2024-1369 IJOI
https://www.ijoi-online.org/

International Journal of
Organizational Innovation

STUDY ON THE CONSTRUCTION OF A NAVAL COMBAT CAPABILITY ASSESSMENT MODEL USING THE FUZZY DELPHI METHOD COMBINED WITH ***VIKOR*** ANALYSIS

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Abstract

This study addresses the challenges of assessing the combat effectiveness of naval vessels by applying an innovative methodology that combines the Fuzzy Delphi Method with VIKOR analysis. It aims to integrate the fuzzy information into the experts' opinions to improve the accuracy and objectivity of the assessment process. The fuzzy Delphi Method effectively converges the experts' opinions. It reduces the subjective bias, while the VIKOR analysis method ranks the multi-criteria decision of the warship's combat power and provides the decision maker with a scientific basis for selection. The combination of these two methods not only increases the breadth and depth of the assessment and ensures that the decision is scientific and practical. It is concluded that the evaluation model proposed in this study can accurately assess the combat capability of naval vessels and provide sound scientific support for naval vessel selection and deployment decisions. The application of this model is of great significance in enhancing the maritime security strategy in the Asia-Pacific region and even in promoting the steady development of

maritime economic activities, and it also provides a new perspective and methodological basis for research in related fields.

Key words: Naval Vessel Warfare Assessment, Fuzzy Delphi Method, VIKOR Analysis.

Introduction

According to the (Gray, 2015) in-depth analysis of Nicholas John Spykman's theory of geopolitics, we understand that geographical location has a decisive influence on a country's diplomatic and military strategies. Especially in today's globalized and geopolitical environment, the strategic importance of certain key regions is highlighted. The Asia-Pacific plays a crucial role in maintaining regional security and balance among these regions due to its unique geographical location and rich maritime resources. With the increasing growth of maritime economic activities and the continuous demand for national defense and security, the assessment of the capabilities of naval vessels has become a key element in securing national interests and strengthening regional defense capabilities. Therefore, a scientific and objective evaluation of the combat power of naval vessels is of great importance for formulating effective national defense strategies and maritime policies.

To meet this challenge, this study proposes a decision proposal process that combines the Fuzzy Delphi Method (FDM) and the VIKOR Method. Through the fuzzy integration of expert opinions and systematic weight comparison, a comprehensive and accurate assessment of the combat capability of naval vessels is made. This method not only exploits the advantages of the Fuzzy Delphi Method in dealing with uncertain information but also incorporates the ability of the VIKOR Method to weigh multi-criteria decision problems to provide scientific and objective ship selection and configuration recommendations to senior managers or decision-makers.

In addition, the theoretical contribution of this study lies in the first application of the combination of the Fuzzy Delphi Method and the VIKOR method in naval combat effectiveness assessment. This enriches the application of fuzzy theory and multi-criteria decision analysis and provides a practical scientific basis for naval ship selection and strategic planning.

Literature Review

Existing methods for assessing the tactical strength of ships in the Navy

According to the Comprehensive Guide to Naval Fleet Training issued by the Naval Command of the Ministry of Defense and the Comprehensive Practice Manual for Naval Fleet Training issued by the Naval Education and Standards Development Command, the assessment of the combat effectiveness of Taiwan naval ships is mainly based on the Navy's all-volunteer training management and combat readiness system. In previous studies, the assessment design relied too much on individual subjective feelings and had certain limitations, which caused bias in the assessment results and affected the objectivity and reliability of the study.

Therefore, this study proposes that the evaluation should be redesigned to introduce objective and systematic evaluation criteria through quantitative indicators, standardized evaluation procedures, and diversified data sources to reduce the influence of personal preferences and improve the credibility and validity of the evaluation. Based on the theories and literature of relevant scholars such as (Liu, 2015), this study establishes a framework for assessing the value of ship combat effectiveness, which includes four main components (e.g., Table 1) and nine criteria (e.g., Table 2) to form a comprehensive assessment system. The framework aims to overcome the shortcomings of existing assessment methods, enhance the persuasiveness and applicability of research conclusions, and provide a solid foundation for further research and application.

