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A Systematic Review of Marine Risk Assessment: The Fuzzy Analytic Hierarchy Process (FAHP)

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Abstract: This systematic review examines the marine risk assessment (MRA) by identifying the most viable method in assessing marine risks using the latest technology. This paper centers on the Fuzzy Analytic Hierarchy Process (FAHP) where the techniques and advantages of FAHP in facilitating important decisions were analyzed. A systematic review of the literature was conducted to highlight the significance and potentials of FAHP in providing a comprehensive risk assessment analysis which serves as a standard applicable guideline in the marine industry. To begin, a systematic search was conducted in three electronic databases (Mendeley, Scopus, and ScienceDirect) to gather relevant material. They're a database of sorts. Following the completion of the data, a systematic review was done in accordance with the findings. This document, which focuses on a variety of risk assessment disciplines, offers the analysis and outcomes of many studies that used a variety of analytical approaches, all of which were conducted using FAHP. Furthermore, the findings of this analysis provide further insights and choices in the area of hierarchical decision-making, particularly in the realm of risk assessment.

Keywords: Marine, risk assessment, FHAP

1. Introduction

The demands of the Fourth Industrial Revolution (IR4.0) have established technical innovations as a significant moving force for various managements and organizations. This next phase of innovation is currently being ushered in by the maritime sector with the implementation of an intelligent platform that enables information to be accessible and managed with the touch of a button [1]. This phase is known as Maritime Spatial Planning (MSP), and it is widely used in industrialised countries as it covers operations in marine regions utilising specific tools for managing, analysing, and predicting hazards. These countries include the United States, Canada, and Australia. Various marine zones, ranging from coastal to open-sea regions, are being created all over the world in an effort to encourage ocean management and governance that is sustainable [2]. The MSP has attracted the attention of both prominent figures in the scientific and political arenas. MSP is a fundamental instrument in supporting sustainable marine growth, and it serves both an ecological and social aim in assessing and allocating the spatial and temporal distribution of human activities in marine ecosystems [3]. This is done through the Marine Spatial Planning (MSP) programme.

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Marine Spatial Planning, also known as MSP, is a practical approach to creating and enforcing a more rational arrangement of the use and interaction of marine space, striking a balance between the need to protect marine habitats and the demands of development, and accomplishing social and economic goals in an open and coordinated manner [4]. Marine spatial planning, also known as MSP, is a public process that involves observation and allocation. The purpose of this process is to achieve ecological, economic, and social goals, which are typically defined in the political process of the spatial and temporal distribution of human activities in marine areas.

The ten stages that were taken to construct MSP are outlined in Fig. 1. The phases contribute to an ongoing, iterative goal of learning and adjusting throughout the course of time. These ten initiatives phases have been used to provide direction to other nations on the implementation of the MSP itself, and prior to being confirmed as a reference, they have also been subjected to a large number of reviews and feedbacks from all relevant stakeholders.

