The evaluation and optimization of port efficiency

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ABSTRACT

This paper mainly aims at the evaluation and optimization of port efficiency, reasonably sets the key performance indicators of personnel, technology and process, and builds the AHP model, the fuzzy comprehensive evaluation model, the cost efficiency balance optimization model and the effectiveness evaluation model of port efficiency based on the ideas of AHP, fuzzy mathematics and mathematical programming. To solve the problem of evaluation and optimization. Building the model and implementing the model with concrete and visible data helps us solve our problems.

Keywords: System maturity level; Analytic hierarchy process (AHP); Fuzzy comprehensive evaluation; Optimize

1 INTRODUCTION

Since China put forward the Silk Road Economic Belt strategy in 2014, major ports at home and abroad have faced major development opportunities. In this way, how to improve the efficiency of port logistics operation has become an important topic. To improve efficiency, we first need to determine how to effectively measure the efficiency of port operations [1].

Here, we take NOVIGO (The company name "NOVIGO" used in this paper is purely fictitious, and is only used as an example to illustrate our model and the data in this paper is obtained by querying the data of relevant real companies) Company as an example to present our port operation efficiency analysis method. Now, let's assume that NOVIGO needs to make the right decisions about three key parts of its management: people, technology, and process to make the port more efficient. Therefore, in this paper, we will solve the problem of NOVIGO Company. The model proposed based on this example is our port efficiency evaluation and optimization model.

A port is a port area where ships and passengers transfer cargo between marine and land transportation facilities. Talley called the port an engine of economic development. Therefore, in a rapidly changing competitive market, port development is a strong driving force for economic growth. The results of the study show that it is crucial for developing countries to improve port infrastructure and logistics to achieve higher economic growth gains. An increase in efficiency represents an improvement in performance. Port efficiency is a crucial component of port performance. Therefore, it is natural to find that port efficiency is so important, so it is also necessary to evaluate it [2].

2 METHODOLOGY

2.1 General Framework

The research object of this paper is the current port operation system. In problem 1 and 2, the main research content is to measure the current port operation system maturity level and optimize the system. Problem 3 and 4 requires the formulation of protocols to measure the effectiveness of the port operation system and to analyze the sensitivity of the established mathematical model in multi-scene.

To solve these problems, we will do the following:

Considering the different importance of key performance indicators corresponding to the three factors of people, technologies and processes to the research object, we select indicators in a multi-dimensional manner, and use the analytic hierarchy process (AHP) to obtain the weight of each indicator. Then, we established a fuzzy comprehensive evaluation model to classify the maturity level of the current port operation system, so as to obtain a systematic and objective comprehensive evaluation

After the current port operation system maturity level was identified using the above model, we establish a cost-efficiency balance optimization model to optimize the port operation system. We determine the efficiency function and the cost function and fit the data using a primary function, a quadratic function, and a cubic function, as well as an exponential function. To avoid the impact of different dimensions on the problem, we standardize the efficiency function as well as the cost function. Finally, we weighting combine multiple objective functions and optimize the analysis allowing the company to maximize the potential of their data assets.

Establish a port operation system Effectiveness Assessment Model. The relationship between the Effectiveness and maturity of port operation system is obtained by fitting a Effectiveness determination function. We can establish the quantitative model of port operation system maturityp to calculate the system maturity value based on the membership degree, and thus to obtain the maturity determination function, and then we can use the effectiveness determination function to evaluate the effectiveness of NOVIGO Company port operation system.

Analyze the generalizations of the model. We use the model promotion to demonstrate and analyze how the system maturity metric assessment model could be applied to other industries.

In summary, the whole modeling process can be shown as follows:

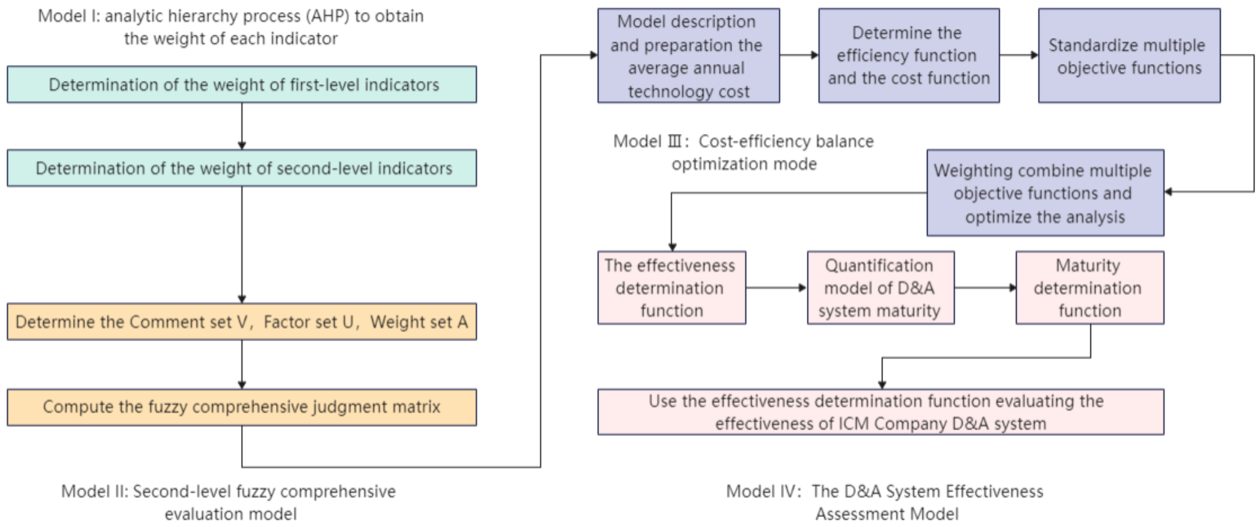


Figure 1: Model Overview

Our models rely on the following assumptions. Some assumptions are throughout the text. These assumptions will simplify the problem. Other assumptions may not be as follows, but will be put forward in the model push.

2.2 Model Assumption

1. Assumption 1: the volume of tasks the NOVIGO completes can be quantified by an indicator of the company.

Justification: Quantifying the task volume ensures that many concepts in the model can be quantified to ensure smooth modeling.

2. Assumption 2: The amount of time per task achieved by the technology used has a lower limit

Justification: Due to the limitation of global technical level, The amount of time per task achieved cannot be 0 or close to 0, so The amount of time per task achieved must have a certain lower limit.

