Study on the selection and optimization of key elements in the offshore wave prediction

Dongzi li
School of marine science, technology and environment, Dalian Ocean University, Dalian, Liaoning, 116023, China
Author e-mail: 1445877244@qq.com

Abstract. The accuracy of inshore wave prediction is closely related to the key elements selected in the prediction. There is a problem of selecting and sorting the key information needed in wave forecasting. This paper combines AHP with DEA to build a new evaluation model of selecting scheme. By calculating the relative weight of the key information in each selecting scheme and calculating the relative efficiency value of the model, the importance sorting of the elements needed in wave forecasting is obtained, and the specific selection scheme is verified by an example Application. The established AHP-EDA model has the value of trial and extension in supporting the key element selection process of wave prediction.

1. Introduction
Wave prediction is to calculate and forecast the future wave state of the sea area by combining the initial wave state of the sea area. Nearshore wave has its own particularity. Marine scientific experiment, mariculture, transportation and engineering construction are greatly affected by nearshore wave, which requires higher accuracy of wave prediction. Different from the waves in the open sea, the factors that affect the generation, development and attenuation of the waves in the near shore are very complex. The problem of superposition or reduction of the factors is prominent. The selection and sequencing of the prediction factors will directly affect the accuracy of the wave prediction. In the wave prediction, the characteristic wave height, period, wave direction, etc. in the statistical sense should be given, and sometimes the internal structure spectrum of the wave should also be predicted. There are five main factors that must be paid attention to in the offshore wave forecast: ① meteorological environment. The spatial and temporal distribution of wind speed and direction on the sea surface in the forecast period. ② geographical environment. It mainly includes the shape of continental boundary, the distribution of coastal elevation and the distribution of coastal seawater depth. ③ initial distribution. It can be obtained from field observation or previous prediction results. ④ celestial gravity. The moon and the sun are the main objects with tidal force, and the relative position of the moon and the sea has a greater impact on the tide and waves. ⑤ accidental events. Near shore underwater blasting, earthquake, volcanic eruption and rapid movement of large platform on the sea. In the same inshore area, the factors affecting the wave prediction cannot be fixed, so it is necessary to select and evaluate the best scheme. Analytic hierarchy process (AHP) is a system method that takes a complex multi-objective decision-making problem as a system, decomposes the objective into multiple objectives or criteria, and then decomposes it into several levels of multi-objective, and calculates the hierarchical single ranking and total ranking through the qualitative index fuzzy quantitative method, as the objective and multi scheme optimization decision-making system.
method. Data envelopment analysis (DEA) is to use linear programming method to evaluate the relative effectiveness of the same type with comparability. This paper attempts to condense the advantages of the two methods, establish the selection model of inshore wave forecast elements based on AHP-DEA, determine the hierarchy and structure with AHP, take DEA as the decision-making unit, take the relative weight of influencing elements as the output of DEA, establish an optimization evaluation model, calculate the relative efficiency value of the model, and obtain the reliability ranking of the forecast scheme.

2. Selection and evaluation model of prediction factors for inshore waves

2.1. Building a hierarchical structure model

When analytic hierarchy process (AHP) is used to study a problem, the relevant factors should be divided into several levels according to the causality of the problem. Usually, it is decomposed into target layer (top layer), criterion layer (middle layer) and scheme layer (bottom layer). When a certain level contains more factors, it can be further divided into several sub-levels.

2.2. Constructing judgment matrix

After the establishment of the hierarchical structure, a judgment matrix is constructed by comparing the influence factors of one layer with those of the next layer, and determining the relative advantages and disadvantages with the method of scoring. Starting from the bottom, for P₁, P₂…Pₙ, has a total of N schemes. From the perspective of criterion Cᵢ, the advantages and disadvantages of the two schemes are compared, and the scoring scale of 1-9 is adopted (see Table 1). The results of the comparison are represented by the influence elements in the judgment matrix below.

\[
A = \begin{bmatrix}
a_{11} & a_{12} & \cdots & a_{1n} \\
a_{21} & a_{22} & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & a_{nn}
\end{bmatrix}
\]