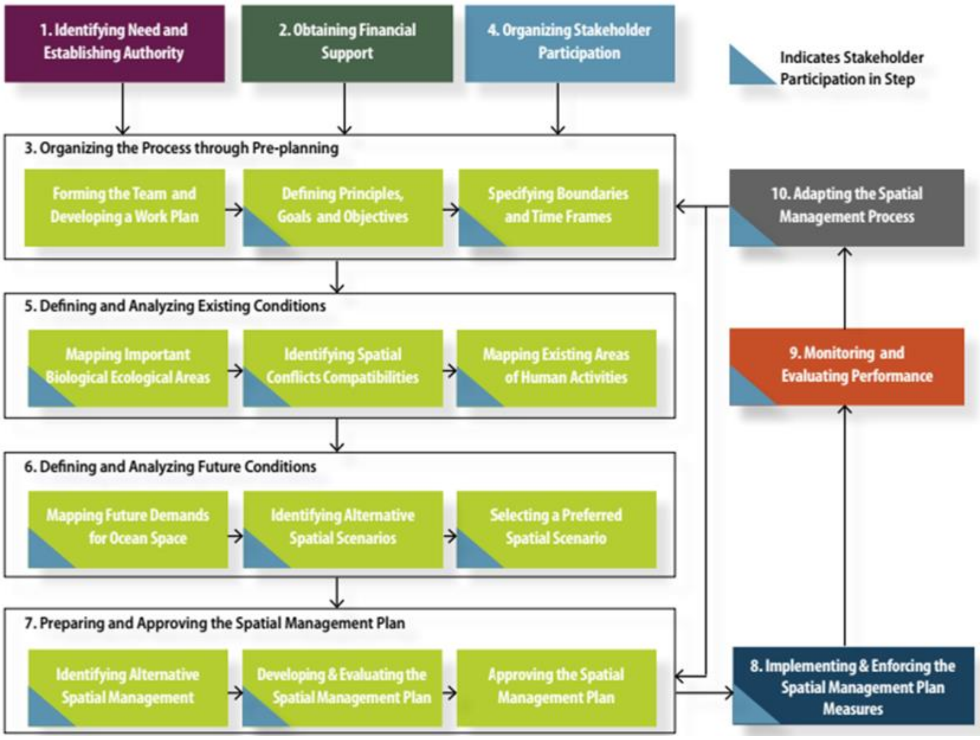

Fig. 1 - Step by step approach by MSP [5]

Concentrating on the third phase of the MSP stage of implementation, which is structuring the process through preplanning so that the objective-based MSP process can be organised through this step. It is referred to as "pre-planning" because it is the stage of planning that prepares the groundwork for later phases of planning [6]. In order for this function to be carried out, the pre-planning process needs to determine the following:

(i) a group of people
(ii) a timetable or work plan
(iii) the planning boundaries and timeline
(iv) a guiding concept
(v) a collection of broad goals
(vi) a group of particular and quantifiable goals and objectives
(vii) an analysis of the potential risk posed by the things that could go wrong during the planning process and the various backup plans that could be implemented.

According to the list shown above, all preliminary planning should include an analysis of the potential hazards posed by things that could go wrong while the planning is being done [7]. Consider what aspects of the MSP processes could potentially cause a delay or sabotage important steps and operations, what the design period in between needed tasks entails, and the various alternative risk management strategies that are at your disposal.

These risks must be frequently evaluated to enhance MSP’s governance and performance, making risk assessment methodology a priority. Risk is the probability of something bad happening [8]. It is the uncertainty from an operational impact on societal aspects such as health, well-being, wealth, buildings or the environment. The International Standard (ISO) defines risk as "the effect of uncertainty on goals" [9] where it acknowledges that risk assessment reflects the management approach or system of choice of many fields, including medical and research facilities, engineering design and in particular insurance.

Risk comprehension, description, concepts alongside measurement and management methodologies vary according to fields. In this case, marine risk assessment commonly adheres to the ISO 31000, the common international standard for risk management designed for any field [10]. The marine and offshore industry has conducted its risk assessment on marine activities such as fishing, oil splintering and navigation [11]. Findings [12] shows that activities such as deep-sea mining also practices the controls and measures in line with the policies set by UNCLOS, highlighting the importance of risk criteria in assessing management options. Another journal [13] outlined a list of the latest publications concerning marine risk evaluation.

Despite the need for risk assessment, the most viable and successful technique in providing a reliable evaluation result remains underexplored. Thus, this paper explores the role of the Fuzzy Analytical Hierarchy Process (FAHP) as an effective technique in assessing marine risks. FAHP belongs to the multi-criteria decision analysis (MCDA) process, an approach used to facilitate the decision-makers in considering situations with multiple criteria [14]. MCDA is used to logically evaluate and compare multiple conflicting criteria to reach the best possible decisions, rendering it useful when stakeholders have varying interests, values and objectives. FAHP is adopted as an assessment method for an irrigation project involving criteria such as technical, managerial, environmental, social and economic aspects [15]. Using this approach, the efficiency of irrigation projects can be measured via a systematic decision-making methodology. FAHP also considers the factors relating to subjectivity, allowing the ranking of important criteria [16]. Moreover, the FHAP enables decision makers to take any action in a timely and accurate manner, which is a significant benefit.

1.1 Aim and Research Objectives

This paper discovers that FAHP is capable of enabling decision making based on a variety of risk assessment parameters, and it does so in an effective manner. Because there is a shortage of methodological guidance and current methodological reference, it contributes to the body of knowledge by providing insights into essential approaches for marine risk assessment.