3. Assumption 3: NOVIGO corporation ensures that they perform at least 1M tasks a day and that employees work no more than 12h per day.

Justification: Given the normal operation of NOVIGO corporation, it is reasonable to complete at least 1M tasks a day. And considering the normal personal rest time, it is reasonable to assume that employees work no more than 12h per day.

4. Assumption 4: Suppose that the technology cost contains only the cost of the technology use itself, regardless of the profits earned.

Justification: Because of the company's financial reasons, the company may not be able to invest a lot of money to introduce technology at a single time. Therefore, the late revenue changes brought about by the technology can be temporarily ignored, but only consider the cost of preparing the relevant technology.

2.3 Model Preparation: Identify key performance indicators

In order to measure the current port operation system maturity level for NOVIGO Corporation, we need to determine the key performance indicators corresponding to the three factors of people, technologies and processes. After consulting relevant materials and based on the analysis of experts, we determined the corresponding performance indicators as shown in Figure 1 below [3]:

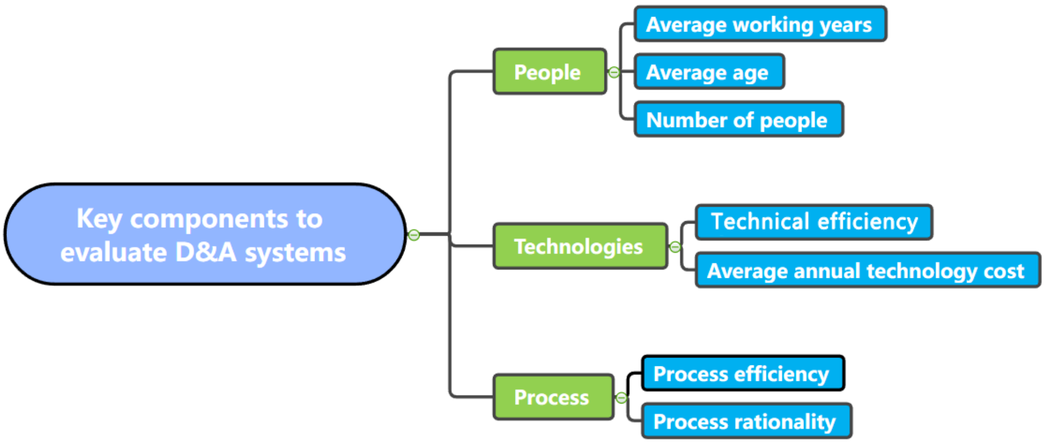


Figure 2: Three factors and their key performance indicators

For the purpose of subsequent evaluation, we need to quantify each index. The subordinate indicators of "People" can be directly quantified directly; in the subordinate indicators of "Technology", we use the amount of time per task achieved to quantify the technical efficiency, and the average annual technology cost can be directly quantified. The quantification of the subordinate indicators of "Processes" is slightly more complicated, as we describe below.

3 MODEL I: analytic hierarchy process (AHP) to obtain the weight of each indicator

The analytic hierarchy Process (AHP) is a decision-making method proposed by The American operational research scientist Satie in the early 1970s. It decomposes the elements related to decision-making into levels such as objectives, criteria and schemes, and conducts qualitative and quantitative analysis on this basis. Using analytic hierarchy process to determine the weight can effectively avoid the decision maker to put forward a set of even implied contradictory data due to the lack of consideration, so the use of analytic hierarchy process can effectively avoid this problem.

In order to ensure robustness of weighting results to ensure the correctness of subsequent calculations, we according to the analytic hierarchy process (AHP) adopted the following three different methods to evaluate the weight, and the weight vector of three methods and the comparison analysis, so to avoid the deviation produced by using a single method for the weight, the conclusion will be more comprehensive and more effective.

Person, technologies and processes in Figure 1 were recorded as first-level indicators, and key performance indicators of these three factors were recorded as second-level indicators.

3.1 Determination of the weight of first-level indicators

3.1.1 Construction of judgment matrix

First of all, we consulted the literature to understand the opinions of experts in this field, and gave the judgment matrix corresponding to the three indicators of people, technologies and processes as shown in Table 2 below:

	People	Technology	Process
People	1	1/4	1/3
Technology	4	1	2
Process	3	1/2	1

Table 2: The judgment matrix of three indicators of people, technologies and processes

3.1.2 Conduct a consistency test on the judgment matrix.

Step1: We calculated the maximum eigenvalue of this judgment matrix using MATLAB [4]:

$$\lambda_{max} = 3.0183. \tag{1}$$

Step2: Calculate the Conformance Index(CI):

$$CI = \frac{\lambda_{max} - n}{n-1} = 0.00915. \tag{2}$$

Step3: Find the corresponding average random consistency index(RI):

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

Table 3: average random consistency index and square order

By the table above， $\mathrm{RI} = 0.52$.

Step4: Calculate the consistency ratio(CR)

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} = 0.0176. \tag{3}$$

According to the calculation results, $\mathrm{CR} < 0.1$. Obviously the conclusion holds, so the consistency of the judgment matrix is acceptable.

3.1.3 Arithmetic average method for weight.

Weights were obtained using the arithmetic averaging method, The judgment matrix A was first normalized by column, the weight vector ω is then obtained by summing the normalized matrix by rows and then dividing each element in the matrix by n in rows, Each element in the weight vector ω:(ω: Weight, which reflects the importance of an indicator)

$$\omega_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \tag{4}$$

In this expression, $i = 1, 2, \cdots, n$, a_{ij} represents (i, j) in judgment matrix A, the calculation results are obtained:

$$\omega_{11} = \begin{bmatrix} 0.1226 \\ 0.5571 \\ 0.3202 \end{bmatrix} \tag{5}$$

3.1.4 Geometric averaging method for weight.

The elements of the judgment matrix A are multiplied by the row to obtain a new column vector, each component of the new vector is open to n times, and finally normalize the column vector to get the weight vector ω, each element in ω:

$$\omega_i = \frac{(\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}}{\sum_{k=1}^{n}(\prod_{j=1}^{n} a_{kj})^{\frac{1}{n}}}, \quad (i = 1, 2, \cdots, n) \tag{6}$$

$$\omega_{12} = \begin{bmatrix} 0.1220 \\ 0.5584 \\ 0.3196 \end{bmatrix} \tag{7}$$

3.1.5 Eigenvalue method for weight.

The maximum eigenvalue of the judgment matrix A_1 and its corresponding eigenvector are obtained, and then the resulting eigenvector is further normalized.

