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An integrated approach for evaluation of best Oil spill cleaning methods by analytical hierarchy process and multi-objective optimization by ratio analysis

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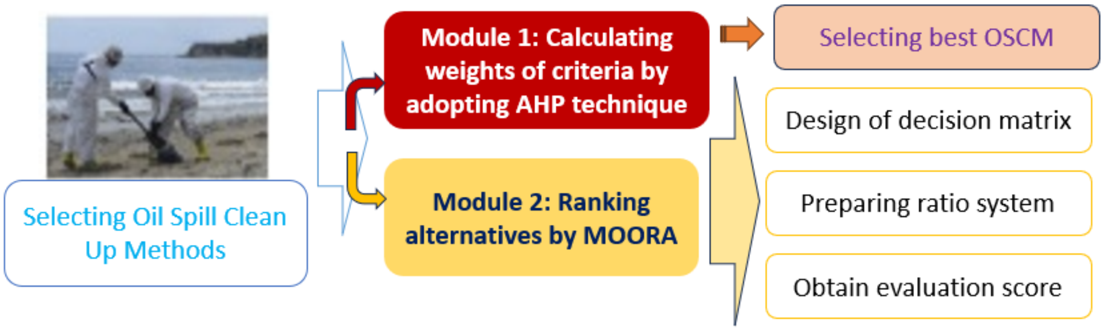
Article

ABSTRACT



Oil spills are considered as form of pollution that happen in marine eco system which releases liquid petroleum hydrocarbon into sea water. Oil floats in water as separate particles. Because oil spills are highly toxic, they can damage the biotic and abiotic components of the environment in which they occur. In the last few years, there have been many large and small spills in the ocean. Therefore, it is necessary to develop some effective ways to clean up oil spills. There are many cleaning options according to the type and amount of spilled liquid, environment, and weather conditions. More importantly, cleaning should be faster, more efficient, and more effective when restoring the site to its original state. There are many options, contradictions, and decisions to choose the right cleaning method. The purpose of this article is to develop an integrated model for selecting oil spill cleaning methods, including the Analytic Hierarchy Process (AHP) and Multi Objective Ratio Analysis Optimization (MOORA). When using AHP to compute criteria weights, the MOORA technique is used for evaluation and selection of the best cleaning method. The proposed model seems to be the best one to evaluate and select choices.

Keywords: Oil spill, AHP, MCDM, ratio analysis.

INTRODUCTION

Huge quantities of oil are discharged through accidents by tankers, barges, refineries, oil rigs etc. when oil is transported via sea routes.[1] The oil release, generally, spreads to wide area leading to a oil covering on sea water which proves fatal for aquatic animals. Due to toxicity, oil released through oil spills destroys aquatic animals and sea birds. The oil layer will persist for many years after deposition through any oil spill in the region. Internal transfer of oil and bunker operation are the sources of oil spills which contaminate coastal areas, and causing stern health issues for people, plant and animal life.[2] Another reason for oil spills is surge in petroleum products production that results in enormous shipping and related oil spills. Oil spills lead to pollution of sea areas, harm fisheries, spoil marine ecosystem and surrounding places of seashore areas which impact the tourism. In addition, the oil spills lead to health issues of the people who inhale dangerous fumes and consume contaminated fishes from the sea water bodies. It is estimated that it will take months together to clean the affected area to restore to the normalcy.[3] The destruction produced by the oil spills has serious problems in all countries. It is clear that country or tourist locations located nearer to oil wells and sea areas have great probabilities of socio-economic impact and disastrous ecological effects.[4]