A represents the judgment matrix of P layer influencing factors to Cᵢ. \(a_{ij}\) is from the perspective of Cᵢ, the relative merits of Pᵢ versus Pⱼ, and the judgment matrix have the following properties:

1) \(a_{ij} > 0\)
2) \(a_{ij} = 1/a_{ji}\)
3) \(a_{ii} = 1\)

Table 1. The meaning of scale.

| Scale | Scale meaning                        |
|-------|--------------------------------------|
| 1     | Representing two elements is of equal importance. |
| 3     | Compared to two elements, one element is slightly more important than the other. |
| 5     | Compared to two elements, one element is obviously important than the other. |
| 7     | Compared with the two elements, one element is more important than the other. |
| 9     | Compared to two elements, one element is the most important than the other. |

(2, 4, 6, 8 are the median of the adjacent judgment matrices).

2.3. Hierarchical single ranking and consistency comparison

2.3.1 hierarchical single ranking. Hierarchical single-ranking is calculated according to the judgment matrix. For a certain influencing factors in the upper level, the next level is related to the value of the quality (or importance) of the influencing factors. The specific method is to judge the characteristic vector W of the largest Characteristic root \(\lambda_{max}\) of the matrix A. It satisfies the following formula:

\[
AW = \lambda_{max}W
\]
The component value of eigenvector $W$ is the value of its corresponding Influencing factors. The square root method can also be used for the calculation of $W$. The calculation steps are as follows:

1. Calculate the product of every row element of the judgment matrix $M_i$:

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

2. Calculate the $N$ root $\overline{W}_i$ of $M_i$:

$$\overline{W}_i = \sqrt[N]{M_i} \tag{3}$$

3. Regularized $\overline{W}_i$ and get normalized weight $W_i = \frac{\overline{W}_i}{\sum_{i=1}^{n} W_j} \tag{4}$

2.3.2 Consistency check. The hierarchical single-ranking work is based on the judgment matrix, while the judgment matrix is based on two-to-two comparison. If two-to-two scores have objective consistency, the judgment matrix must satisfy $a_{ij} = a_{ik} / a_{jk} (i, j, k = 1, 2, \cdots, n)$ . We call that the judgment matrix satisfying upper form has complete consistency. However, because objective things are complex and people’s understanding is one-sided, the judgment matrix may not have complete consistency, but general consistency is required. Therefore, the judgment matrix should be consistency checked before single sorting. The steps are as follows:

1. Calculate the maximum Characteristic root $\lambda_{\text{max}}$ of the in pairs judgment matrix:

$$\lambda_{\text{max}} = \sum_{i=q}^{n} W_i$$ \tag{5}

2. Calculate consistency index $CI$

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1} \tag{6}$$

3. The average random consistency index is obtained by simulating the random matrix of different orders. For the 1~9 order judgments matrix, T.L. Saaty gives the $RI$ value, as shown in Table 2.

| Order $n$ | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $RI$      | 0   | 0   | 0.58| 0.90| 1.12| 1.24| 1.32| 1.41| 1.45|

4. Calculate consistency ratio $CR$

$$CR = \frac{CI}{RI} \tag{7}$$

If and only when $CR < 0.1$ is considered, It is acceptable to consider its inconsistency.

2.4. Establishment of DEA model
Since the relative weight of each prediction scheme is the greater the better, it is regarded as the output of DEA model, while the prediction scheme is regarded as the decision-making unit, so the DEA model with only output can be established. Here only the representation of the model is given, and the specific derivation can be seen in the literature.
\[
\max \{ \delta + \varepsilon (\sum_{r=1}^{s} y^r_0) \} \\
\text{s.t.} \quad \sum_{j=1}^{n} \lambda_j y_{rj} - s^+_r = \delta y^r_0, r = 1, 2, \ldots, s \\
\sum_{j=1}^{n} \lambda_j = 1 \\
\lambda_j \geq 0, j = 1, 2, \ldots, n, s^+_r \geq 0
\]

\[\text{Eq. (8)}\]

\[
y_{rj} \text{ is the } j \text{ decision-making unit, which is, the output of the prediction scheme to the } r \text{ type, } y^r_0 \text{ is }
\]

the output of the evaluated decision-making unit to the } r \text{ type, and } \varepsilon \text{ is the non-Archimedes infinitesimal. However, this paper use the above model to evaluate the relative efficiency of DMUs, the final result is likely to be that multiple DMUs are relatively effective at the same time, but the model cannot make further evaluation and comparison of these effective units. Therefore, this paper uses an improved DEA model to further evaluate the DEA effective unit, so as to fully rank all prediction scheme. The specific form of the model is given here, and the derivation is shown in document.

\[
\max \{ \delta + \varepsilon (\sum_{r=1}^{s} y^r_0) \} \\
\text{s.t.} \quad \sum_{j=1}^{n} \lambda_j y_{rj} - s^+_r = \delta y^r_0, r = 1, 2, \ldots, s \\
\sum_{j=1}^{n} \lambda_j = 1 \\
\lambda_j \geq 0, j = 1, 2, \ldots, n, s^+_r \geq 0
\]

\[\text{Eq. (9)}\]

The main difference between Eq. (8) and Eq. (9) is that the production possibilities set of Eq. (9) does not include the evaluated unit } j_0 \text{, Eq. (9) compares it with the linear combination of all other DMUs in the sample, excluding the body } j_0 \text{, when evaluating the element } j_0 \text{. The result is that effective DMU can increase its investment proportionally while maintaining its relative effectiveness. In this DEA model, the maximum proportion of a DMU that can increase its input and still maintain relative effectiveness is called the DEA efficiency of the DMU. Obviously, the efficiency may be greater than 1. Since the relative efficiency of DEA is } v = 1/\delta \text{. Therefore, the evaluation of the prediction scheme can be directly based on the size of } \delta \text{. The smaller the } \delta \text{ is, the smaller the error is, the better the prediction scheme is.}

3. An example of the application of the evaluation model of prediction scheme

Under a bad weather condition, three alternative schemes of near shore wave forecast are proposed, which are A, B, C. in each scheme, meteorological environment elements, geographical environment elements, initial distribution elements and celestial gravity elements are the main influencing factors, and AHP-DEA model is applied to carry out empirical analysis.

3.1. Establish a hierarchical structure model

It is known from the topic that the prediction scheme is evaluated as the target layer, four evaluation factors as four evaluation indexes constitute the criterion layer, and three received investment schemes constitute the scheme layer. The hierarchical structure chart is shown in Figure 1.
3.2. Determine the weight coefficient of scheme level in four evaluation factors

We should select the academic authority of wave forecasting and the experts from the Forecasting Department to form an evaluation group. According to the influence degree of the three schemes under the four evaluation factors, we should make a comparison between the two, determine the score value and construct a judgment matrix. According to formula (1) and formula (2), the importance weight of the prediction scheme to the criterion layer and the consistency test parameters can be calculated. See Table 3 for details.

Table 3. Hierarchical single ordering of meteorological environmental factors

| Meteorological | A  | B     | C  | Sorting result |
|----------------|----|-------|----|----------------|
| A              | 1  | 1/7   | 1/3| 0.088          |
| B              | 7  | 1     | 3  | 0.6694         |
| C              | 3  | 1/3   | 1  | 0.2426         |

$\lambda_{max} = 3.006 \quad CI = 0.003 \quad CR = 0.006 < 0.1$

Table 4. Hierarchical single ordering of the influence of geographical environment elements

| Geography | A     | B     | C  | Sorting result |
|-----------|-------|-------|----|----------------|
| A         | 1     | 3     | 1  | 0.4286         |
| B         | 1/3   | 1     | 1/3| 0.1428         |
| C         | 1     | 3     | 1  | 0.4286         |

$\lambda_{max} = 2.9999 \quad CI < 0 \quad CR < 0 < 0.1$

Table 5. Hierarchical single ordering influenced by initial distribution elements

| Initial elements | A | B | C | Sorting result |
|------------------|---|---|---|----------------|
| A                | 1 | 2 | 5 | 0.5816         |
| B                | 1/2| 1 | 3 | 0.3090         |
| C                | 1/5| 1/3| 1 | 0.1095         |

$\lambda_{max} = 3.0037 \quad CI = 0.00185 \quad CR = 0.0036 < 0.1$

Table 6. Hierarchical single ordering of the influence of the elements of celestial gravitation

| Celestial attraction | A | B | C | Sorting result |
|----------------------|---|---|---|----------------|
| A                    | 1 | 1 | 2 | 0.4            |
| B                    | 1 | 1 | 2 | 0.4            |
| C                    | 1/2| 1/2| 1 | 0.2            |

$\lambda_{max} = 3 \quad CI = 0 \quad CR = 0 < 0.1$

For the convenience of future computation, the above results are represented in the same table, as shown in Table 7.

Table 7. The results of AHP are summarized.

|               | Meteorological | Geography | Initial elements | Celestial attraction |
|---------------|----------------|-----------|------------------|---------------------|
| A             | 0.088          | 0.4286    | 0.5816           | 0.4                 |
3.3. Application of DEA model to comprehensive evaluation

According to the results of table 7, (9) establish the DEA model of formula A evaluation (10).

\[
\max [\delta_i + \epsilon(\sum_{i=1}^{n} s_i^+)] \\
\text{s.t.} \quad 0.6694\lambda_2 + 0.2426\lambda_3 - s_i^+ = 0.088\delta_i \\
0.1438\lambda_2 + 0.4286\lambda_3 - s_i^+ = 0.4286\delta_i \\
0.309\lambda_2 + 0.1095\lambda_3 - s_i^+ = 0.5816\delta_i \\
0.4\lambda_2 + 0.2\lambda_3 - s_i^+ = 0.4\delta_i \\
\lambda_2 + \lambda_3 = 1 \\
\lambda_1, \lambda_2 \geq 0, s_i^+ \geq 0, r = 1,2,3,4
\]

(10)

The \( \delta_i = 0.4646 \) of scheme A is obtained. Similarly, The evaluation values of B and C can be obtained. They are \( \delta_2 = 0.3614 \), \( \delta_3 = 0.8617 \), respectively. You can know \( \delta_2 < \delta_1 < \delta_3 \). It can be concluded that scheme B is the best of these wave prediction schemes.

4. Conclusion

The essence of prediction scheme evaluation is to compare the influence factors of multiple pre selection schemes, adopt one scheme in the scheme group, and exclude other schemes in the scheme group. All adopt some specific technical methods, through quantitative analysis and comparison, to select the most credible scheme. In the actual near shore prediction scheme, there are not only four evaluation indexes, but also some accidental events such as near shore blasting, near shore earthquake, volcanic eruption and high-speed movement of offshore platform. The evaluation of offshore wave prediction scheme is a complex system engineering, and its uncertainty is related to many factors. In order to make the selection of scheme more scientific and effective, this paper constructs an AHP-DEA evaluation model, which is introduced into the evaluation of prediction scheme, quantifies various evaluation factors of prediction scheme according to the importance of evaluation factors, and then selects the best prediction scheme.

Acknowledgments

Thank you for the support of "blue talent class" project of Dalian Ocean University! Thank you for the guidance of Professor Fu Wantao of Dalian Ocean University, and the guidance of Professor Sun Chengzhi and researcher Li Kan of Dalian Naval Academy!

References

[1] Wang, T.N., Wang, X.L., Luan, S.G. (2013) Numerical simulation of typhoon waves in Qinglan fishing port of Hainan Province. Journal of Dalian Ocean University, 28:506-510.
[2] Ma, Y.L. (2007) Application of AHP-GCP model in venture capital project evaluation. Science and Technology Management Research, 9:86-90.
[3] Zhong, H. (2010) DEA improved model of enterprise technological innovation capability evaluation. system science journal, 18:86-90.
[4] He, J. (1995) Only output (or input) data envelopment analysis and its application. Journal of systems engineering, 3:16-22.
[5] Li, K., Sun, S.D. (2008) Research on torpedo scheme evaluation based on AHP-DEA model. torpedo technology, 16:8-11.