FAHP was used as an analytical technique in a reputable study to help efficiently distribute gas in the Qazvin Province while concurrently overcoming a management issue [17]. In a similar manner, FAHP was utilized in the analysis of energy systems, particularly those that are now dependent on fossil fuels [18] in order to combat the depletion of fossil fuel reserves, the risk of environmental degradation, and global issues like as climate change. In this scenario, renewable energy resources and environmentally friendly technologies are significant possible alternatives; hence, decision-making strategies that support these alternatives on a worldwide scale are required. According to the findings of the previous research, it is abundantly evident that the FHAP approach has the benefit of prioritizing all factors that have in site consideration to as a factor and assisting the decision maker in coming to the best possible choice. This article presents a complete examination of the study carried out by previous researchers, in addition to a diversity of perspectives and approaches to the concept of FAHP.

2. Methodology

This study focuses on the four most important aspects of the process of conducting a systematic literature review, which are: (1) the development and validation of the analysis protocol/publication standard/reporting guidelines; (2) the formulation of the study question; (3) the implementation of systematic search strategies; and (4) the quality assessment [19]. The search for the information was carried out using online database systems. The approach of systematic literature review given below utilized a total of 100 various articles.

In order to search for the desired research literature, pertinent keywords were chosen. During the preliminary stages of the search, Mendeley Desktop, Scopus, and Science Direct were utilized as our primary research tools. When doing their search, the writers combined many terms by using the Boolean operator. In this particular research project, a total of four primary manual search strategies, including hand-picking, backward tracking, forward tracking, and snowballing, were utilized. The collected literature was then organized and studied in accordance with the following categories: the beginnings of FAHP, the steps involved in FAHP, and the advantages of FAHP.

2.1 The Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process, also known as AHP, is a structured method for organizations and the analysis of difficult decisions that is based on both mathematics and psychology [19]. It is a computer-based framework that provides decision-makers with the ability to leverage knowledge as well as various models in order to address unstructured problems [20]. It is possible to define it as an interactive decision support system that is designed to enhance the decision-making stages of identifying the problem, selecting the relevant data, identifying the approach used in the decision-making process, and evaluating alternative selection [21]. This system can be described as having the goal of improving the decision-making stages. The Analytic Hierarchy Process (AHP) makes use of qualitative and quantitative variables to construct a hierarchical structure during the decision-making process. This structure provides decision-makers with assistance in selecting the optimal solution based on criteria that were previously established for model selection [22].

After then, the idea of the AHP technique was expanded upon by Van Laarhoven & Pedrycz [29], who presented the fuzzy logic in AHP (FAHP) [23]. Their method illustrates how decisions can be made during the pair comparison process even when ambiguities are present by showing how these choices can be made (i.e., determine the corresponding weights). Buckley [24] contributed significantly to the development of this technology by proposing the geometric means approach, which allowed for the calculation of weights alongside fugitive numbers (i.e., the defuzzification process). The imprecision of the assignment itself is the primary justification for employing fluorescence number comparisons as ratios in pair analysis. Therefore, the advertising careers offered by the FAHP were organized in such a way as to rectify this error through the use of circular thinking. There have been a significant number of studies done using FAHP in a variety of fields [25], such as the selection of suppliers or partners as an option, the selection of methods, the evaluation of green suppliers, buildings, organizational management, quality management, supply chain design, company environmental evaluation, and patient prioritization.

2.2 The Fuzzy Analytic Hierarchy Process (FAHP)

The FAHP incorporates the AHP approach and the fuzzy definition where more evaluations can be carried out using the combination of fuzzy and AHP techniques [26]. FAHP is an alternative to the subjective limitations of AHP [27]. A triangular fuzzy number as shown in Fig. 2 is used in the AHP scale to obtain a more flexible value of a coupled comparisons [28] where this procedure includes the synthetic extent analysis in priority processing which is carried out to rank potential acceptors.

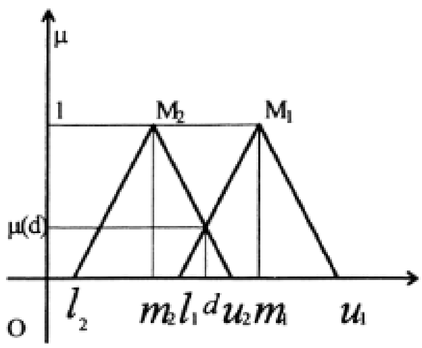

Fig. 2 - An example of FAHP's triangular fuzzy number [29]

The steps involved as illustrate in Fig. 3 in the decision-making process using FAHP is as summarized below [30]:

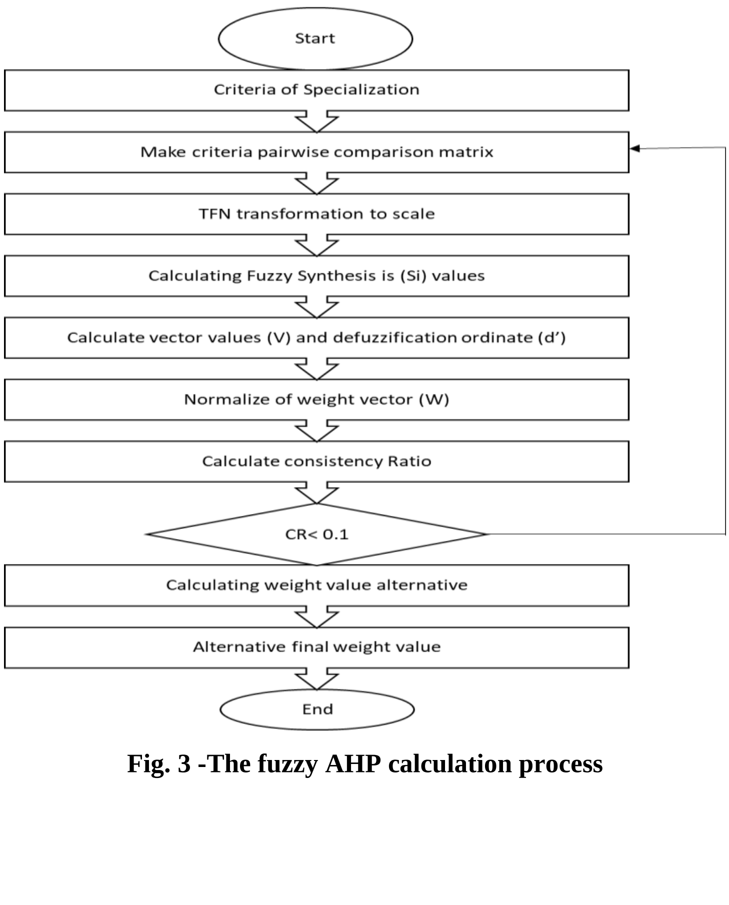

Fig. 3 -The fuzzy AHP calculation process

1) Defining the problem and identifying the aim. The MCDA procedure's initial stage is where the majority of its focus should be placed. The researchers are required to construct a hierarchical structure, beginning with the purpose of the investigation
2) Creating a hierarchical structure beginning with a general-purpose, followed by criteria and available options. A more structured technique entails splitting the problem into hierarchical categories, where a constructed system has the potential to assist decision-making by evaluating and recognizing quality gemstones in an effective and accurate manner utilizing the FAHP algorithm [31]. It would be impractical to analyses stones that are not of the same quality and qualities, thus the system bases its judgment on the kind of stone instead. This is why the system bases its conclusion on the type of stone.
3) Forming a matrix of pairwise comparison. The pairwise comparison that describes the influence of each element on each criterion as shown in fig.4. The term "pairwise comparison" refers to any procedure that compares criteria in pairs in order to establish which criteria is more desirable, which criteria has a bigger amount of some quantitative property, or whether the two entities are the same. The number of important factors in an analysis that are subjected to these pairwise comparisons is typically limited to seven at most [32]. A different name for this is "expert choice." It is necessary to conduct pairwise comparisons of each criterion and sub criterion among the same groups. There are criteria within criteria, and then there is a sub criterion 1 within a sub criterion 1a, 1b, and 1c, as shown in Fig. 4. The same procedure should be followed for the sub criterion 2 and others.