In the evaluation process, the arithmetic mean of the performance values of each criterion indicator under the four main dimensions was calculated after summing the values. Then, according to the instruction manual, a fixed weight of 0.20 is assigned to each of the four components of manning and equipment status, 0.25 to training performance, and 0.35 to identification effectiveness, and finally, the average values of the four components are weighted according to the weights to obtain the final evaluation score of the ship's combat effectiveness.

Although the above assessment process provides the Navy's standard operating procedures regarding the Code of Conduct, some points deserve consideration. For example, (Saaty, 1990) pointed out that using subjective opinions to assign fixed weights to each organization may not reflect the actual contribution of each organization to overall combat effectiveness, thus compromising the objectivity and representativeness of the assessment results. Therefore, it is necessary to re-examine the relative importance of each component and criterion through a more rigorous multi-criteria decision analysis to establish a more comprehensive and referential assessment model.

Fuzzy Delphi Method, FDM

This paper outlines the development of the Delphi Method (DM) and its evolution. The Delphi Method, initially developed by the RAND Corporation in the 1950s, is a systematic way of gathering and integrating anonymous expert opinion to predict future trends. The method relies on repeated questionnaires to statistically analyze expert knowledge and judgment, to achieve an objective consensus from subjective predictions (Bouzon, , M. ; Govindan, K.; Rodriguez, C.; Campos, L. M., 2016)

Table 1. Table of literature for structural assessment

Structural	Vintages	Scholar	Theory / Proposition
Staffing	2010	Edgar H. Schein	Organisational Culture Theory
Equipment Status	1993	UNAL,R et.al	Optimisation of quality design
Training Effectiveness	2008	Eduardo Salas ea.al	Team Training Effectiveness
Determination of Effectiveness	2016	JamesD. Kirkpatrick ea.al	Evaluation of Training Procedures

Table 2. Criteria Assessment Literature Table

Structural	Vintages	Scholar	Theory / Proposition
Staffing	2012	John P. Kotter	Leadership and Change Management
Wheel Equipment	2012	Nancy G. Leveson	System security engineering
Warfare Equipment	2012	Nancy G. Leveson	System security engineering
Basic Training	2008	Eduardo Salas et al.	Enhancing Training Effectiveness
Coastal training control	2008	Eduardo Salas et al.	Enhancing Training Effectiveness
On-site training	2008	Eduardo Salas et al.	Enhancing Training Effectiveness
Group Training	2008	Eduardo Salas et al.	Enhancing Training Effectiveness
Routine Forensics	2023	Larry Diamond et al.	Enhancement of operational capability
Random testing	2023	Larry Diamond et al.	Enhancement of operational capability

Despite its widespread use, the Delphi Method has limitations, such as the difficulty of quantifying the subjectivity and uncertainty of expert opinions and the need for objective criteria for consensus formation. To address these issues, (Dalkey, Norman; Helmer, Olaf, 1963)proposed the Delphi Interacting Group Method (DIGM) in 1963, which introduces statistics such as medians and quartiles and visual feedback mechanisms to facilitate communication and understanding among experts, thereby improving the quality of consensus.

Subsequently, the Fuzzy Delphi Method (FDM) was proposed to combine fuzzy set theory with the Delphi method to deal with the subjectivity and uncertainty of experts' opinions in complex decision problems and (Murray, T. J.; Pipino, L. L.; Van Gigch, J. P., 1985) first introduced the FDM in 1985, which transforms experts' opinions into fuzzy values through fuzzy theory to achieve more objective and consensus assessment results. Further studies, such as (Ishikawa, A.; Amagasa, M.; Shiga, T.; Tomizawa, G.; Tatsuta, R.; Mieno, H., 1993)applied fuzzy theory to forecasting problems, and (Hsu & Yang, 2000) conducted FDM modeling using triangular fuzzy numbers to simplify the analysis process and improve the stability of the results (Kuo, Y.F; Chen, P.-C., 2008). The Delphi Method and its derivatives are important in predicting future trends and dealing with complex decision-making problems. With the introduction of statistics, visual feedback, and fuzzy theory, these methods have evolved to improve the objectivity and stability of expert consensus.

