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Technical Analysis of Quayside Bridge Maintenance Scheme based on AHP

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Abstract

In the event of an accident, the first thing is to analyze the scene of the accident and assess the damage of the damaged mechanical equipment. Accurate damage assessment is an important theoretical basis for the formulation of the follow-up maintenance plan. The second thing is to find a maintenance provider who can provide maintenance services. Different maintenance providers offer different prices and different maintenance methods. When choosing a maintenance scheme, enterprises should not only consider the quotation level and maintenance time of maintenance providers, but also consider the use stability and maintenance quality of equipment after maintenance. Therefore, how to choose the optimal maintenance plan has a great impact on port enterprises. In this paper, based on the analytic hierarchy process, the maintenance scheme of specific accidents is analyzed, and the optimal scheme is obtained by comparison, which provides a certain scientific basis and reference method for the post accident maintenance.

Keywords

Quayside Bridge; Analytic Hierarchy Process; Set Pair Analysis.

1. Introduction

Container machinery and equipment in the manufacture of the corresponding production standards, when put into use will also have the provisions of the rated load and user manual. In port operation, machinery and equipment are closely related, and often a certain equipment is damaged, so the consequence may be that shutdown will bring economic damage, and in serious cases, it will cause casualties. Therefore, for economic and safety considerations, it is necessary to carry out daily maintenance of port machinery and equipment, so as to ensure that accidents can be reduced within the scope of human control The frequency and frequency of the fault can ensure the safe and stable operation of the equipment. Nevertheless, some unexpected accidents are unpredictable for port operations. These accidents are often very sudden and without warning. The reasons may be human operation errors or other natural reasons, which are difficult to predict and prevent through scientific means. We can only make up for the losses caused by the accidents through post maintenance. For example, on April 18, 2015, a crane ship was hit by the lower boom of towing to a quayside container crane of Xiamen Songyu Wharf at a numbered position about 850 meters away from the wharf front, causing serious damage to the crane. The damage to the quayside bridge after the collision is shown in Figure 1 below.

In the event of an accident, the first thing is to analyze the scene of the accident and assess the damage of the damaged mechanical equipment. Accurate damage assessment is an important theoretical basis for the formulation of the follow-up maintenance plan. The second thing is to find a maintenance provider who can provide maintenance services. Different maintenance providers offer different prices and different maintenance methods. When choosing a

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maintenance scheme, enterprises should not only consider the quotation level and maintenance time of maintenance providers, but also consider the use stability and maintenance quality of equipment after maintenance. Therefore, how to choose the optimal maintenance scheme has a great impact on port enterprises.

2. Introduction to the Theory of AHP

2.1. Introduction of Analytic Hierarchy Process

The basic idea of analytic hierarchy process (AHP) is to decompose the complex problem into several different factors, and sort these factors according to the dominant relationship among them. From the target layer to the middle sub target layer and criterion layer, and then to the lowest scheme layer, these factors are arranged respectively, and the AHP model for the problem is established. After the model is established, the experts need to construct the mutual judgment matrix between the elements, sort the elements hierarchically, and use the matrix to calculate the corresponding element weights. After the results are obtained, the consistency test is needed. Finally, the hierarchy is sorted to get the weight of each decision-making layer for the total goal. This paper will use AHP to determine the weight of each index system.

2.2. Introduction of Set Pair Analysis

Set pair analysis (SPA) was proposed by Zhao Keqin, a Chinese scholar, in 1989. It is an effective method to analyze and deal with uncertain information. At present, it has been applied in military and national defense, artificial intelligence, management, decision-making and selection. When selecting maintenance scheme, many factors need to be considered, such as warranty period, maintenance quality and other criteria are qualitative indicators, which are difficult to quantify compared with maintenance cost and maintenance time. Therefore, set pair analysis method is adopted to solve the quantitative problem and uncertainty characteristics of qualitative indicators in evaluation method.

The basic idea of set pair analysis is as follows:

a. Set pair and its representation.

A set pair is a unit composed of two interrelated sets, which can be denoted as sp. it can be represented by capital letters, such as set pair P. If it needs to be expressed by equation, it can be recorded as. This equation shows that set pair P is composed of set a and set B.

b. Same, different and opposite connection.

If set a and set B have some identical or opposite characteristics, they are referred to as having identical or opposite relations. When set a and set B have the same connection, it can be recorded as; when set a and set B have the opposite connection, it can be recorded as. When a and B have a certain connection, they are neither identical nor antagonistic, which is called differential connection.

c. Connection degree.

A set and a set constitute a set pair. Let a set and a set form a set pair. Let a set and a set form a set pair. Let a set and a set form a set pair. Then the connection degree of the two sets can be expressed by the following formula:

$$\mu(A,B)=\frac{S}{N}+\frac{F}{N}i+\frac{P}{N}j$$

Where S / N, f / N and P / N represent the degree of identity, degree of difference and degree of opposition of set pair h respectively.

Formula 4-1 can be written as:

$$\mu(A,B) = a + bi + cj$$

Where, the meaning is as follows:

1) And as the coefficients of difference degree f / N and opposition degree p / N, the values are different. The value range of is [- 1,1], which is different in different cases; the value of is - 1;

2) From the definition of connection degree, we can see that,, satisfies the normalization condition, that is, satisfies:

$$a + b + c = 1$$

The specific method flow diagram is shown in the figure below.

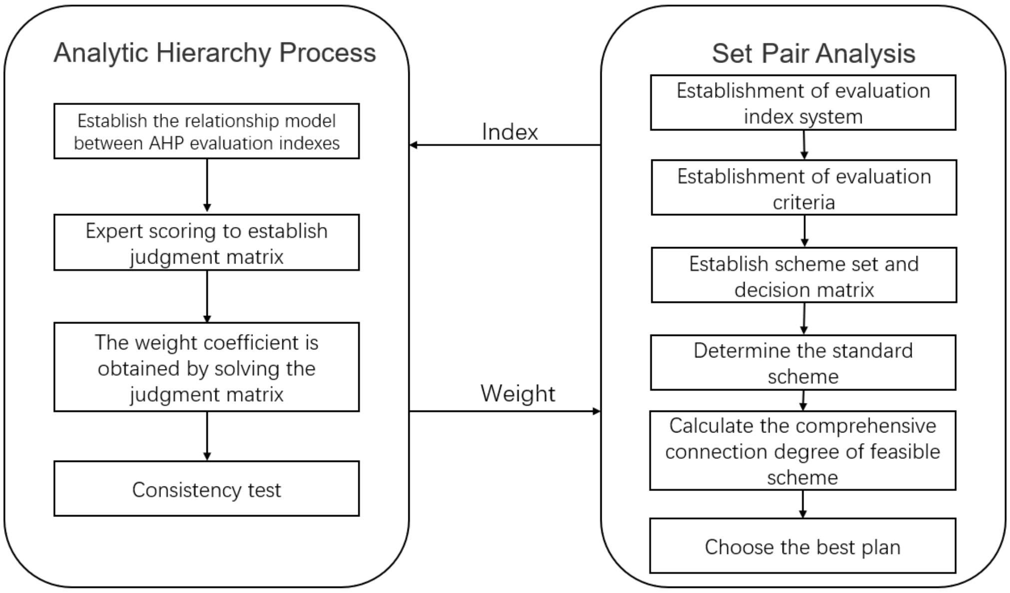

Figure 1. Flow chart of AHPFlow chart of AHP

3. Model Analysis

3.1. Case Introduction

After the accident, three maintenance schemes were put forward based on the opinions of experts and manufacturers. The cost and maintenance method of each maintenance scheme were different, and the best one should be selected from the three maintenance schemes. The first scheme is proposed by the third-party professional maintenance organization, mainly in the way of on-site maintenance; the second scheme is proposed by the original manufacturer of the bridge crane, mainly in the way of returning to the factory for maintenance; the third scheme is given by the original manufacturer of the bridge crane, mainly in the way of on-site maintenance. The specific quotation information of the three maintenance schemes is as follows.

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Table 1. Quotation cost of scheme A

Serial number	Project name and content	Amount: RMB
1	Building materials fee	1,400,000
2	Construction labor cost	1,100,000
3	Travel and design expenses of construction personnel	150,000
4	Transportation cost of structural parts	50,000
5	Equipment cost	400,000
6	Transfer costs	500,000
7	Inspection and special inspection	200,000
8	Insurance expenses	20,000
9	management expense	230,000
10	taxation	450,000
Total		4,500,000

Table 2. Quotation cost of scheme B

Serial number	Project name and content	Amount: RMB
1	Building materials fee	450,000
2	Construction labor cost	892,550
3	Tools and tooling	300,000
4	Equipment leasing	4,800,000
5	Terminal occupancy fee	1,500,000
6	Shore bridge transportation and sea binding	7,800,000
7	Maintenance scheme design	200,000
8	Inspection and special inspection	250,000
9	insurance premium	20,000
10	management expense	1,576,250
11	taxation	2,947,588
Total		20,286,338

Table 3. Quotation cost of scheme C

Serial number	Project name and content	Amount: RMB
1	Material cost	500,000
2	Construction personnel	1,176,750
3	Tools and tooling	200,000
4	freight	380,000
5	Equipment leasing	250,000
6	Scaffolding	200,000
7	Transfer costs	600,000
8	Maintenance scheme design	200,000
9	Inspection and special inspection	250,000
10	Adjustment and restoration	600,000
11	On site traffic	33,200
12	insurance premium	20,000
13	management expense	390,995
14	taxation	731,161
Total		5,532,106

3.2. The Establishment of Evaluation Index System

According to the actual situation of the accident in this paper, the various factors considered in the comprehensive maintenance scheme are analyzed. In the construction of the index system, three first level indicators and seven second level indicators are used. Through this index system, the maintenance scheme can be scientifically evaluated. The specific situation of the index system is shown in the figure below.

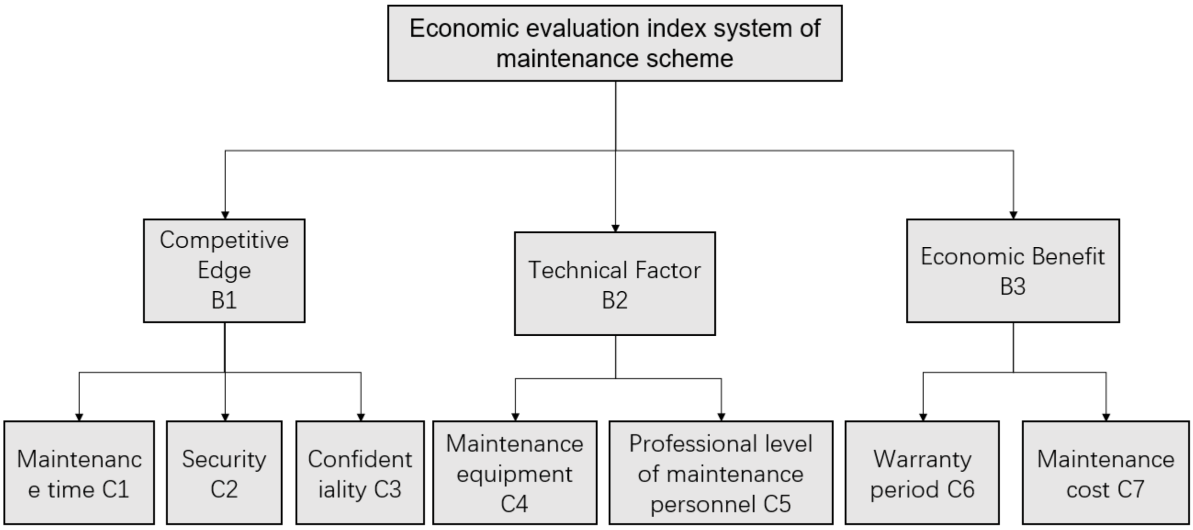

Figure 2. Evaluation index system

3.3. Determination of Index Weight

a. Construct judgment matrix

Each criterion layer with downward membership is regarded as the first element of the judgment matrix. The element is placed in the upper left corner of the matrix, and the criteria belonging to it are arranged in the next first line and the last line respectively. Then the judgment matrix is filled in.

The judgment matrix is represented by the following formula:

$$A = (a_{ij})_{m\times n}$$

Where a_{ij} is the ratio of the importance of elements i and j to the elements of the upper criterion layer. The judgment matrix has the following properties: $a_{ij} > 0; a_{ij} = 1/a_{ji}; a_{ij} = 1$. Therefore, the judgment matrix is symmetric. When filling in the judgment moment, you can first fill in the diagonal element (a_{ii}=1) in the judgment matrix, and then complete the filling of other elements in the matrix.

Table 4. Judgment matrix (a)

A	B1	B2	B3
B1	1	3	1/3
B2	1/3	1	1/5
B3	3	5	1

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(b)

B1	**C1**	**C2**	**C3**
C1	1	3	1/3
C2	1/3	1	1
C3	3	1	1

(c)

B2	C4	C5
C4	1	1
C5	1	1

(d)

B3	**C6**	**C7**
C6	1	5
C7	5	1

b. Hierarchical single sort and consistency test

Hierarchical single row refers to the weight of each factor on the same level relative to a factor on the upper level which is related to them. CI (consistency index) is calculated according to the following formula.

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

Where $\lambda_{\max}$ is the largest eigenvalue of the judgment matrix.

Table 5. Average random consistency index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RI	0	0	0.52	0.89	1.12	1.24	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58

Then we need to calculate the consistency ratio (CR), and the calculation formula is as follow.

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

When CR < 0.10, the consistency of the judgment matrix meets the requirements, otherwise, the factors of the judgment matrix need to be adjusted.

The values of the judgment matrix are tested for consistency of the single permutation of the consistency hierarchy. The test results are shown in the table below.

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Table 6. Consistency test results

Element	A	B1	B2	B3
$\lambda_{\max}$	3.3085	3	2	2
$C.I.$	0.0385	0	0	0
$C.R.$	0.074	0	0	0
Inspection	Pass	Pass	Pass	Pass

c. Weight calculation results

After calculating the weight of each index, in addition, it is necessary to check the consistency of the total ranking of the levels, and the weight value of the total ranking combination can be obtained through the superposition of the weights among the levels. According to the calculation results, the weight results of each index in the evaluation system can be obtained, and the specific values are shown in the table below.

Table 7. Weight calculation results

B	C
Competitive edge(0.26)	Maintenance time(0.6)
	Security(0.2)
	Confidentiality(0.2)
Technical factors(0.10)	Maintenance equipment(0.5)
	Professional level of maintenance personnel(0.5)
Economic performance(0.64)	Warranty period(0.17)
	Maintenance costs(0.83)

3.4. The Establishment of the Model

The ideal scheme is set as $P=\{\mathrm{p}_m\}$, and all the indexes in the scheme are the optimal indexes. The selection standard of the optimal index can not be generalized, and the nature needs to be distinguished. The ideal scheme should meet the following principles: when the index is a benefit index, the maximum value should be taken as the optimal index; when the index is a cost index, the minimum value should be taken as the optimal index, that is, the following formula should be satisfied.

$$p_m=\begin{cases}\min z_m, z_m \text{ is a cost index}\\ \max z_m, z_m \text{ is Benefit index}\end{cases}$$

The selection of maintenance scheme for Quayside bridge is $W=\{F,Z,Q,X,L\}$.The selection of maintenance scheme for Quayside bridge is a key problem. Where: $F=\{F_n\}$ is the set of three reference schemes, F_n is the n th reference scheme; $Z=\{Z_m\}$ is in the evaluation system, $Q_m=\{\mathrm{q}_m\}$ is the set of all evaluation indexes, q_m is the m-th evaluation index; Z_m is the set of all weights in the evaluation system, q_m is the weight of indexes, and meets the condition of

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$0 \le q_m \le 1, \sum q_m = 1$; $X = (x)_{n \times m}$ is the set pair matrix, that is, the matrix composed of quantitative values corresponding to three feasible schemes F and index H ; $L = (l)_{n \times m}$ is the connection matrix composed of three feasible schemes and ideal schemes.

3.5. Determine the Degree of Connection

The inverse set method of dissimilarity refers to the analysis of the similarities and differences between the two attributes.

Let the feasible scheme and the ideal scheme form a set pair set. The capital letter S can be used to represent the set pair set, that is, the relationship between $S = \{F_n, P\}$, A_n and P can be expressed by the following formula.

$$u = \frac{t}{m} + \frac{e}{m} i + \frac{y}{m} j$$

Among them, m represents the number of set pair attributes in set pair set; t represents the number of common attributes in set pair set; y represents the number of opposite attributes in set; e represents the number of set pair attributes that are neither opposite nor common in two sets; i represents the difference marker, with the value range of [- 1,1]; j in the formula, it represents the opposition coefficient, with the value of - 1.

To sum up, the expression of connection degree can also be expressed as $u = a + bi + cj$, where a, b, c represents the degree of identity, degree of difference and degree of opposition in a set pair.

3.6. Establishment of Connection Matrix

When analyzing the accident maintenance scheme, it is necessary to compare the feasible scheme with the ideal scheme, establish the set pair relationship between them by using the hierarchical set pair combination analysis method, and obtain the best maintenance scheme through the correlation calculation of the set pair scheme connection degree. In this study, we will apply the method to the economic analysis of the maintenance scheme, and we only need to choose the best maintenance scheme among the three feasible schemes. Therefore, for the analysis of the maintenance scheme and the ideal scheme, we only need to analyze the same degree, and the degree of difference and opposition can not be discussed in this study.

From the above formula, in the expression of the degree of connection, the sum of a, b, c is 1. According to this condition, when we establish the contact matrix, the formula for the same degree is shown below.

$$l_{ij} = \begin{cases} \frac{p_m}{z_m}, p_m \le h_m \\ \frac{z_m}{p_m}, h_m < p_m \end{cases}$$

According to the above formula, the contact matrix is:

$$L = \begin{pmatrix} l_{11} & \cdots & l_{1m} \\ \vdots & \ddots & \vdots \\ l_{n1} & \cdots & l_{nm} \end{pmatrix}$$

In the above formula, $l_{ij}\{i=1,2,\cdots n,j=1,2,\cdots m\}$ is the same degree, that is, the same degree of the scheme and the corresponding ideal index.

3.7. Calculation of the Same Degree

When calculating the same degree, AHP is used to calculate the weight of each target, and the weight of each index is determined, and then the same degree is weighted. The calculation formula of the same degree is as follows.

$$u_i = \sum_{i=1}^{n} a_i w_i, i = 1, 2, \cdots n$$

Among them, w_i is the weight of the first layer index of the criterion layer; a_i is the same degree between the first layer index of each feasible scheme and the ideal scheme. The index synthesis method is used to calculate the value of a_i, and the calculation formula is as follows.

$$a_i = \sum_{j=1}^{q} l_{ij} w_{ij}, i = 1, 2, \cdots, p; j = 1, 2, \cdots, q$$

Among them, p is the number of indicators in the first level of the criteria layer; q is the number of secondary indicators corresponding to the first level indicators.