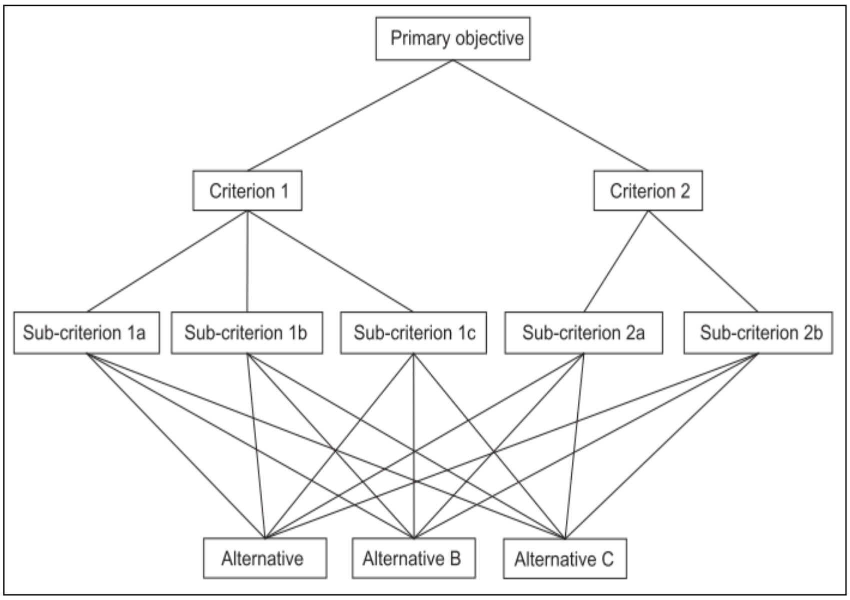

Fig. 4 - A typical AHP decision hierarchy [31]

4) Normalizing the matrix. A pairwise comparison table is shown in Fig. 5, and it is linked to Table 1, which illustrates the relative relevance of left and right criteria on a scale ranging from the same level of importance to an exceedingly high level of importance. For instance, if the first expert chooses a score of 5 for the left criterion, this reveals that the left criteria are strong importance (refer to Table 1) than the right criteria.

Left Criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Right Criteria

Fig. 5 - Pairwise between left criteria and right criteria [32]

Table 1 - Indicator of intensity important [33]

Relative importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to objective
3	Weak importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	One activity is strongly favoured and demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed between two adjacent judgments

5) Calculating weight values or priority of own vector. The weight of each alternative element is determined according to the weight of the criterion element where the decision is made. The criteria comparison importance and transformation to scale criteria can be calculated in the process workflow, resulting in the ranking of each option upon the completion of the review. The decision-maker can then decide upon the key priorities decision. After getting the scores for all of the pairwise comparisons, the weights are then independently determined based on the group that was constructed using the pairwise comparisons. Calculating the weights for the criterion and then the weights for the sub-criteria comes first, as shown in Fig. 6. This is followed by calculating the weights for the sub-criteria.

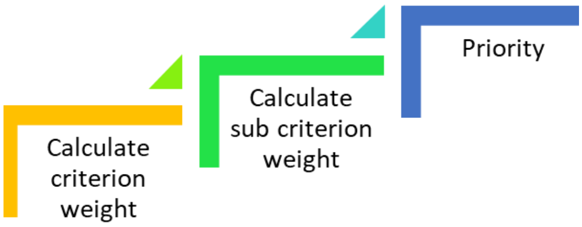

Fig. 6 - Process of weightage calculation

The calculation that is provided in Eq. (1) [34] is used to arrive at the value for the weight. Calculations will be done using tables, and Microsoft Excel will be utilized as an assistive tool throughout the process.

$$\text{Weightage} = \frac{1}{\text{No. of comparison 1}} \times \left(\frac{\text{Rating}_{\text{C in comparison 1}}}{\Sigma\text{Rating comparison 1}} + \cdots + \frac{\text{Rating}_{\text{C in comparison n}}}{\Sigma\text{Rating comparison n}}\right) \quad (1)$$

After calculating the two weights, the priority can then be categorized according to the weights that were calculated before. The formula for calculating priority, which is depicted in Eq. 2 [36], involves multiplying the weightage of the criteria with the weightage of the sub criteria. The formula was then simplified by [35] in order to make it more easily understandable, as illustrated in Eq. 3 [35].

$$V(A_{ik}) = \sum_{k=1}^{n} w_1\, w_{k(1)} v(a_{ik}) \quad (2)$$

where: $v(a_{ik})$ = value function, w_1 = criterion weightage of criteria associated to subcriteria, $w_{k(1)}$ = criterion weightage of subcriteria.

$$\text{Priorities} = w_1 \times w_{k(1)} \quad (3)$$

This priority result is the FHAP's final output, and by comparing the values of the higher priority levels, we may establish which hierarchy of criteria is the major path.

