, which takes the system as the research object, can better deal with qualitative factors and plays a better role in decision evaluation [2]."

In Liu Tianshou et al. (2019), "Port security management maturity evaluation by interval number entropy weight TOPSIS" [3], many scholars' researches on port security management evaluation are cited, mainly focusing on port, shipping and handling links, mostly using hierarchical analysis and fuzzy comprehensive evaluation method. For example, Liu mentioned, "Yang et al. [4] proposed a fuzzy evidence inference method for port facility safety to quantitatively analyze facility safety risks and cost effectiveness; Li et al. [5] used the fuzzy comprehensive evaluation method to construct a fuzzy comprehensive evaluation model of oil spill risk and quantified fuzzy factors based on the affiliation function to determine the risk factor matrix. "

There are few existing studies on the maturity of D&A systems in port companies [6]. Therefore, this paper will focus on the construction and evaluation of the D&A

X. Yuan et al. (Eds.): ICEKIM 2023, AHCS 13, pp. 1830–1840, 2023.
https://doi.org/10.2991/978-94-6463-172-2_203

system maturity index system of ICM port company to improve customer satisfaction and loyalty, and hopefully it can be subsequently applied to other port companies or even other industries.

2 The Construction of D&A System Maturity Evaluation Index System Based on Hierarchical Analysis Method

In this paper, we address the attributes of ICM company with container port traffic resource allocation as the target layer and people, technology, and process as the criterion layers. Personnel sub-criteria layer: measured by the number of employees, age structure, education level, computer application level, and innovation awareness. Technology sub-criteria layer: measured by whether the whole operation is paperless, whether the logistics nodes are visualized, and whether the collection and distribution methods are rationalized. Process sub-criteria layer: measured by the arrival punctuality of sea (land) transportation, sea (land) transportation departure punctuality, document flow efficiency, cargo detention, cargo storage planning in the port, and customer complaints.

Multiplying the product of the scores of each row of the judgment matrix by N times:

$$\vec{\omega}_i = \sqrt[n]{\prod\nolimits_{j=1}^{n} a_{ij}}, \quad (i = 1, 2, 3, n) \tag{1}$$

The weight vector is obtained by normalizing $\vec{\omega}_i$:

$$\omega_i = \frac{\omega_i}{\sum_{i=1}^{n} \omega_i}, \quad (i = 1, 2, 3, n) \tag{2}$$

Consistency test:

$$\lambda_m = \frac{1}{n} \sum\nolimits_{i=1}^{n} \frac{(B\omega)_i}{\omega_i} = \frac{1}{n} \sum_{i=1}^{n} \frac{\sum\limits_{j=1}^{n} a_{ij} w_j}{w_i}, \lambda_m \tag{3}$$

is the maximum eigenvalue of the judgment matrix A;

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{4}$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{5}$$

where n is the order of the judgment matrix, CI is the consistency test index, RI is the mean random consistency index and CR is the test coefficient. If CR < 0.1, the matrix is consistent; if CR $>= 0.1$ then the matrix needs to be adjusted.

A total of 15 copies of the questionnaire were distributed, and relevant industry personnel were invited to fill in the questionnaire. Arithmetic averaging of the questionnaire scores was performed to determine the final judgment matrix as Table 1. Through the square root method, the judgment matrix was calculated using MATLAB software to determine the weight size of each index.

The set of vector weights is

$$W = \left(0.5278\ 0.3325\ 0.1396\right)^T \tag{6}$$

The judgment matrices and weights of other indicators are shown in Table 2, Table 3, and Table 4.

First, the maximum eigenvalue of the first-level judgment matrix was calculated using MATLAB software as

$$\lambda_{\max} = 3.0536 \tag{7}$$

Next, a consistency test is performed

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{3.0536 - 3}{2} = 0.0268 \tag{8}$$

Table 1. Judgment matrix of the criterion layer to the target layer

A	B_1	B_2	B_3	W_i
B_1	1	2	3	0.5278
B_2	0.5	1	3	0.3325
B_3	0.3333	0.3333	1	0.1396
CR: 0.0516; $\lambda_{max:}$ 3.0536				

Table 2. Judgment matrix of the first-level indicators on B1

B_1	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	W_i
B_{11}	1	2	0.5	0.3333	0.3333	0.1124
B_{12}	0.5	1	0.5	0.3333	0.3333	0.0852
B_{13}	2	2	1	0.5	0.5	0.1745
B_{14}	3	3	2	1	2	0.3572
B_{15}	3	3	2	0.5	1	0.2707
CR: 0.0290; $\lambda_{max:}$ 5.1299						