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LITERATURE REVIEW

The cleaning of oil spill is aimed to reduce the consequences on normal and economic sources. The suitable selection of spill cleaning methods considering location and occurrence of spill will greatly reduce the effects of spills. It is necessary to have adequate skills and familiarity on properties of oil, magnitude and characteristics of oil spill, nature of oil, climate conditions, adjacent ambiance, aquatic performance etc. In reality, oil spill cleaning processes lead to adverse environmental problems if there is no care is taken to have a tradeoff between its effects and aftermath of cleanup activities.[1] Dispersant method is influenced by environmental (sea conditions) and oil composition and climatic weather conditions[2]. Advantages and disadvantages of ground and marine oil spills reactions are explained[3]. AHP method is applied to choose suitable oil spill cleaning method for calm sea conditions.[4,5,6] MODIPROM method is proposed for selecting logistics centre location.[7] Oil spill cleanup methods are categorized into physical, chemical, thermal and biological.[1,8] Many emerging techniques of oil spill cleaning methods are proposed to clean the oil spills.[5,14,19] A variety of magnetic nanocomposites materials and techniques are now available for oil spill cleanup. The techniques such as Fe_3O_4/PS nanocomposites,[9] magnetic nanocomposite of collagen and superparamagnetic iron oxide nanoparticles,[16] Core shell Fe_2O3@C water-repellent and superoleophilic nanoparticles[17] are proposed for oil spill cleanup.

Factors like class and quantity of oil spill, weather situation and surrounding environment play key role while selecting suitable cleaning methods.[10] MOORA technique is used to choose the best non-conventional machining process under various criteria which conflict with each other.[11] Usage of dispersants is mainly affected by nature of oil, temperature, wind speed and sea environment.[12] A MCDM approach is developed using MOORA for selecting automobile of a marble company. The criteria weights are computed by MACBETH method and final selection is done by MOORA technique.[13] Karande et al. used MOORA method for selecting best material.[15] Chakraborty used MOORA approach for choosing the suitable unconventional manufacturing methods.[18]

Physical methods include booms, skimmers and adsorbent materials. Chemical methods are dispersants. In situ-burning is a thermal method and bioremediation is a biological method. There are many emerging technologies to clean oil spill have been developed in the recent past with good recovery efficiency.[5,14,19] Aggressive techniques like dispersants and in situ burning are not suitable for sensitive areas such as MPAs. The existence of marine protected areas (MPAs) is inadequate to lower the number of accidents and the volume of oil spill. With a single and huge volume of oil spill can result in environmental damage to the tune of billions of dollars.[20] Many sorbent materials have limited oil absorption potential and good water absorption properties. The polyolefin-based superabsorbent polymers have better features for oil spill cleanup process.[25]

Based on the literature review, it is found that evaluation of oil spill cleaning methods needs to be carefully evaluated for choosing proper method. With the aim of protecting marine ecosystem and surrounding people from harmful effects of oil spills it is suggested to have a standard system to evaluate and select oil spill cleaning methods. This paper is focused on development of integrated AHP-MOORA model that relates multiple conflicting criteria that comes under MCDM. This paper has five subsections. The section 2 addresses the latest developments and importance of oil spill cleaning methods and their evaluation to select the best alternative. Section 3 explains the integrated model and phases involved in AHP and MOORA methods. Section 4 discusses real time problem solved by AHP-MOORA. Section 5 consists of conclusion and opportunity to extend the proposed research work.

INTEGRATED AHP-MOORA MODEL FOR SELECTING OIL SPILL CLEANUP METHODS (OSCM)

The proposed approach contains the following modules which is detailed below:

Module 1: Calculating weights of criteria by adopting AHP technique.

Module 2: Ranking alternatives by MOORA.

The proposed model has following steps as illustrated in Figure 1.