6) Measuring consistency. Measuring consistency can be develop by calculating the value of the index of consistency (CI). Determining the consistency ratio (CR) using the following formula [36]:

$$CR = \frac{\lambda_{max} - n}{RI(n-1)} \quad (4)$$

where: λ_{max} = total of priority, n = number of criteria, RI = weight of random criteria. If the CR, the ratio of CI and the random index (RI), is less than 10%, the matrix can be considered as having an acceptable consistency. The consistency ratio is used to ensure that the results of prioritizing are reliable and acceptable for further analysis.

3. Results and Discussion

The findings of this review article can be divided into three groups based on their importance; (1) deriving priorities (2) systematic and in-depth analysis and (3) accommodating both qualitative and quantitative criteria. Each of the groups can serve as a reference for a guideline that will be used in the future to conduct a marine risk assessment using FHAP.

3.1 FAHP Deriving Priorities

For instance, in future marine risk assessment and in order to determine the factor risks that are the most accurate, dealing with the risk in marine environments listed human behavior, workplace safety, and climate. The criteria that were defined are founded on a review of the research from earlier studies. After that, for each cluster of criteria, make a list of the subsidiary criteria that are related with it. Given this information, the number of criteria cannot be greater than seven, as doing so will make the pairwise comparison matrix stage more complex. The general structure of the hierarchical organization is depicted in Fig.7. Last but not least, the dependent flow of each component through the hierarchical structure is shown by the arrow in the diagram.

The FAHP has the advantage of explaining a hierarchical structure of criteria [37], thus, enabling users to focus better on specific criteria when assigning weights. It is necessary to use a pair-wise comparison of the criteria concerning the objectives alongside the alternatives concerning the criteria, to determine priorities between the elements of a hierarchy [38].

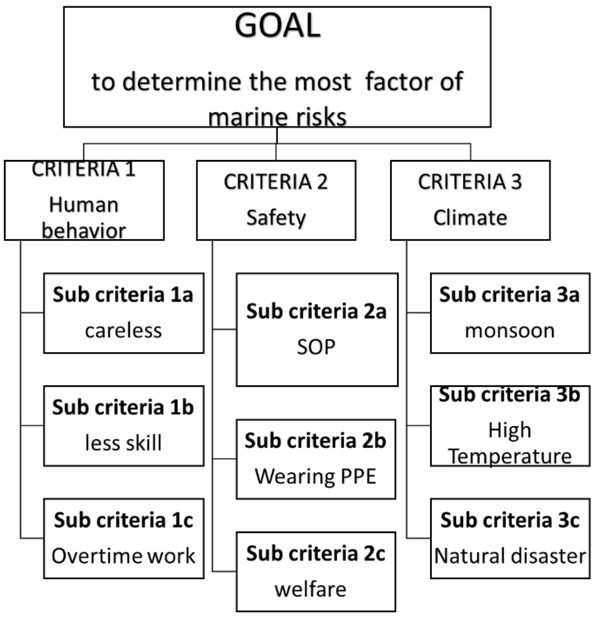

Fig. 7 - The Fuzzy AHP criteria hierarchal structure

The FAHP eases the process for marine administrators and organizations in identifying the highest risk as a priority as output of FHAP process. Additionally, the subsequent step of risk control and avoidance can also be easily determined allowing for fast and appropriate action to be taken. For the sake of this illustration, the high priority are associated with Criteria 1 (human behavior), which means that the decision maker can concentrate first on taking any action about it. Therefore, this process responds to marine sustainability in the development of Marine Spatial Planning (MSP).