Table 3. Judgment matrix of first-level indicators on B2

B_2	B_{21}	B_{22}	B_{23}	W_i
B_{21}	1	2	2	0.4934
B_{22}	0.5	1	2	0.3108
B_{23}	0.5	0.5	1	0.1958
CR: 0.0516; $\lambda_{max:}$ 3.0536				

Table 4. Judgment matrix of first-level indicators on B3

B_3	B_{31}	B_{32}	B_{33}	B_{34}	B_{35}	B_{36}	W_i
B_{31}	1	2	3	3	2	0.5	0.2258
B_{32}	0.5	1	2	3	2	0.3333	0.1566
B_{33}	0.3333	0.5	1	2	0.5	0.25	0.0821
B_{34}	0.3333	0.3333	0.5	1	0.5	0.25	0.0609
B_{35}	0.5	0.5	2	2	1	0.3333	0.1161
B_{36}	2	3	4	4	3	1	0.3584
CR: 0.0241; λ_{max}: 6.1521							

Third, random one-time test indicators were calculated

$$CR = \frac{CI}{RI} = 0.0516 \tag{9}$$

Since CR < 0.1, the judgment matrix passed the consistency test. Given that the other factor weight values are calculated similarly, the detailed steps are not given. The final weights are shown in Table 5.

The final results of relationship between the indicators of D&A system maturity based on hierarchical analysis method are shown in Fig. 1.

Table 5. Final weights

Criteria layer	Weights	Indicator layer	Intra-group weights	Combination weights
B_1	0.5278	B11	0.1124	0.0593
		B12	0.0852	0.045
		B13	0.1745	0.0921
		B14	0.3572	0.1886
		B15	0.2707	0.1429
B_2	0.3325	B21	0.4934	0.1641
		B22	0.3108	0.1034
		B23	0.1958	0.0651
B_3	0.1396	B31	0.2258	0.0315
		B32	0.1566	0.0219
		B33	0.0821	0.0115
		B34	0.0609	0.0085
		B35	0.1161	0.0162
		B36	0.3584	0.0501

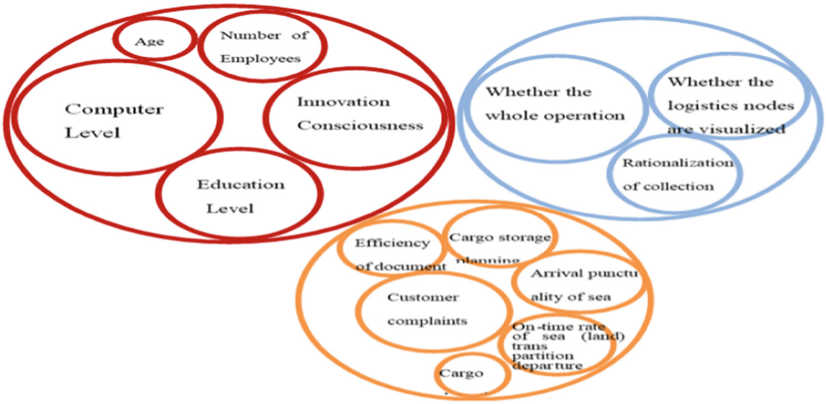

Fig. 1. Relationship between the importance of indicators

3 Analysis of the Effectiveness of D&A System Based on Fuzzy Comprehensive Evaluation Method

In this paper, the rubric set is divided into 5 levels, namely poor (0–1), poor (1–2), moderate (2–3), good (3–4), and good (4–5). For example, the first row of the matrix indicates that 16.7% of the respondents considered "Number of ICM staff B11" to be "good", 44.4% considered it to be "better", 22.2% considered it to be "better", and 22.2% considered it to be "better". ", 22.2% consider it as "fair", 11.1% consider it as "poor", 5.6% consider it as "poor ". The other results follow in this order.

The weights calculated by the hierarchical analysis are shown in Table 6.

The weight judgment matrix and evaluation matrix of each secondary index factor have been determined (Fig. 2).

$$B_i = W_{B_i} \times R_i \tag{10}$$

$$R_1 = \begin{pmatrix} 0.167 & 0.444 & 0.222 & 0.111 & 0.056 \\ 0.222 & 0.500 & 0.167 & 0.111 & 0.000 \\ 0.167 & 0.556 & 0.222 & 0.056 & 0.000 \\ 0.111 & 0.667 & 0.056 & 0.111 & 0.056 \\ 0.167 & 0.556 & 0.111 & 0.167 & 0.000 \end{pmatrix} \quad R_2 = \begin{pmatrix} 0.056 & 0.111 & 0.500 & 0.167 & 0.167 \\ 0.000 & 0.167 & 0.444 & 0.222 & 0.167 \\ 0.056 & 0.056 & 0.556 & 0.167 & 0.000 \end{pmatrix}$$

$$R_3 = \begin{pmatrix} 0.167 & 0.500 & 0.167 & 0.167 & 0.000 \\ 0.278 & 0.444 & 0.111 & 0.167 & 0.000 \\ 0.222 & 0.500 & 0.111 & 0.111 & 0.056 \\ 0.167 & 0.611 & 0.056 & 0.111 & 0.056 \\ 0.222 & 0.556 & 0.111 & 0.111 & 0.000 \\ 0.278 & 0.500 & 0.167 & 0.056 & 0.000 \end{pmatrix} \quad B_1 = \mathrm{W}_{B_1} \times \mathrm{R}_1 = (0.152 \quad 0.578 \quad 0.128 \quad 0.116 \quad 0.026) \quad B_2 =$$

$$\mathrm{W}_{B_2} \times \mathrm{R}_2 = (0.038 \quad 0.118 \quad 0.494 \quad 0.173 \quad 0.178) \quad B_3 = \mathrm{W}_{B_3} \times \mathrm{R}_3 = (0.235 \quad 0.505 \quad 0.140 \quad 0.112 \quad 0.008)$$

Table 6. Summary of weights

Target layer	Tier 1 Indicators	Weights	Tier 2 Indicators	Portfolio weights	Combined weights	Sorting
Container port traffic resource allocation A	people B1	0.5278	Number of ICM personnel B11	0.1124	0.0593	7
			Age structure of ICM personnel B12	0.0852	0.0450	9
			Education level of ICM personnel B13	0.1745	0.0921	5
			Computer application level of ICM personnel B14	0.3572	0.1885	1
			Innovation awareness of ICM personnel B15	0.2707	0.1429	3
	technology B2	0.3325	Full operation B21	0.4934	0.1641	2
			Logistics node B22	0.3108	0.1033	4
			Collection and distribution mode B23	0.1958	0.0651	6
	process B3	0.1396	Ocean Freight (Ground) Arrival Punctuality B31	0.2258	0.0315	10
			Sea freight (land) departure on-time rate B32	0.1566	0.0219	11
			Documentary flow efficiency B33	0.0821	0.0115	13

(*continued*)

Table 6. (*continued*)

Target layer	Tier 1 Indicators	Weights	Tier 2 Indicators	Portfolio weights	Combined weights	Sorting
			Cargo detention B34	0.0609	0.0085	14
			In-port cargo storage planning B35	0.1161	0.0162	12
			Customer complaints B36	0.3584	0.0501	8

The evaluation results of the above level indicators form the evaluation matrix of each target level as

$$R_A = \begin{pmatrix} 0.152 & 0.578 & 0.128 & 0.116 & 0.026 \\ 0.038 & 0.118 & 0.494 & 0.173 & 0.178 \\ 0.235 & 0.505 & 0.140 & 0.112 & 0.008 \end{pmatrix}$$

The fuzzy matrix of each level of indicators can be obtained from

$$A = W_A * R$$

$$A = (0.5278 \quad 0.3325 \quad 0.1397) \times \begin{pmatrix} 0.152 & 0.578 & 0.128 & 0.116 & 0.026 \\ 0.038 & 0.118 & 0.494 & 0.173 & 0.178 \\ 0.235 & 0.505 & 0.140 & 0.112 & 0.008 \end{pmatrix}$$

$$= (0.126 \quad 0.415 \quad 0.251 \quad 0.135 \quad 0.074)$$

$$F = (5 \quad 4 \quad 3 \quad 2 \quad 1)^T$$

$$Z_A = A \times F = (0.126 \quad 0.415 \quad 0.251 \quad 0.135 \quad 0.074) \times \begin{pmatrix} 5 \\ 4 \\ 3 \\ 2 \\ 1 \end{pmatrix} = 3.383$$

$$Z_{B_1} = B_1 \times F = 3.713\ ,\ Z_{B_2} = B_2 \times F = 2.666,\ Z_{B_3} = B_3 \times F = 3.846$$

Fig. 2. Final calculating process

This yields the evaluation levels of indicators at each level, as shown in Table 7; By surveying the staff of a port, a total of 40 questionnaires were distributed and 35 were returned, with an effective rate of 88%; The affiliation data of each indicator were obtained, as shown in Table 8; The fuzzy assessment results and scores of other indicators in the indicator layer can be obtained, as shown in Table 9.

W = (0.5278 0.3325 0.1396) WB1 = (0.1124 0.0852 0.1745 0.3572 0.2707)
WB2 = (0.4934 0.3108 0.1958) WB3 = (0.2258 0.1566 0.0821 0.0609 0.1161 0.3584)

The results and scores of each indicator layer are known, which are the fuzzy evaluation results of the criterion layer indicators, as shown in Fig. 3.

In summary, it can be seen that the index system contributes highly in port operations and the validity of D&A system maturity is significant [6].

Table 7. Evaluation results of indicators at each level

Target layer	Tier1 Indicators	Evaluation Level	Tier 2 Indicators	Overall Score	Evaluation Level
Container port traffic resource allocation A 3.383 (good)	People B1	3.713 (good)	Number of ICM personnel B11	3.556	Good
			Personnel age structure B12	3.833	Good
			Education level of personnel B13	3.833	Good
			Computer application level of employees B14	3.667	Good
			Personnel innovation awareness B15	3.722	Good
	Technology B2	2.666 (general)	Full range of operations B21	2.722	General
			Logistics nodes B22	2.611	General
			Collection and distribution mode B23	2.611	General
	Process B3	3.846 (good)	Ocean Freight (Ground) Arrival Punctuality B31	3.667	Good
			Sea freight (land freight) departure on-time rate B32	3.833	Good
			Documentary flow efficiency B33	3.722	Good
			Cargo detention B34	3.722	Good

(*continued*)

Table 7. (*continued*)

Target layer	Tier1 Indicators	Evaluation Level	Tier 2 Indicators	Overall Score	Evaluation Level
			In-port cargo storage planning B35	3.889	Good
			Customer complaints B36	4.000	Better

Table 8. Affiliation data of each indicator

Criteria layer	Weights	Indicator layer	Intra-group weights	Higher	High	Average	Low	Lower
B_1	0.5278	B_{11}	0.1124	0.7429	0.1429	0.1143	0.0000	0.0000
		B_{12}	0.0852	0.7714	0.1714	0.0571	0.0000	0.0000
		B_{13}	0.1745	0.7143	0.2000	0.0857	0.0000	0.0000
		B_{14}	0.3572	0.7429	0.1714	0.0857	0.0000	0.0000
		B_{15}	0.2707	0.0571	0.6857	0.2286	0.0286	0.0000
B_2	0.3325	B_{21}	0.4934	0.9429	0.0571	0.0000	0.0000	0.0000
		B_{22}	0.3108	0.9143	0.0857	0.0000	0.0000	0.0000
		B_{23}	0.1958	0.9714	0.0286	0.0000	0.0000	0.0000
B_3	0.1396	B_{31}	0.2258	0.8286	0.1714	0.0000	0.0000	0.0000
		B_{32}	0.1566	0.8571	0.1429	0.0000	0.0000	0.0000
		B_{33}	0.0821	0.8286	0.1714	0.0000	0.0000	0.0000
		B_{34}	0.0609	0.9143	0.0857	0.0000	0.0000	0.0000
		B_{35}	0.1161	0.9429	0.0571	0.0000	0.0000	0.0000
		B_{36}	0.3584	0.9714	0.0286	0.0000	0.0000	0.0000

Table 9. Fuzzy evaluation results and scores of other indicators

Indicators	Higher	High	Average	Low	Lower	Score	Grade
B_1	0.5547	0.3124	0.1252	0.0077	0.0000	78.28	High
B_2	0.9396	0.0604	0.0000	0.0000	0.0000	88.79	High
B_3	0.9027	0.0972	0.0000	0.0000	0.0000	88.05	High

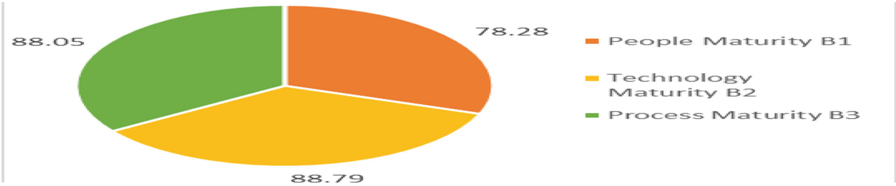

Fig. 3. Fuzzy evaluation results of criterion-level indicators

4 Conclusion

According to Fig. 1, people are more important than technology, followed by process. Among the people indicators, the computer level of employees is the highest, followed by innovation awareness and education, while age and quantity are less important. Among technology, full operation, logistics nodes, and consolidation and distribution methods all have a high proportion, and whether the full operation is paperless is the most important. Customer complaints in the process occupy a high proportion. All indicators have a strong influence on the maturity of D&A system [7].

The maturity evaluation index system has been improved and optimized, and the gap between before and after is still obvious. The research in this paper not only enhances the strength level of ICM, but also provides reference for port enterprises and other industries to evaluate the maturity of their systems.

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