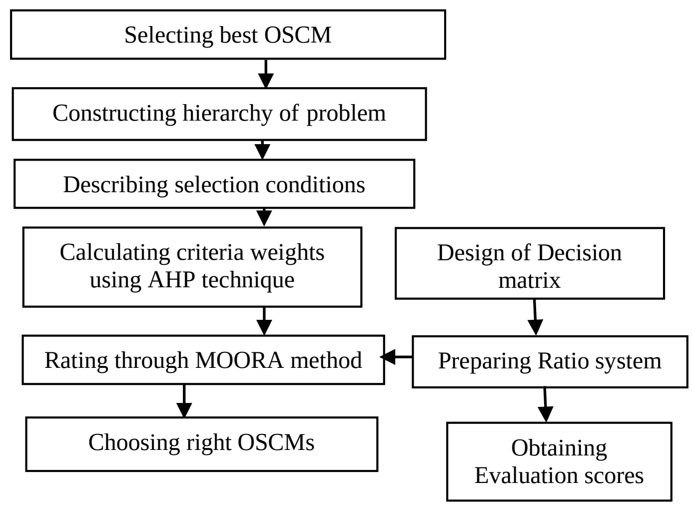

Figure 1. Oil spill cleaning methods selection by AHP-MOORA model

CALCULATION OF CRITERIA WEIGHTS USING AHP METHOD

AHP method prioritizes and ranks choices of MCDM which is based on judgmental scores given by experts to make pairwise comparison of criteria. AHP starts with definition of MCDM problem, its selection criteria and defining alternatives available. The complicated MCDM problem is reduced in a hierarchical structure. Set of pairwise comparisons matrix are developed for the calculation of criteria weights through combining the results. The salient attributes of AHP method are detailed here under:

i. AHP deals both tangible and intangible parameters that impact the choice of selection.
ii. AHP scientifically standardizes the selection problem that includes meticulous evaluation.
iii. The AHP proposes relatively easy but theoretically outstanding methodology to evaluate alternatives.
iv. AHP contains elementary hierarchy to resolve challenging MCDM problems and to evaluate quantitative and qualitative data.

The AHP procedure includes the following steps to compute comparative weights of assessing criteria:

Step 1: Defining appropriate selection variables.

Step 2: Building decision hierarchy by breaking complex MCDM as various levels.

Step 3: Obtaining pairwise comparison matrix 'X' using (3.1):

$$\begin{array}{c} \\ B_1 \\ B_2 \\ \vdots \\ B_n \end{array} \begin{array}{c} \begin{array}{cccc} B_1 & B_2 & \cdots & B_n \end{array} \\ \begin{bmatrix} 1 & k_{12} & \cdots & k_{1n} \\ 1/k_{12} & 1 & \cdots & k_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/k_{1n} & 1/k_{2n} & \cdots & 1 \end{bmatrix} \end{array} \quad (3.1)$$

where k_{ij} =1 and k_{ji}=1/ k_{ij} ,i,j =1,2,⋯,n

B_1,B_2,...,B_n are selection parameters and x_{ij} are decision elements .

The two elements are compared and the values are fixed through a range varies between 1, 3, 5, 7, and 9.[22]

Step 4: Verifying the consistency of pairwise comparison matrix:

As stated by Saaty consistency ratio (CR) is the ratio between and Consistency index (CI) and random index (RI) as mentioned by 3.2 and 3.3 [21,23]:

$$CR= CI / RI \quad (3.2)$$

$$CI=(\lambda_{max}-1)/ (n-1) \quad (3.3)$$

In (3.3), n and λ_{max} signifies matrix size and Eigen value respectively. Judgement consistency is verified by calculating the *CR* and *CI* values as shown in Table 1. The CR is satisfactory if the CI value is below 0.10 .

Table 1. RI values for various n values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.6	0.9	1.1	1.2	1.3	1.4	1.4	1.5

Step 5: Computing weight of pairwise comparison matrix *w* by column normalization i.e. adding elements of all row and divide the value by corresponding no of row elements.

MOORA method

The basic step in MOORA technique is to formulate decision matrix that has alternatives scores regarding the selection parameters. MOORA approach is applied to study the privatization in changing economic conditions[24]. The MOORA method delas with multiple objective optimization[25].