The results that were produced are simultaneously directed toward avoiding accepting the perspectives of numerous decision makers who take the time to evaluate and have a variety of doubts about the situation [39], [40]. FHAP can, in an indirect manner, save time, and the procedure itself is more methodical than more conventional methods. As a result, the management level has offered this way to assist decision makers in evaluating a component that is more influential, particularly in marine risk management that will be adopted in Marine Spatial Planning. As soon as this marine risk assessment is downloaded into Marine Spatial Planning, Marine Spatial Planning will become completed and ready to face a variety of risks in the future.

3.2 Systematic and In-Depth Analysis

A more thorough and comprehensive study of the variables can better be understood by accounting for lower and more accurate measures where knowledge can be derived from experience and the use of other tools. The AHP can be used in risk assessment and planning of different contexts where the priority list, selection of best policies, allocation of resources, prediction of results and temporal dependence can be identified [41], [42].

FAHP can be used to analyze various types of variables in future marine risk assessments where the ability of FAHP in handling the complex analysis can aid in useful decision-making. This advantage offers the opportunity for immediate and reliable decisions.

As a consequence of the selected criteria and sub-criteria, a number of different analyses can be carried out based on the output of FHAP. For instance, FHAP can be integrated with Geographic Information System to carry out these analyses (GIS). The Geographic Information System (GIS) is a tool that, depending on the data that has been saved, may evaluate, predict, and offer any relevant information. The capabilities of GIS have been recognized by a variety of organizations, and these organizations use GIS in governance to simplify the management of organizations [43]. Because it is so simple to use and because it is in such high demand right now, Geographic Information Systems (GIS) can perform query operations and, at the same time, acquire the correct answer in a short amount of time through its use. Therefore, this is the primary objective of marine Spatial Planning, which was developed with the intention of administering marine management on a platform that contains a range of information and allows all relevant stakeholders to share all of the data and information that is helpful in it.

3.3 Accommodating Both Qualitative and Quantitative Criteria

The FAHP framework enables both qualitative and quantitative criteria alongside expert knowledge to be incorporated. An extensive analysis on the differences between the fuzzy AHP and conventional AHP was conducted for small matrix scales considering quantitative and qualitative aspects [44]. Since the judgment matrix determines the weight of the FAHP assessment method, the weight achieved is often subjective. Future research can consider the subjectivity of the assessment method to improve FAHP in assessing future marine risk analysis. The Risk Assessment Matrix (RAM) supports the determination of weight in all risk management criteria, rendering a reliable and accurate integration [45], [46].

It is beneficial when the figures produced at the FHAP level are translated to visual through the process of integrating with GIS, as this offers a number of advantages. Instead of having data displayed in a quantitative format, all of the values that were gathered will be presented in a map. This will allow the decision maker to perform an indirect visual evaluation that is qualitative in nature and is backed by information gained from the visual. To put the incredible benefits of combining GIS and mathematical approaches into perspective, consider the following: An illustration of this may be shown by looking at the same case, which is to determine which worker or supervisor the worse behavior has based on location. It also makes it easier for any company to prepare solutions to problems that have been encountered without having to evaluate an excessive amount of complicated numbers in the form of tables.

4. Conclusion

On the whole, the FAHP is an efficient method of analysis for future marine risk assessment. FAHP transforms a goal into a decision based on the analysis of the real world. It is a decision-making system that can adequately and efficiently evaluate marine risks and make decisions using its algorithm. Therefore, a complete guide of the FAHP methodological process for future studies should be provided.

Decisions that require support methods are challenging to model. A compromise should be reached between the degree of modelling perfection and its usability. FAHP has demonstrated this compromise in the past and has currently progressed in usability and structure where it is extensively adopted by academicians and practitioners. Its main advantages of outlining the hierarchy of the problem, different methods for analyzing sensitivity and verification of consistency contributes to resolving management issues effectively.

The hierarchical process provides decision makers with several benefits, including the ability to plan the next step by referring to the hierarchy, which allows them to look at the findings in a targeted manner while also providing them with the ability to look at the results. One single diagram can convey a thousand pieces of information, both explicit and implicit.

The researcher came to the conclusion that the findings of this work provide unwavering evidence that FHAP is an innovative approach that is suited to the task of carrying out marine risk assessment. It is recommended for the needs of marine spatial Planning in completing the elements in it to try the FHAP method in solving any problems that arise to complete and prepare for any eventuality that may occur in the future. This is done in order to fulfil the requirements of marine spatial Planning.

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