Using MATLAB, the weight vector is:

$$\omega_{13} = \begin{bmatrix} 0.1220 \\ 0.5584 \\ 0.3196 \end{bmatrix} \tag{8}$$

As shown above, the weight vectors obtained by the three methods can be considered to be the same within the allowable error range. Therefore, we can take the weight vectors:

$$\omega_1' = \begin{bmatrix} 0.1220 \\ 0.5584 \\ 0.3196 \end{bmatrix} \tag{9}$$

3.2 Determination of the weight of second-level indicators

We still use three methods to calculate the weight. The process is the same as the above steps, which will not be repeated here (the judgment matrix is put in the appendix) and the results will be given directly:

3.2.1 people

Key performance indicators of people factors are average working years, average age, and number of people,The judgment matrix of the three indicators is: (A: Judgment matrix, which is used to determine the weight size of each indicator)

$$A_2 = \begin{bmatrix} 1 & 2 & 4 \\ 0.5 & 1 & 2 \\ 0.25 & 0.5 & 1 \end{bmatrix} \tag{10}$$

The weight vectors obtained by the three methods are as follows:

$$w_{21} = \begin{bmatrix} 0.5714 \\ 0.2857 \\ 0.1429 \end{bmatrix} \qquad w_{22} = \begin{bmatrix} 0.5714 \\ 0.2857 \\ 0.1429 \end{bmatrix} \qquad w_{23} = \begin{bmatrix} 0.5714 \\ 0.2857 \\ 0.1429 \end{bmatrix} \tag{11}$$

As shown above, the results of the three methods are within the error allowable range, namely the weight vector. Let's take the weight vector to be：

$$\omega_2' = \begin{bmatrix} 0.5714 \\ 0.2857 \\ 0.1429 \end{bmatrix} \tag{12}$$

3.2.2 Technologies

The key performance indicators of the technologies factors are the technical efficiency and the average annual technology cost.

The judgment matrix of the two as the column index is：

$$A_3 = \begin{bmatrix} 1 & 2 \\ 0.5 & 1 \end{bmatrix} \tag{13}$$

The weight vectors obtained by the three methods are as follows:

$$w_{31} = \begin{bmatrix} 0.6667 \\ 0.3333 \end{bmatrix} \qquad w_{32} = \begin{bmatrix} 0.6667 \\ 0.3333 \end{bmatrix} \qquad w_{33} = \begin{bmatrix} 0.6667 \\ 0.3333 \end{bmatrix} \tag{14}$$

As shown above, the results of the three methods are within the error allowable range, namely the weight vector. Let's take the weight vector to be：

$$\omega_3' = \begin{bmatrix} 0.6667 \\ 0.3333 \end{bmatrix} \tag{15}$$

3.2.3 processes

The key performance indicators of processes factors are process efficiency and process rationality.

The judgment matrix of the two as the column index is：

$$A_4 = \begin{bmatrix} 1 & 2 \\ 0.5 & 1 \end{bmatrix} \tag{16}$$

The weight vectors obtained by the three methods are as follows:

$$w_{41} = \begin{bmatrix} 0.6667 \\ 0.3333 \end{bmatrix} \qquad w_{42} = \begin{bmatrix} 0.6667 \\ 0.3333 \end{bmatrix} \qquad w_{43} = \begin{bmatrix} 0.6667 \\ 0.3333 \end{bmatrix} \tag{17}$$

As shown above, the results of the three methods are within the error allowable range, namely the weight vector. Let's take the weight vector to be：

$$\omega_4' = \begin{bmatrix} 0.6667 \\ 0.3333 \end{bmatrix} \tag{18}$$

After the above steps, we find the weights of first-level indicators and the key performance indicators corresponding to first-level indicators respectively. Next, we quantitatively analyse and measure the current port operation system maturity level for NOVIGO Corporation through fuzzy comprehensive evaluation.

4 MODEL II: Second-level fuzzy comprehensive evaluation model

Fuzzy comprehensive evaluation method is a widely used method in fuzzy mathematics [5]. It is mainly used in the evaluation of the situation determined by multiple factors, the basic idea is to make a separate comment on each factor and try to consider all the factors to make a comprehensive comment. It applies the theory of fuzzy information processing to the actual evaluation. It can consider the related indexes of the evaluation object and give reasonable evaluation value to various quantitative and non-quantitative fuzzy indexes and fuzzy relations contained in the evaluation object. It has universality and can be used to evaluate both subjective and objective indicators. Due to the existence of a large number of fuzzy boundary phenomena in the real world, fuzzy comprehensive evaluation is widely used, especially in the subjective weight multi-index comprehensive evaluation, fuzzy comprehensive evaluation plays a very important role [6].

In this problem of measuring the current port operation system maturity level for NOVIGO Corporation, we divided the evaluation indicators into two levels, so we need to establish a Second-level fuzzy comprehensive evaluation model for the evaluation.

4.1 Determine the Comment set V, Factor set U, Weight set A

In this model, we need to determine the comment set, factor set, and weight set, as follows [7]:

$$V=\{\text{excellent, good, medium, poor}\} \tag{19}$$

$$A_i = \omega_i (i = 1,2,3,4) \tag{20}$$

$$U = \{U_1, U_2, U_3\} = \{people, technologies, processes\} \tag{21}$$

$$U_1 = \{average\ working\ years\ , average\ age\ , number\ of\ people\ \} \tag{22}$$

$$U_2 = \{technical\ efficiency\ , average\ annual\ technology\ cost\ \} \tag{23}$$

$$U_3 = \{process\ efficiency\ , process\ rationality\ \} \tag{24}$$

4.2 Compute the fuzzy comprehensive judgment matrix

In order to achieve the purpose of quantify each index, we first need to specify the concept of "unit task quantity": we use random sampling survey, randomly selected 90 days in a day, statistics of daily total task volume (in the model assumption part, we have assumed that NOVIGO daily task volume can be quantified by a certain index), and seek the average, we remember the daily task volume as unit task volume M.