The calculation procedure of MOORA technique is as follows:

Step 1: Defining the objective and developing right evaluation criteria

Step 2: Devising decision matrix by relating the alternatives and selection criteria

A decision matrix is developed with row and column that denotes alternatives and criteria respectively. Equation 3.4 depicts the decision matrix wherein the information are signified as $H_{u\times v}$ where h_{ij} is the dimensionless value of i^{th} alternative on j^{th} criterion, u and v denote the alternatives and criteria count correspondingly.

$$H = [h_{ij}] = \begin{pmatrix} h_{11} & h_{12} \cdots & h_{1v} \\ h_{21} & h_{22} \cdots & h_{2v} \\ \vdots & \vdots & \vdots \\ h_{u1} & h_{u2} \cdots & h_{uv} \end{pmatrix} \quad (3.4)$$

Step 3: Determining ratio system as mentioned by (3.5):

$$h^*_{ij} = \frac{h_{ij}}{\sum_{i=1}^{u} h^2_{ij}} \quad (3.5)$$

j= (1, 2…n), h_{ij} is a non-dimension number that ranging from 0 to 1, that shows normalized performance of any alternative about a precise criterion.

Step 4: Computation of Performance value of criteria

Here, h^*_{ij} values are summed up in case of beneficial criteria and detracted for non- beneficial criteria. The optimization problem is modified as shown in equation (3.6):

$$R_i = \sum_{j=1}^{l} w_j * h^*_{ij} - \sum_{j=l+1}^{m} w_j * h^*_{ij} \quad (3.6)$$

In 3.6, l represents count of criteria (increased for beneficial classes) and m represents number of criteria (minimized for non-beneficial classes). R_i denotes performance value of i^{th} alternate with regard to overall criteria.

Step 5: The performance values 'R_i' may be +ive or -ive based on the total number of beneficial and non-beneficial measures existing in the problem. The raking is done based on the values of performance score of each choice. The alternatives are categorized as best or worst on the basis of high 'R_i' and low 'R_i' value correspondingly.

Empirical study

The proposed model calculates criteria weights using AHP method by consolidating judgements of several specialists work in the domain. Secondly, MOORA method is applied to calculate judgement scores based on ratio system for ranking the four OSCMs.

4.1 Problem statement and construction of decision hierarchy

The present work is dealing with an oil spill cleaning selection problem that consists of 4 OSCMs namely skimmer, sorbent, dispersant and magnetic nano-composite which is selected based on Economics of cleaning (EC), Oil absorption capacity (OC), Response time (T) and Spill position and size (SS) as placed in the level-2. In level-3, the alternatives are arranged connecting with all criteria as shown in Figure 2.

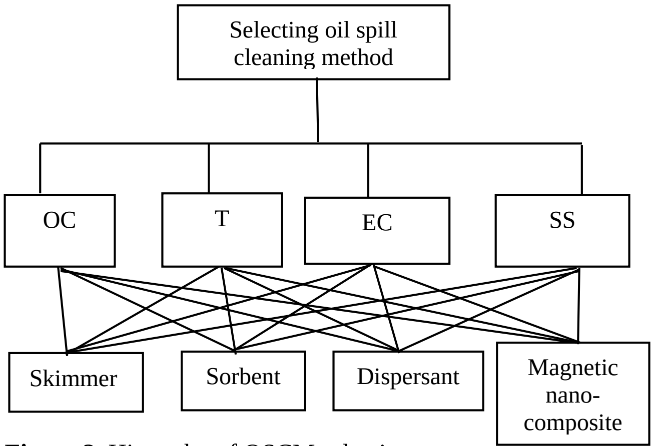

Figure 2. Hierarchy of OSCM selection

Calculation of weights by AHP

The proposed model starts with application of AHP by collecting the judgements from the experts who are familiar and expertise in aquatic eco-system, environmental engineering field, engineers with multi-domain expertise and naval institutions. The computational procedure of AHP is made simpler with EXCEL program which computes the weights of the parameters by means of the scores assigned by experts and Saaty's scale. The performance statistics of four OSCMs are depicted in Table 2.