The Fuzzy Delphi Method (FDM) is efficient for integrating expert opinion and dealing with uncertainty in decision-making problems. It overcomes the limitations of the traditional Delphi Method in dealing with ambiguity and uncertainty by introducing fuzzy set theory. The operational process consists of several critical steps in a systematic cycle to reach an expert consensus and distill more accurate forecasts and decision recommendations.

First, identifying the research question and the required team of experts is the initial stage of FDM. This stage requires a clear definition of the scope and objectives of the study and a careful selection of experts with knowledge and experience in the relevant fields to ensure quality and diversity of opinions.

Next, a preliminary questionnaire is designed and distributed to the experts, which is essential in gathering their initial opinions. The questionnaire should contain open-ended questions or statements about the research problem, allowing the experts to provide their insights and predictions. These comments reflect the experts' initial understanding and assessment of the problem and provide the basis for subsequent analysis.

The collected expert opinions are then converted into fuzzy values using fuzzy set theory. In this study, the triangular fuzzy number semantic scale index (Karam, A.; Hussein, M.; Reinau, K. H., 2021)used, a conversion process in which qualitative opinions provided by experts are quantified into fuzzy mathematical expressions such as triangular fuzzy number or trapezoidal fuzzy number for statistical analysis. This step is at the heart of FDM and allows the uncertainty in the expert opinion to be accurately characterized and processed. This is followed by the iterative integration of opinions through an iterative consultation and feedback mechanism. Based on the statistical analysis of the ambiguity scores, a feedback report is generated and fed back to the experts so that they can see how their opinion differs from that of the group and adjust or confirm it. This cycle is repeated until a certain level of consensus is reached or a predetermined number of cycles is reached.

Finally, recommendations are refined and formulated based on the consensus expert opinion. These recommendations are expressed as fuzzy values that provide a comprehensive view of the research problem and solutions, reflecting the diversity of expert opinion while considering the precise handling of uncertainty. Through the above process, the fuzzy Delphi Method effectively combines the subjective judgment of experts with the advantages of fuzzy set theory, providing a systematic and flexible method for solving complex decision problems. This method increases the robustness and adaptability of decision-making and provides a tool for decision-makers to make more accurate predictions of future trends.

VIKOR analysis method

VIKOR analysis, full name VlseKriterijumska Optimizacija I Kompromisno Resenje (Multi-criteria Optimisation and Trade-off Solution), was first proposed in 1998 to solve the Multi-criteria Decision-Making Problem with Conflicting Criteria (MCDM) (Opricovic, S.; Tzeng, G.-H., 1998). The method is particularly suited to decision-making situations where a balance must be struck between several criteria and focuses on finding a compromise closest to the ideal solution using a composite metric.

The core idea of the VIKOR method is to first define the most desirable (positive or desired) and least desirable (negative or worst) states of each decision option under all evaluation criteria. The positive ideal solution reflects the best performance of each option on all evaluation criteria, while the negative ideal solution shows the worst performance. By calculating the distance of each option from the positive ideal solution, a composite evaluation function is created that considers the combined effect of all criteria, the relative importance of each criterion, and the balance between maximizing group utility and minimizing individual regret.

Based on this, (Opricovic, S.; Tzeng, G.-H., 1998) proposed calculating ranking indicators for each option to assist the decision maker in reaching the final decision. This method aims to find a compromise solution close to the positive ideal solution. It has the consensus of the decision-makers, thus achieving the best compromise in the multi-criteria decision-making process.

When applying the VIKOR methodology, the first step is to define the decision problem and identify the evaluation criteria. This stage involves thoroughly understanding the decision environment and identifying factors influencing the decision. The selection of decision criteria should cover all aspects of the problem to ensure the comprehensiveness and accuracy of the analysis. According to (Opricovic, S.; Tzeng, G.-H., 1998) the VIKOR process is as follows.

First, relevant data is collected, and each decision option is evaluated against different criteria. This step requires quantification of the performance of the candidate options under each criterion to facilitate subsequent analysis. The evaluation results from the decision matrix are the basis for the VIKOR analysis.

Next, a standardization process is carried out to convert the data in the decision matrix into an un-quantified form to eliminate the effect of measurement units between criteria and ensure that comparisons between criteria are fair and consistent. Standardization involves calculating the best (ideal) and worst (negative ideal) values for each criterion. The closeness of the candidate solution to the ideal solution is then calculated. This involves calculating two leading indicators for each decision option: the distance from the ideal solution and the distance from the negative ideal solution. This calculation considers the weighting of each criterion and reflects the decision maker's subjective judgment of the importance of different criteria.

Finally, all decision options are ranked based on the calculated closeness. This ranking is based not only on the proximity of the solutions to the ideal solution but also on the distance to the negative ideal solution. The highest-ranked solution is the best choice, achieving the best overall performance considering all criteria.

Through the process described above, the VIKOR methodology provides a systematic and effective way for decision-makers to find a solution closest to the collective best solution when considering multiple criteria and facing multiple choices. This approach emphasizes the importance of compromise in decision-making and is of great practical value in solving complex and multi-variable decision problems. By combining FDM and VIKOR, this study develops an integrated decision support system that can deal with the ambiguity in the assessment and find the best compromise solution among the multi-dimensional criteria, thus improving the accuracy, reliability, and practicality of the assessment of the combat effectiveness of naval ships. Applying this methodology will likely provide a more scientific and rational analytical tool for assessing and making decisions on the combat effectiveness of naval ships.

Empirical Analysis

Research Process Description

The methodology used in this study blends the FDM and VIKOR approaches to provide an innovative solution framework for the evaluation process. The framework is based on two key concepts:

First, introducing FDM significantly improves the efficiency of dealing with uncertainty and ambiguity in the evaluation process. By accurately capturing and quantifying the subjective judgments of experts, the methodology improves the integration of evaluation criteria setting and expert evaluation, thereby increasing the adaptability and flexibility of the evaluation process.

Secondly, the VIKOR method provides a strategy for finding a compromise close to the ideal solution in a multi-criteria decision environment. This approach is particularly suited to evaluation situations where a balance between multiple performance indicators is required, allowing the decision-maker to strike a balance between maximizing group benefits and minimizing individual regrets.

Finally, the combination of FDM and VIKOR excels in dealing with ambiguous information in evaluation and achieving practical trade-offs between the many evaluation criteria to construct an integrated decision support system. Applying this innovative methodology significantly enhances the evaluation's accuracy, credibility, and practicality and contributes significantly to academic research.

Modeling Procedure and Steps

Structure, Criteria, Indicator Items, and Overall Structure of the Preliminary Draft Naval Vessel TPV Assessment

This study builds on the current methodology for assessing the combat effectiveness of naval vessels in the National Army Training Management and Force Maintenance System (NATMFS) by referring to the key influencing dimensions, criteria, and indicator items for assessing the combat effectiveness of naval vessels in the NATMFS. The initial framework of this methodology is intended to provide a precise reference framework for the naval ship TPV assessment conducted by this study and serve as a basis for developing a Fuzzy Delphi Method expert opinion survey questionnaire.

By systematically analyzing and evaluating the combat power values of naval vessels through this methodology, a scientific and practical assessment model is developed that not only reflects the comprehensive combat power of naval vessels under multi-dimensional criteria but also provides decision-makers with a set of decision-support tools for force employment and operational command at the strategic level (as shown in Tables 1 and 2).

Use of FDM to establish the structure, criteria, indicators, and overall framework for assessing the combat effectiveness of naval vessels.

The first survey round was conducted using a preliminary expert questionnaire designed using the above framework (See Tables 1. and 2.), initially developed from naval training manuals and literature.

A total of 25 active naval officers of the rank of Captain or above, with at least nine years of naval experience, were selected as experts for this questionnaire round. During the first round of expert interviews, the experts were asked to conduct a detailed review of the assessment framework's components, criteria, and indicator items to verify their applicability and relevance. In addition, the experts were asked to rate the importance of each indicator and were encouraged to suggest possible extensions, modifications, or mergers to enrich and improve the assessment model. Once the questionnaires have been collected, the data will be analyzed in detail to adjust and optimize the assessment framework.

Round 1. Expert questionnaire analysis

The results of the questionnaire analysis are as follows. The four scoring frame thresholds for the four scoring framework items.
There were nine criteria items, and eight evaluation criteria items were above the thresholds.

There was a total of 37 assessment indicators, with 34 assessment criteria items exceeding the threshold. During the first round of the questionnaire survey, experts were invited to make a comprehensive assessment and suggest new, revised, and combined assessment items.

After collation, four new indicators were added, and two structural items were combined as a preliminary draft for the second round of questionnaires.

Round 2. Expert Questionnaire Survey

After the first round of screening and expert suggestions, a second round of expert questionnaires was designed to conduct the second survey. A total of 25 active naval officers with the rank of Captain or above and nine years or more of naval experience were selected as experts for this round of questionnaires.

Round 2. Expert questionnaire analysis

The second round of expert questionnaire analysis results showed that all components and criteria items of the evaluation framework were retained entirely. Only two items were deleted from the evaluation indicators. Therefore, based on the survey and analysis results, this study has successfully established a complete framework for assessing the combat effectiveness of naval vessels, consisting of four dimensions, eight criteria, and 33 indicators.

Calculation of Tactical Strength of Ship Indicators

To ensure the rigor of the research process and the comprehensiveness, practicality, and comparability of the results, and to avoid relevant parameter data containing state military secrets, this study relies on the information on the Republic of Taiwan Navy ships provided in the Pape, A. (2021). *Jane's Fighting Ships 2019-2020.* as a reference. Six Kinging-class warships (French Lafayette-type warships) from the 124-ship fleet assigned to the Navy's Main Battle Fleet were selected as the objects for combat value analysis and evaluation.

In this study, the statistical analysis software Minitab (version 21.4) was used to generate the performance values of each indicator project for the evaluation of the combat effectiveness of each ship by the stochastic method.

Determine the best and worst values for all criteria items.

For the indicator items under each criterion, the performance rating of each ship under each criterion item is obtained by summing its performance values and calculating the arithmetic mean.

Calculate and rank the strength of each ship.

Using the standardization process described in the VIKOR method, we could rank the ships regarding their combat power, providing important decision support information for commanders when deploying forces and performing various operational tasks. This provides essential decision-support information for commanders when deploying forces and performing various operational tasks.

In further analysis, it can be concluded that the critical criteria for the low BPV of the ships are mainly focused on the criteria "Battle System Equipment," "Shore Training Control," "Combined Training," and "Routine Identification." These criteria have relatively low performance values but are highly important and should be prioritized for improvement. Based on the conclusions of the data, specific improvement strategies and directions can be formulated, and the integrated combat capability of a single ship or even the entire naval fleet can be improved, paving a scientific and systematic way to enhance the operational effectiveness of the Navy.

Conclusions

This study is based on the current assessment method of naval ship combat effectiveness in the National Army Training Management and Tactical Readiness System (NTMTRS). It refers to the system's key influencing factors, criteria, and indicators as a basis for establishing a more comprehensive and scientific assessment model of naval ship combat effectiveness. A holistic and scientific assessment model is developed using qualitative research methodology and Multi-Criteria Decision Making (MCDM) theory from Decision Science and Operations Research. The results of this study are summarized below:

First, the evaluation framework initially developed in this study through the application of FDM has successfully integrated and tested the consensus of the expert community through two rounds of expert questionnaire surveys to filter out the appropriate and critical evaluation dimensions, criteria, and indicator items, and finally established a comprehensive evaluation framework containing four dimensions, eight criteria, and 33 indicators. This process demonstrated the effectiveness of the fuzzy Delphi method in obtaining expert consensus and adapting the evaluation framework to the actual needs.

Second, the model developed by further applying the VIKOR analysis provides commanders with decision-making references to optimize ship deployment and operations. This method not only effectively ranks the combat effectiveness of ships but also reveals the main factors leading to the lack of combat effectiveness and then formulates targeted improvement strategies, which cannot be achieved by the traditional simple weighted arithmetic mean calculation method.

In conclusion, this study has successfully established a comprehensive and scientific model for assessing the combat effectiveness of naval vessels by combining the FDM and VIKOR analyses. This innovative result enhances the substantive support for the combat effectiveness assessment and decision-making of China's naval fleet and fills the relevant gap in the academic literature.

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