Table 8. Index value of each feasible scheme

B	C	Plan A	Plan B	Plan C	Ideal solution P
Competitive edge	Time required	0.4	0.9	0.4	0.4
	Security	0.7	0.8	0.7	0.8
	Confidentiality	0.3	0.8	0.8	0.8
Technical factors	Maintenance equipment	0.5	0.8	0.8	0.8
	Professional level of maintenance personnel	0.6	0.9	0.9	0.9
Economic performance	Warranty period	0.2	0.7	0.7	0.7
	Maintenance costs	0.2	0.9	0.3	0.2

The set pair matrix can be obtained from the above table:

$$X = \begin{pmatrix} 0.4 & 0.7 & 0.3 & 0.5 & 0.6 & 0.2 & 0.2 \\ 0.9 & 0.8 & 0.8 & 0.8 & 0.9 & 0.7 & 0.9 \\ 0.4 & 0.7 & 0.8 & 0.8 & 0.9 & 0.7 & 0.3 \end{pmatrix}$$

According to the specific value of the maintenance scheme in the table, the optimal index in each index is selected as the index of the ideal scheme, so the ideal scheme P can be obtained, $P = (0.4 \quad 0.8 \quad 0.8 \quad 0.8 \quad 0.9 \quad 0.7 \quad 0.2)$.

In this paper, it is not necessary to get the best scheme for the selection of the scheme, but only need to choose the best scheme among the three feasible schemes, so the same degree of each feasible scheme can be calculated. So we can get the connection matrix L.

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$$L=\begin{pmatrix} \frac{0.4}{0.4} & \frac{0.7}{0.8} & \frac{0.3}{0.8} & \frac{0.5}{0.8} & \frac{0.6}{0.9} & \frac{0.2}{0.7} & \frac{0.2}{0.2} \\ \frac{0.4}{0.9} & \frac{0.8}{0.8} & \frac{0.8}{0.8} & \frac{0.8}{0.8} & \frac{0.9}{0.9} & \frac{0.7}{0.7} & \frac{0.2}{0.9} \\ \frac{0.4}{0.4} & \frac{0.7}{0.8} & \frac{0.8}{0.8} & \frac{0.8}{0.8} & \frac{0.9}{0.9} & \frac{0.7}{0.7} & \frac{0.2}{0.3} \end{pmatrix}$$

According to the formula, each scheme can be calculated:

Plan A: $\{a_1,a_2,a_3\}=\{0.85,0.646,0.878\}$

Plan B: $\{a_1,a_2,a_3\}=\{0.667,1,0.354\}$

Plan C: $\{a_1,a_2,a_3\}=\{0.975,1,0.723\}$

According to the formula, the degree of identity of each feasible scheme and ideal scheme is as follows:

$$u_i=\{0.8475,0.5000,0.9372\}$$

3.8. Scheme Selection

Through the relevant calculation, the same degree of ideal scheme and the same degree between feasible schemes can be obtained. According to the same value, the scheme can be selected and judged. The same degree indicates the proximity between feasible scheme and ideal scheme. If the same value is larger, the more feasible scheme is, the closer the feasible scheme is to the ideal scheme; otherwise, if the same value is smaller, the less feasible scheme is, the less close the feasible scheme is to the ideal scheme.

$$U^*=\max\{u_1,u_2,\cdots,u_n\}$$

Therefore, it can be seen from the above that for the three maintenance schemes, Plan C is more economical, and the maintenance strategy of Plan C should be adopted.

4. Conclusion

Through the analytic hierarchy process, the weight of the evaluation index system will be obtained, and then through the set pair analysis method, the three maintenance schemes will be analyzed, and the maintenance scheme will be scientifically evaluated, and finally the optimal maintenance scheme will be obtained. In the face of equipment damage caused by sudden accidents, this method can make the most scientific choice of maintenance scheme in a short time.

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