Table 2. Decision matrix for Oil spill cleanup methods

OSCMs	Economics of cleaning (EC)	Oil absorption capacity (OC)	Response time (T)	Spill position and size (SS)
Skimmers	9	7	7	7.5
Sorbents	7	8	5	8
Dispersants	6	8.5	4.3	8.5
Magnetic nano-composites	8	8.5	4.8	7

The decision matrix dimension is 4x4 and the weights are calculated by following the steps explained in 3.1. The criteria weights computed are presented in Table 3 and from the table, weight of OAC is higher than other criteria and thus 43% weightage is to considered for this criterion. Based on the steps explained in 3.1, consistency ratio is calculated using AHP method. The CR score is 0.07 which is below 0.1. Hence, it is concluded that the consistency of judgement matrix is quite acceptable. The weights of remaining criteria are computed and depicted in the table 3:

Table 3. Weights of selection parameters

Parameter	Economics of cleaning (EC)	Oil-absorption capacity (OC)	Response time (T)	Spill position and size (SS)
Weight	0.09	0.43	0.32	0.16

Implementation of MOORA technique to rank the alternatives

Among the selection criteria considered for this problem, OC & SS are considered as beneficial criteria (highest scores) and EC & T are non-beneficial criteria (lowest scores). The normalized decision matrix is obtained by equation 3.5 and the cell values are shown in table 4.

Table 4. Normalized decision matrix

Method	Cost effective ness	Oil absorption capacity	Response time	Spill position and size
Skimmer	0.29	0.22	0.25	0.25
Sorbent	0.21	0.28	0.18	0.32
Dispersant	0.18	0.30	0.15	0.28
Magnetic nanocomposite	0.25	0.28	0.14	0.27

Next, evaluation values are computed by Eq. 3.6 for the four cleaning methods and the same is projected in Table 5.

Table 5. Evaluation values of OSCMs

Method	R_i	Rank
Skimmer	0.027	4
Sorbent	0.097	3
Dispersant	0.114	1
Magnetic nano-composite	0.099	2

From the above data, Dispersant method has high R_i values than remaining methods due to this reason it should be given top priority. In addition to this, based on the assessment scores, the second and third rank is assigned to Magnetic nano-composites and Sorbents respectively. Since Skimmer possesses smallest assessment score, it shall be given minimum priority.

Concluding remarks and future scope

Oil spills in the oceans are a major problem affecting aquatic life, tourism and the economy. Most spills cause change in physical and chemical properties of oil. It is important to understand features like the quantity and properties of oil spills, ecological settings, atmospheric conditions and oceanic behavior, restrictions and effects on marine eco-system when choosing the suitable oil cleaning process. There must exist proper trade-off among the impact of spill and efficiency of cleaning process. This research work aims to design a combined model by means of AHP and MOORA to select the optimum OSCM. This research concentrates on analyzing the effectiveness of cleaning methods like skimmers, sorbents, dispersants and magnetic nanocomposites. It is observed that selection of the appropriate cleaning method is influenced by oil absorption capacity, economics, good response time, and leak location and size.

The decision-making hierarchy consists of problem definition, criteria and alternatives at levels from top to bottom. Weights of the parameters are calculated with AHP and the decision matrix obtained from expert scores is consistent. The standard weight is calculated as: oil absorption capacity (0.43), response time (0.32), leak area and size (0.16) and cost effectiveness (0.09). The four cleaning methods are ranked by MOORA method. According to the MOORA evaluation score, the dispersant method was found to be the best choice, while magnetic nanocomposites were found to be the second and adsorbents as the third choice. The following are the merits of using the MOORA:

- (i) Any number of criteria shall be included in the MCDM problem
- (ii) