Index System Establishment for Ship Scheme Demonstration of Self-Propelled Semi-Submersible Repair Ship

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Abstract: The index system for ship scheme demonstration as the decision did not receive enough attention. Based on research status for the ship scheme demonstration index system and characters of the new ship, this paper puts forward a ship scheme demonstration index system for new type self-propelled semi-submersible repair ship according to the relative research and the systematic research by the authors. The reasons for indexes being selected or omitted are analysed and illustrated.

1. Introduction
In order to improve the capability of maintenance support for ships and offshore engineering equipment working, a conceptual design scheme of a new maintenance platform—Self-Propelled Semi-Submersible Repair Ship is put forward in paper[1,2], based on the trend of offshore maintenance demand and the development of modern technology. At preliminary design stage, the designer has to select one or several more solutions with better comprehensive performance from generated multiple ships. Finding the preferred candidate from a number of options is a complicated decision, as there is no reference ship for a new type of large engineering vessel. Furthermore, the lack of related design experience makes this more difficult. Therefore, ship scheme demonstration is a must for this kind of design [3]. A complete and scientific evaluation index system is the key to ensuring the effectiveness and correctness of ship demonstration. This paper aims to select the evaluation index which can comprehensively reflect techno-economic performance of large engineering vessel, then construct the evaluation index system.

2. Evaluation index screening method

2.1. Index selection and index database establishment
We analysed publicly published literature[4-5] related to ship type demonstration and ship preliminary design, and guided by the index system set in “Shipbuilding Industry Standards of the People's Republic of China--Marine carriers performance level rating”(CB3886-2002)[3], based on the relevant literature summary and author’s investigation and research, further integrated first round expert questionnaire, selected total 67 indexes involving 8 criteria layers and established the evaluation index database of the ship type scheme shown in Table 1.
### Table 1. Evaluation index database of ship type scheme

| No. | Criterion layer | Index layer | No. | Criterion layer | Index layer |
|-----|-----------------|-------------|-----|-----------------|-------------|
| 1   | Economic        | fuel consumption per ton: nm | 35  |                  | admiralty coefficient |
| 2   | Necessary       | Necessary freight rate | 36  | Ratio of deadweight, speed and main engine power |
| 3   | Technical       | Net present value | 37  | Lightship weight |
| 4   |                | Payback period | 38  | Ship effective power |
| 5   | performance     | Benchmark of time charter rate | 39  | Technical performance | Variable load coefficient |
| 6   | GT/DWT ratio to deadweight ratio | 40  | Maximum submerged depth |
| 7   | Technical       | Fuel consumption per footage | 41  | Ballast & de-ballast efficiency |
| 8   |                | Annual operating cost | 42  | Number of compartments |
| 9   |                | Ship initial investment | 43  | Hull resistance per displacement |
| 10  |                | Cost-/performance coefficient | 44  | Equipment configuration in engine room |
| 11  |                | DWT/principal-dimensions ratio | 45  | Cargo monitoring system |
| 12  |                | Weight-to-weight ratio | 46  | Positioning equipment |
| 13  |                | Capacity utilization | 47  | Navigation equipment |
| 14  |                | Multifunctional coefficient | 48  | Anchor equipment |
| 15  |                | Coefficient of main deck area | 49  | Communication system |
| 16  |                | Work efficiency coefficient | 50  | Loading system |
| 17  |                | Annual freight volume | 51  | Maintenance facilities |
| 18  |                | Daily freight processing rate | 52  | Living facilities |
| 19  |                | Daily fuel processing rate | 53  | Noise control level |
| 20  |                | Deadweight | 54  | Vibration control level |
| 21  | Work ability    | Cargo tank volume | 55  | Fuel consumption rate |
| 22  |                | Daily compressed natural gas rate | 56  | Energy efficiency design index (EEDI) |
| 23  |                | Working deck area | 57  | NOx emission level |
| 24  |                | Hangar area | 58  | SOx emission level |
| 25  |                | Heli deck area | 59  | Rolling natural period |
| 26  |                | Deck even-distributed load | 60  | Pitch natural period |
| 27  |                | Bollard pull | 61  | Non-dimensional resistance increase times |
| 28  |                | Drilling depth coefficient | 62  | Maneuverability |
| 29  |                | Oil spill recovery capacity coefficient | 63  | Non-dimensional initial turning time |
| 30  |                | Lifting capacity coefficient | 64  | Relative turning diameter |
| 31  | Technical       | Superstructure quality coefficient | 65  | Linear stability index |
| 32  | performance     | Working water depth coefficient | 66  | Non-dimensional initial turning time |
| 33  |                | Cantilever beam moving range coefficient | 67  | Relative turning diameter |
| 34  |                | Ballast tank volume |                |             |

2.2. Elimination of index and establishment of screening models

2.2.1. Correlation-variation coefficient analysis of index elimination. Some indicators in Table 1 have a certain correlation, which can lead to the repeated evaluation of some information in one aspect of the object to be evaluated, thus reducing the reliability of the evaluation result. In order to avoid this
kind of problem, the correlation analysis of the index in the index database is carried out in order to simplify the index system. Specific steps for indicator correlation analysis are as follows:

1) Standardization of evaluation indicators. Due to the different nature and dimension of the evaluation indicators, the initial data is standardized in order to reduce the impact on the analysis results and improve the correctness of the evaluation results. Let \( x_i \) be the original data of the evaluation indicators, \( s_i \) be the evaluation indicators and \( z_i \) be the standardized value. There are:

\[
    z_i = \frac{x_i - \bar{X}}{s_i} \tag{1}
\]

2) Calculate the correlation coefficient among each evaluation indicator. Let \( r_{ip} \) be the correlation coefficient between the \( i \)th indicator and the \( p \)th indicator, \( Z_{ki} \) be the value of \( i \)th the \( k \)th evaluation object, and \( \bar{Z_i} \) be the mean value of \( i \)th indicator. Based on the correlation coefficient calculation formula, then \( r_{ij} \) is:

\[
    r_{ij} = \frac{\sum (Z_{ki} - \bar{Z_i})(Z_{kj} - \bar{Z_j})}{\sqrt{\sum (Z_{ki} - \bar{Z_i})^2}(Z_{kj} - \bar{Z_j})^2} \tag{2}
\]

3) The analysis of index choosing. Let the threshold be \( M \). If \( |r_{ip}| < M \), keep two evaluation indicators at the same time. Otherwise, it indicates that there is a significant correlation between the two indicators. In theory, any one of the two indicators can be deleted to ensure that the information reflected by the indicator is not repeated. However, in fact, the extent of reaction of the index against a certain information of the evaluation object are different due to the difference of meaning of the index and the calculation method. In order to make a reasonable choice of the index, the variation coefficient of the index is used to measure the information content of the index, namely, the ratio of the variance and the mean value of the evaluation value of each index, as shown in the formula 3. Normally, the larger the coefficient of variation of the index characterizes the more obvious the change of the evaluation value of the index for different evaluation objects, namely, the stronger the extent of reaction of the index against the information, and the more valuable the index is.

\[
    V_i = \frac{S_i}{\bar{X}} \tag{3}
\]

Amongst them:

- \( m \)——The total number of indicators involved in the screening.
- \( S_i \)——The variance of indicator \( i \), \( S_i = \sqrt{\frac{\sum (X_i - \bar{X})^2}{m-1}} \)
- \( \bar{X} \)——The mean value of the indicator against an evaluation object, \( \bar{X} = \frac{\sum X_i}{m} \)

2.2.2. Fuzzy Delphi method for index screening. The fuzzy Delphi method introduces fuzzy theory into the Delphi method, and integrates experts’ opinions by using triangular fuzzy numbers to obtain fair statistical data and avoid the influence of extreme values. Based on this, the fuzzy Delphi method is applied to screen the ship type evaluation indicators. The specific process is as follows:

1) Obtain experts’ opinions via questionnaires. Experts score the initial screening indicators, ranging from 1 to 10 points; the higher the expert scores a certain indicator, the more the expert pays attention to the indicator, the more likely the indicator is retained.

2) Process the evaluation data and calculate the triangular fuzzy number of each indicator’s expert score, as shown in formula (4)-(7).

\[
    \overline{T_i} = (L_i, E_i, M_i) \tag{4}
\]
\[ L_i = \min(X_{ij}) \quad (5) \]
\[ E_i = \sqrt[n]{\prod_{j=1}^{n} x_{ij}} \quad (6) \]
\[ M_i = \max(X_{ij}) \quad (7) \]

Amongst them:
- \( \tilde{T}_i \)——The triangular fuzzy number of the expert’s score on the indicator \( i \);
- \( X_{ij} \)——Score for indicator \( i \) by expert \( j \);
- \( L_i \)——The lowest score to indicator \( i \) by experts;
- \( n \)——The total number of experts participating in the scoring;
- \( E_i \)——The geometric mean score of the experts to indicators \( i \);
- \( M_i \)——The highest score to indicator \( i \) by experts.

(3) Selection of evaluation indicators

In paper, the geometric mean value is used as the criterion for the selection of indicators to avoid the influence of extreme values. The arithmetic mean value of the geometric mean value of each indicator is used as the threshold in order to avoid the influence of the subjectively determined threshold on the screening results when experts’ scoring criteria are inconsistent, as shown in formula (8)-(9).

\[
\text{If } E_i \geq \frac{\sum_{m} E_i}{m}, \text{ Indicator } i \text{ is retained; } \quad (8)
\]
\[
\text{If } E_i < \frac{\sum_{m} E_i}{m}, \text{ indicator } i \text{ is rejected.} \quad (9)
\]

3. Index system establishment

3.1. Indicator selection analysis

Based on the criteria and methods for index selection described in Section 2.3, the indicators in Table 1 are quantitatively and qualitatively analyzed. Quantitative analysis provides reference and support for qualitative analysis. The data is derived from the actual techno-economic parameters of the existing ship and the actual calculation of relevant references. A total of 29 indicators are selected from the original 67 evaluation indicators and thus established an evaluation index system for the self-propelled semi-submersible repair ship type scheme demonstration. As shown in Figure1.
3.1.1. Analysis of the reasons for the deletion of some indexes in the “Industry Standard”. The cargoes transported are deck cargoes for semi-submersible repair ship. Transport capacity is not limited by cabin capacity, thus the capacity utilization is not suitable for measuring its transportation capacity. In addition, deadweight / principal dimensions ratio is deleted. Because there is a strong correlation between the index and other indexes in quantitative analysis, and the identification ability is weak indicated in coefficient of variation analysis, that is, the information content of the index is small.

3.1.2. Index system analysis. (1) Economic indicator analysis. The ship is operating in spot market and the profit level is mainly determined by the cost. This paper analyses the particularity of its service market based on the functional positioning: market pricing is mostly a business model with contractual pricing strategy between the owners and the charterers. In this context, the index accounting related to transport income will have a large deviation and the evaluation results will be obviously affected. Further, based on the ship's type characteristics, it can be deployed to non-operating units to undertake sea maintenance and rescue services. In conclusion, the cost indicators are more comparable and instructive for this ship type. As to transaction mode, the operation is always by vessel chartering and freight rate is expressed as charter rate. Therefore, the two indicators of fuel consumption per ton·nm and benchmark of time charter rate are selected, which reflect the economic performance of the semi-submersible repair ship from variable costs and operation cost. It is estimated that there is a strong correlation between ship profitability and ship cargo capacity. Therefore, in the subsequent analysis, it is possible to focus on the analysis of indicators that characterize ship's cargo capacity.

(2) Work ability indicator analysis. The design concept and function of the self-propelled semi-submersible repair ship is positioned as a floating shipyard, with heavy lift transportation, rescue and salvage functions. The evaluation of work ability is to evaluate the realization level of its functions. Five indicators work efficiency coefficient, coefficient of main deck area, bollard pull, oil spill recovery capacity coefficient and lifting capacity coefficient are selected to measure the work capacity of self-sailing semi-submersible repair ship from 5 aspects of bearing capacity, maintenance capacity and rescue, etc, respectively.

(3) Technical performance evaluation indicators analysis. Choose admiralty coefficient and variable load coefficient as evaluation indicator of technical performance. Admiralty coefficient is used to measure the speed, together with the work efficiency coefficient index to reflect the demand
for transporting more cargo at fast speed. Variable load coefficient is used to measure ship's endurance.

(4) Energy saving and environmental protection performance analysis. Where the fuel type is fixed, the Energy Efficiency Design Index (EEDI) has attracted much attention because of the obvious linear correlation between NOx & SOx emission and EEDI. Therefore noise control level, vibration control level and EEDI are selected to reflect energy saving and environmental protection performance.

(5) Other indicators analysis. Equipment advancement, safety, seakeeping quality and maneuverability indicators are with less redundant information and suitable for comprehensive performance evaluation of semi-submersible repair ship. All these indicators can be retained after expert analysis.

4. Conclusion

The study of the ship type evaluation index system plays an important role in the ship type plan demonstration and optimization. Based on current research status, we established the self-propelled semi-submersible ship repair type plan evaluation index system to promote the research of large ship type schemes demonstration. It has innovative, practical significance and application value.

By summarizing the research results of predecessors, it is found that the relevant researches on the evaluation indicators of ship type scheme are mostly focused on the proposal and application of individual economic indicators, with rich literatures and information redundancy of the indicators. However, there are relatively few studies on the technical performances, which ignored the fact that the technical performance can also affect the economic performance of the ship to a certain extent. This explains to a certain extent, that the selection of ship type plan evaluation indicators and the research of ship type evaluation index system are of great necessity, further there is still great research space, which is worthy of in-depth research.

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