4.2.1Relevant index data

After consulting the data of relevant companies, we concluded that during the whole year of 2021, the data of NOVIGO company indicators are shown in the following table:

<table>
<tr><td>Average working years /Year</td><td colspan="2">Average age of staff/Age</td></tr>
<tr><td>3.5</td><td colspan="2">31</td></tr>
<tr><td>Number of staff/Staff</td><td colspan="2">The amount of time per task achieved by the technology used/Hour</td></tr>
<tr><td>6.5</td><td colspan="2">38</td></tr>
<tr><td>Average annual technology cost/Ten thousand dollar</td><td colspan="2">Process rationality&Average T/C（aveT/C)</td></tr>
<tr><td>4.3</td><td colspan="2">2.9</td></tr>
<tr><td colspan="3">Process efficiency&Efficiency value</td></tr>
<tr><td>Daily total volume of tasks completed/M</td><td>Daily number of staff/Person</td><td>Efficiency value</td></tr>
<tr><td>0.98</td><td>10</td><td>0.098</td></tr>
</table>

Table 4: Data sheet of various indicators of NOVIGO Company

Below, we make an explanation of the quantification of process efficiency and process rationality in the table above.

4.2.2 explanation of the quantification of process efficiency and process rationality

To quantify process efficiency and process rationality, we need to build new mathematical models separately.

1. Process efficiency quantification model (efficiency value model)

We stipulated that with the average daily number of personnel, the greater the daily total volume of tasks completed, the higher the efficiency of the process, and the less the average daily number of personnel, the higher the efficiency of the process.

Therefore, we define the concept of "Efficiency value" (E) to quantify process efficiency:

$$E = \frac{\text{Daily total volume of tasks completed}}{\text{Number of staff}} \tag{25}$$

Therefore, the data in Table 3 are naturally reasonably interpreted:

$$E = \frac{0.98}{10} = 0.098. \tag{26}$$

2. Process rationality quantification model (The ratio of tasks to capabilities model)

We stipulate that if people with strong capabilities are assigned a relatively large amount of tasks and people with weak capabilities are assigned a relatively small amount of tasks, then the process is relatively reasonable.

Then we explain the T/C model vividly by the following figure:

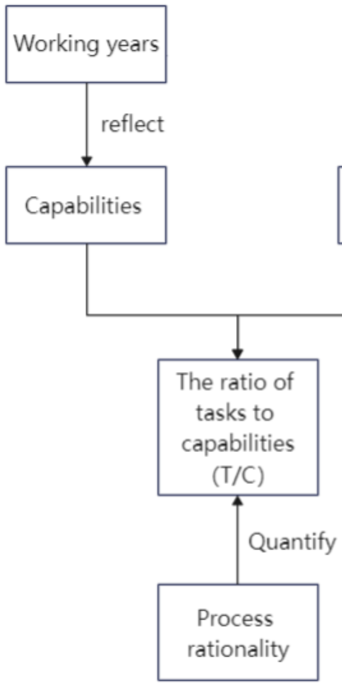


Figure 3: Structural explanation for T/C model

For each staff, we can calculate the T/C (The ratio of tasks to capabilities，which reflects how well the number of tasks for employees match their capabilities)，After finding out the total energy ratio we can obtain the average T/C:

$$aveT/C = \sum_{i=1}^{n} (T/C)_i \,/n \tag{27}$$

We stipulated that the standard T/C was (unit: 0.01 * M / Year):

$$srdT/C = \frac{\text{Daily total volume of tasks completed}}{\text{Average working years} * \text{Number of staff}} = 2.8 \tag{28}$$

Obviously, the more the staff's capability value matches the task volume they get, the closer the sample $aveT/C$ should be verge on $srdT/C$. By referring to relevant literature, 18 staff of the company are randomly selected by random sampling survey, and the following data are given:

Staff1			Staff2		
Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)	Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)
1.47	0.3	4.93	1.28	0.63	2.03
Staff3			Staff4		
Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)	Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)
1.48	0.61	2.44	1.26	0.23	5.6
Staff5			Staff6		
Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)	Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)
0.61	0.27	2.25	1.59	0.83	1.92
Staff7			Staff8		
Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)	Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)
1.56	0.79	1.96	1.93	0.53	3.63
Staff9			Staff10		
Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)	Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)
1.89	0.44	4.33	1.22	0.45	2.71
Staff11			Staff12		
Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)	Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)
1.17	0.31	3.72	0.27	0.28	0.98
Staff13			Staff14		
Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)	Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)
1.98	0.57	3.48	0.89	0.61	1.46
Staff15			Staff16		
Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)	Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)
1.6	0.46	3.52	1.73	0.81	2.13
Staff17			Staff18		
Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)	Daily task volume/0.1M	Working years/ten years	T/C/(0.01*M/year)
0.18	0.13	1.39	0.61	0.27	3.72

Table 5: T/C data of the staff

With excel 's data-processing capabilities, it's not hard to find out:

$$aveT/C = 2.90 \text{（unit: } 0.01 * \mathrm{M/Year}\text{）} \tag{29}$$

4.2.3 Determination of membership degree

We will use different methods to determine the membership degree of each index to each comment, so as to obtain a comprehensive evaluation matrix.

According to the opinions of the experts in this field, we first give the evaluation criteria for some indicators as shown in Table 6 below (unit as above is omitted here):

Index	Types of index	Excellent	Good	Medium	Poor
Average working years	Very large	5	3	2	1
Technical efficiency	Very small	6	7	8	10
Average annual technology cost	Very small	2.5	3.5	4.5	6
Process efficiency	Very large	0.15	0.1	0.08	0.06

Table 6: Evaluation criteria of some indicators

1. Establishment of the index membership function in Table 6

Using the trapezoidal distribution, we can determine that the membership function of the index "Average working year" for the four comments of excellent, good, medium and poor are respectively as follows [8]:

$$\text{Comment "Excellent":} \quad A(x) = \begin{cases} 0, x < a \\ \frac{x-a}{b-a}, \quad a \le x \le b \\ 1, x > b \end{cases}, \text{ 其中, } a = 5, b = 3 \tag{30}$$

Comment "Good": $$A(x)=\begin{cases}0, x<a \\ \frac{x-a}{b-a}, a\le x\le b \\ \frac{c-x}{c-b}, b<x\le c \\ 0, x>c\end{cases} 其中, a=2, b=3, c=5 \quad (31)$$

Comment "Medium": $$A(x)=\begin{cases}0, x<a \\ \frac{x-a}{b-a}, a\le x\le b \\ \frac{c-x}{c-b}, b<x\le c \\ 0, x>c\end{cases} 其中, a=1, b=2, c=3 \quad (32)$$

Comment "Poor": $$A(x)=\begin{cases}1, x<a \\ \frac{b-x}{b-a},\ a\le x\le b \\ 0, x>b\end{cases},\ 其中,\ a=1, b=2 \quad (33)$$

The establishment of the last three index membership functions in Table 5, we also adopt the trapezoidal distribution, the same as the above description, which is not detailed here.

After obtaining the membership function, we can easily calculate the membership degree of the relevant indicators relative to each comment according to the specific values of the company (the membership degree table below).

2. Establishment method of the membership degree of the other three indicators

The other three indicators are intermediate indicators, namely, the closer the value, the better the comments you get. The establishment of its membership function is more complex. We consulted relevant information, randomly selected 10 experts to have a deep understanding of their views, and "voted" according to the opinions of different experts to determine the membership degree of the remaining three indicators to each evaluation.

3. Get the membership degree table

According to the confirmation of the membership degree in the above two steps, we can get the following membership degree table [9]:

First level indicators	Second level indicators	Excellent	Good	Medium	Poor
People	Average working years	0.25	0.75	0	0
	Average age of staff	0.68	0.32	0	0
	Number of staff	0.12	0.56	0.29	0.03
Technology	Technical efficiency	0.5	0.5	0	0
	Average annual technology cost	0	0.2	0.8	0
Process	Process efficiency	0	0.9	0.1	0
	Process rationality	0.83	0.16	0.01	0

Table 7: Membership degree table

The membership matrix corresponding to the three first-level indicators of people, technologies and processes is R_1、R_2、R_3 respectively, the weight matrix has been obtained: ω'_2, ω'_3, ω'_4, then we take the transpose of each of them to get the weighted row vectors :ω_2、ω_3、ω_4.

Then, we can obtain [10]:

$$B_1 = \omega_2 \cdot R_1, \quad B_2 = \omega_3 \cdot R_2, \quad B_3 = \omega_4 \cdot R_3 \tag{34}$$

So as to get:

$$B^* = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = \begin{bmatrix} 0.3543 & 0.6000 & 0.0414 & 0.0043 \\ 0.3334 & 0.4000 & 0.2666 & 0 \\ 0.2766 & 0.6534 & 0.0700 & 0 \end{bmatrix} \tag{35}$$

So far, we have reached the fuzzy comprehensive judgment matrix that determines the final comprehensive judgment.

4.2.4 Get the comprehensive evaluation results

The four comments are judged comprehensively as follows:

$$B = \omega_1 \cdot B^* \cdot \tag{36}$$

Then we can get the following answer:

$$B = [0.3178 \quad 0.5054 \quad 0.1763 \quad 0.0005] \tag{37}$$

It is obvious that comment 3 ("good") has the most membership degree, so the fuzzy comprehensive evaluation result of the NOVIGO port operation system is "good".

5 MODEL Ⅲ: Cost-efficiency balance optimization model

5.1 Model description and preparation the average annual technology cost

From the analysis results of the fuzzy comprehensive evaluation, we can know that the company's port operation system does not reach a perfect or more perfect degree, and on the contrary, there is still a lot of room for optimization of the system. Analysis the relationship between the two floor indicators, we can find that "technology" corresponding to obvious constraints between the two key performance indicators, that is, the improvement of technical efficiency, often accompanied by the increase of the average annual technology cost and the average annual technology cost often accompanied by the decline of technical efficiency. In this way, it is not easy to find the balance between them, which can also serve as a breakthrough point to optimize the port operation system.

To this end, we build a cost-efficiency balance optimization model to optimize the port operation system. Below, we first give the pseudo-code to explain the algorithmic ideas of the model:

Algorithm : Cost-efficiency balance optimization

Input: $\eta(T), W(T), \omega_\eta, \omega_W, D_T$

Output: T

Step1:Carry out the forward transformation of multiple objective functions

Step2:Standardize multiple objective functions

Step3: Weight multiple objective functions into single objective functions $f(T)$

Step4:Find the maximum value of function $f(T)$

End

Below, we perform a specific implementation of the model:

We assume that under the condition of a certain number of staff, the time spent using a certain technology to complete the unit task quantity is T (unit: time).Due to global technology constraints, T cannot be very small or even tend to 0, and we hypothesize that:

When other conditions remain unchanged, it takes 4h to complete the unit task when a good technology is used, and this time is called the optimal time consumption, recorded as PT.

In addition, we believe that NOVIGO employees work no more than 12 hours a day and are guaranteed to complete a minimum of at least 1M per day, so the maximum T is 12h, called the bottom line time consuming, recorded as DT.

In this model, we do not consider the profit increase brought by technical efficiency improvement to NOVIGO companies.

5.2 Determine the efficiency function and the cost function

5.2.1 Efficiency function

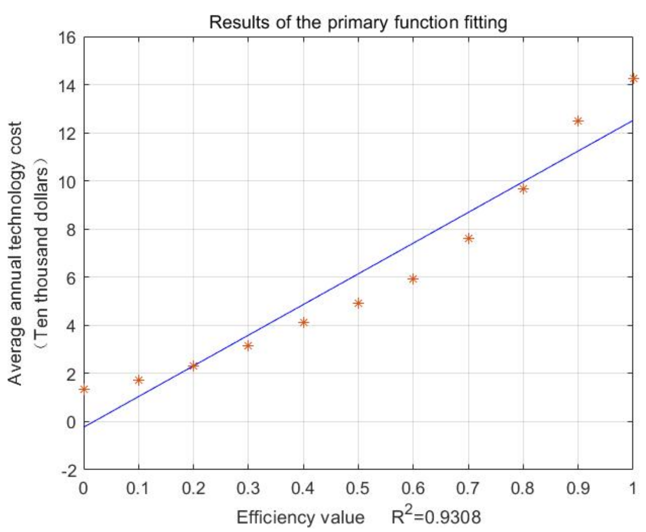
Efficiency can be quantified by Tand the values of efficiency are often distributed over the interval[0,1], where we map T to the interval [0,1] by linear mapping, using the image as the efficiency value. The following functions are given:

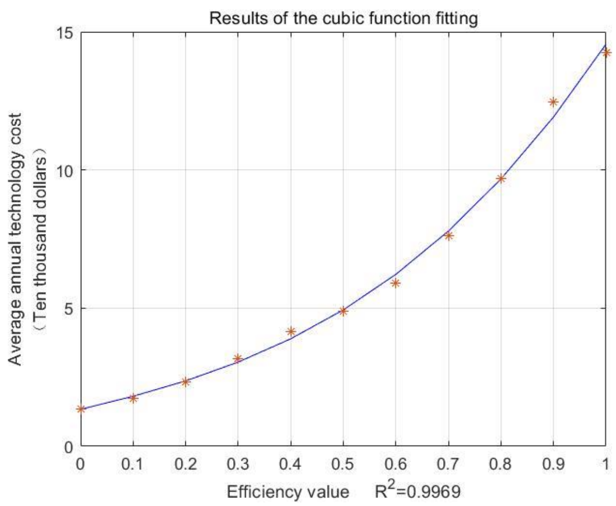
$$\eta = \left(1 - \frac{T-PT}{DT-PT}\right) * 100\% \quad (4 \le T \le 12) \tag{38}$$

5.2.2 Cost function

Efficiency can be determined directly by$T$, and technology cost can be directly determined by technical efficiency, so it is not difficult to know that cost can be determined by T indirectly.

To obtain the relationship between cost and T, we first give the relationship between cost and efficiency. After consulting the relevant information, we know that between efficiency and cost is not a simple linear relationship, in order to seek the most appropriate relationship between them, we collected the relevant data and fitted the results to the analysis. (R^2 Represents goodness of fit)





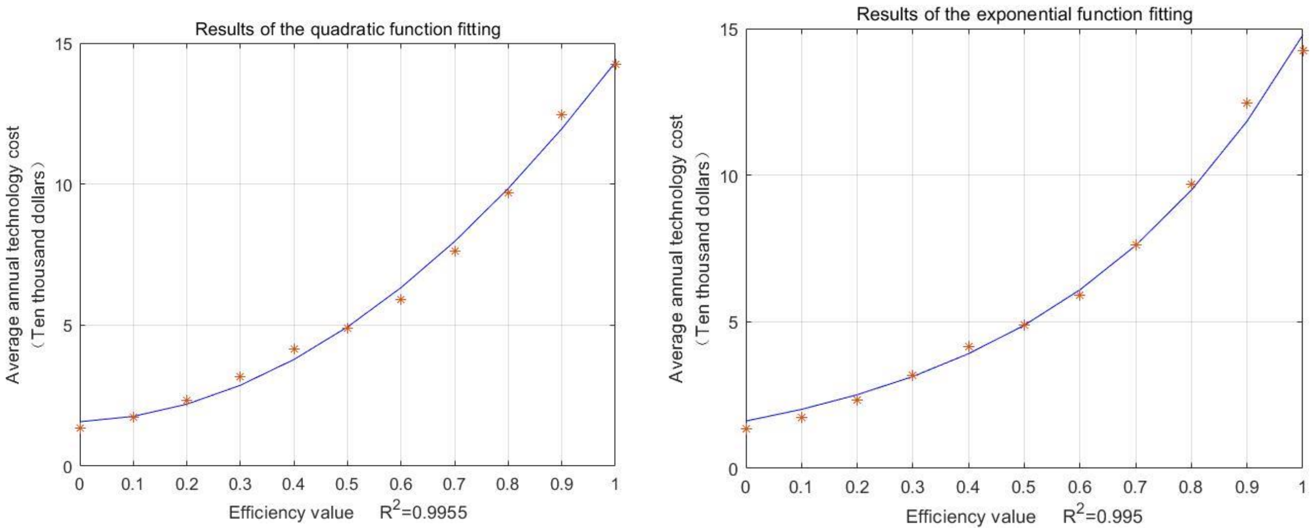


Figure 4: Result of functions fitting

As shown in the figure above, we fit the data using a primary function, a quadratic function, and a cubic function, as well as an exponential function.

As shown in the figure, the cubic function has the best goodness of fit, the quadratic function is second, then the exponential function, with the worst fit. Considering that in addition to pursuing the goodness of fit, the simplicity of the fitting function should be pursued. Therefore, ultimately we use the quadratic function as a function between cost （W ） and efficiency （η (Technical efficiency)）, as follows (the function coefficients are automatically derived by the MATLAB fitting tool):

$$\mathrm{W} = 12.04 * \eta^2 + 0.7079 * \eta + 1.573 \text{ (unit: ten thousand dollar)} \tag{39}$$

Therefore, we can further give the functional relationship between W and T:

$$W = 0.1881 * T^2 - 4.6035 * T + 29.7248 \text{ (unit: ten thousand dollar)} \tag{40}$$

When optimizing, we want the value of W to be as small as possible. Therefore, in order to smoothly carry out the subsequent optimization process, we first carry out the forward transformation of the indicator W.

We know from the quadratic function $\Delta < 0$ that the value of W is constant positive. Therefore, we can directly take the reciprocal to carry out the forward transformation of the indicator W.

$$W' = \frac{1}{0.1881 * T^2 - 4.6035 * T + 29.7248} \quad \text{(unit: ten thousand dollar}^{-1}\text{)} \tag{41}$$

5.3 Standardize multiple objective functions

To avoid the impact of different dimensions on the problem, we standardize the efficiency function as well as the cost function. Here, we have both the two function expressions simultaneously divided by, the maximum value of the function within the range of T.Using MATLAB as a tool, it is easy to find out:

$$W'_{max} = \frac{2500}{3923}, \quad \eta_{max} = 1 \tag{42}$$

Therefore, the standardized function expression is:

$$\text{Cost function}: \mathrm{W}'_s = \frac{1}{0.1199 * \mathrm{T}^2 - 2.934 * \mathrm{T} + 18.94} \tag{43}$$

$$\text{Efficiency function}: \eta_s = \left(1 - \frac{\mathrm{T} - \mathrm{PT}}{\mathrm{DT} - \mathrm{PT}}\right) \tag{44}$$

5.4 Weighting combine multiple objective functions and optimize the analysis

In model I, we have determined the weight size of the technical efficiency and the average annual technology cost, so we can combine the two to turn the double objective function into a single objective function to facilitate the optimization of the problem. The weighted objective function is:

$$f(T) = \omega_3'(1,1) * \eta_s + \omega_3'(2,1) * W_s' \tag{45}$$

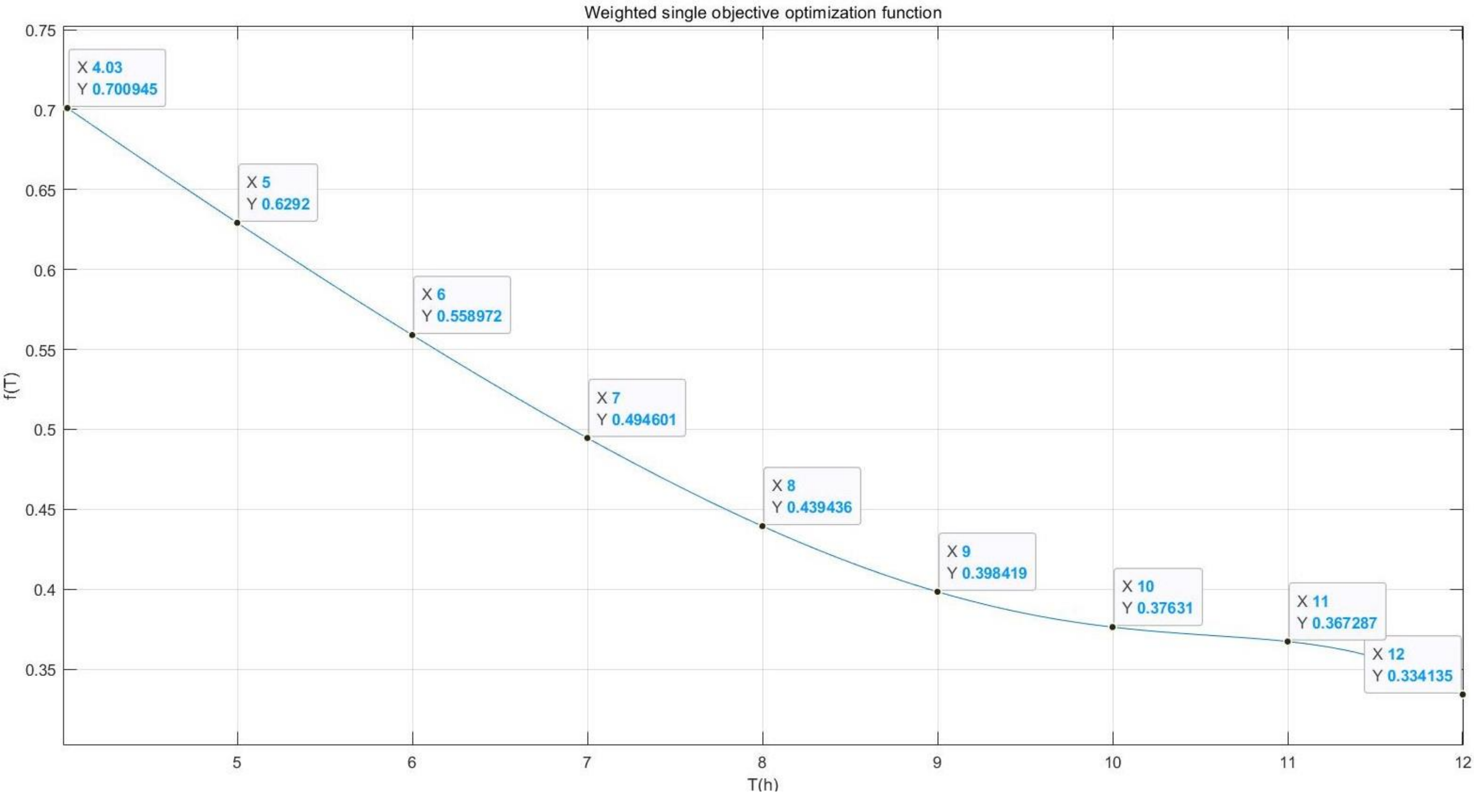


Table 8: Weighted single objective optimization function

After finishing: $$\mathrm{f(T)}=1-\frac{\mathrm{T}}{12}+\frac{1}{0.3597*\mathrm{T}^2-8.802*\mathrm{T}+56.82} \tag{46}$$

The function image is shown as follows:

According to the image, the function decreases monotonically within the definition of T and takes the maximum when $\mathrm{T}=4$,

$$\mathrm{f(T)}_{\max} = 0.7032 \tag{47}$$

Thus, the smaller the value of T , the greater the extent that our system is optimized.

6 MODEL IV: The port operation system Effectiveness Assessment Model

6.1The effectiveness determination function

Obviously, the effectiveness of the port operation system has a certain positive correlation with its maturity. In our opinion:

1. The system is not efficient when the maturity is below a value of 1.
2. The system continues to be effective when the maturity is above a certain value of 2.
3. The validity of the system increases with maturity when maturity belongs to the interval $\mathrm{p}\epsilon[\mathrm{p}_1,\mathrm{p}_2]$.

Referring to relevant information, we know that effectiveness increases exponentially when maturity grows uniformly when $p \epsilon [p_1, p_2]$.

Set p as maturity, p between 0,100, and set f(p) as effectiveness, both f(p) between 0,1. As the exponential function grows too fast, the function value will be too large. Therefore, we do not directly take the exponent as a constant of nature, but normalize it first and then take e as an exponent.

Then, the following functions determine the level of effectiveness:

$$f(p) = \begin{cases} 0, & p < p_1 \\ ae^{\frac{p}{100}} + k, & p_1 \leq p \leq p_2 \\ 1, & p > p_2 \end{cases} \tag{48}$$

6.2 Quantification model of port operation system maturity p

6.2.1 Maturity value segmentation

First, we specify maturity$p\epsilon[0,100]$, and below we quantify maturity p using relevant conclusions from the fuzzy comprehensive evaluation model.

In the fuzzy comprehensive evaluation model, we use four comments: "excellent", "good", "medium", and "bad" (recorded as comment 4, comment 3, comment 2, comment 1 respectively) to evaluate the maturity of the system. We stipulate that the four comment levels each correspond to four mature value segments, i. e:

$$\text{Comment } i \to [25 * i, 25 * (i + 1)] \tag{49}$$

6.3 Maturity determination function

6.3.1Establish function

Based on 8.1, we model and calculate the system maturity values based on membership degree.

In the final comprehensive evaluation matrix, the rank of the maximum membership degree is the rank of the maturity of the port operation system, which is recorded as Mi.Let the membership degree of comments 1,2,3,4 be $BL_i(i = 1,2,3,4)$ (Membership), and let each comment correspond to a maturity improvement value, $HM_i(i = 1,2,3,4)$ (Maturity improvement value):

$$HM_1 = 0, \quad HM_2 = 8, \quad HM_2 = 16, \quad HM_4 = 25 \tag{50}$$

After defining HM, we give the functional formula for calculating the maturity value based on the comment rating and membership as follows:

$$p(Mi, HM_i) = 25 * (Mi - 1) + \sum_{i=1}^{4} HM_i * BL_i \tag{51}$$

6.3.2 Understanding of maturity determination function and explanation of rationality.

The above maturity determination function showed us that $p$is obtained from the addition of the two parts:

① **Base value**: the lower limit of the maturity interval corresponding to the comment rating of the system.

② **Raised value**: It is determined by the membership degree of the system in different comments. Each comment has its raised value, which is multiplied by the membership and HM value of the comment.

We consider the influence of each comment on the different directions and degrees of comprehensive maturity, and reasonably set up $HM_i(1,2,3,4)$.The maximum value of HM_4 is 25, guaranteeing $p$can take the maximum value of 100 within its domain; the minimum value of HM_1 is 0, ensuring that the membership of the “poor ”comment does not make any contribution to the total increase of maturity and $p$can take the minimum value within its domain.

During the determination of the HMvalue, we specify the maximum of it as 25,25 as the interval length of each comment maturity interval. Moreover, within the error allowed range, we can think that the membership sum of the four comments in the fuzzy comprehensive evaluation matrix is 1. Therefore, our regulations can ensure that the total maturity increase value will not exceed 25, so the system maturity must be within the maturity section corresponding to the comments of the system.

From the above, the determination of our maturity function is reasonable and feasible.

6.3.3 Materialize effectiveness determination function parameter

From our division of the maturity segment, we can reasonably specify the values of the critical independent variables $p_1 and\ p_2$ in the effectiveness determination function:

$$p_1 = 5, p_2 = 95$$

Invalid or persistently effective system should be relatively difficult to achieve: system maturity is difficult to approach 0 or 100, so the values of $\mathrm{p_1}$ and $\mathrm{p_2}$ are very close to two extreme values.

To ensure the continuity of the function, the following equation holds:

$$\begin{cases} f(5) = 0 \\ f(95) = 1 \end{cases} \tag{52}$$

It's not hard to calculate it:

$$\begin{cases} a = 0.6517 \\ k = -0.6851 \end{cases} \tag{53}$$

At this point, all the parameters in the effectiveness determination function have been materialized, and to make the function more intuitive, we give an image of the function:

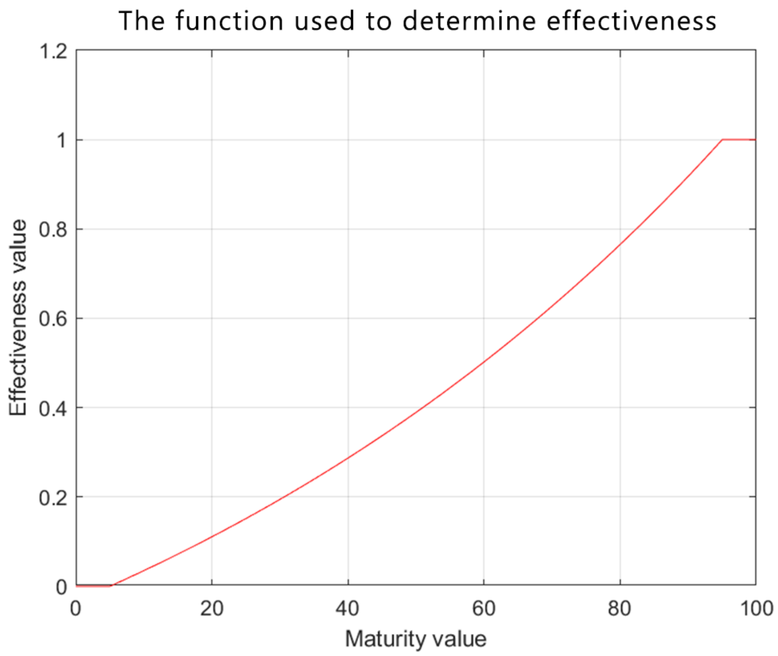


Figure 4: Effectiveness determination function

6.4 Use effectiveness determination function evaluating the effectiveness of port operation system.

6.4.1 Determine the current port operation system maturity level

In the fuzzy comprehensive evaluation model, we finally obtain a comprehensive evaluation matrix for the company's port operation system:

$$B = [0.3178 \quad 0.5054 \quad 0.1763 \quad 0.0005] \tag{54}$$

It is easy to see that comment 3 has the most significant membership

$$Mi = 3. \tag{55}$$

From the maturity determination function, we can calculate the specific maturity values of the NOVIGO port operation system as:

$$p = 56.8765 \tag{56}$$

From the effectiveness determination function, we can calculate the effectiveness of NOVIGO Company port operation system as:

$$f(p) = 0.4659. \tag{57}$$

By the above model, we suggest complete and reasonable protocols that NOVIGO should put in place to measure the effectiveness of their port operation system.

7 MODEL DISCUSSION

7.1 Strengths

In model III, we utilized the curve-fitting function of MATLAB to determine that the functional relationship between cost and efficiency is more objective and persuasive.

In model I, we use three methods to calculate the index weights, strongly ensuring the robustness of the calculation results.

7.2 Weaknesses

The optimization model only optimized the model for the two key performance indicators under the technology index, and did not optimize the model from all aspects.

AHP has obvious drawbacks, when making pairwise comparisons with respect to the criteria and alternatives, the decision maker must give an exact number based on somewhat vague feeling, and all these relative priority numbers are restrict to integers. These unfounded processes can lead to errors and inconsistence [11].

7.3 Possible improvement

If there is more relevant data, the weight of each index can be determined by the entropy weight method, so that the results can be more objective.

8 CONCLUSION

This paper presents a model for evaluating the operational efficiency of ports, using NOVIGA company as an example. We have identified methods to optimize port efficiency and demonstrated the effectiveness of our model in evaluating port operational systems. Our research has been successful in achieving its objectives. In future studies, we may expand the range of indicators to further optimize and improve our model, enabling it to better assist port companies in evaluating and improving their efficiency.

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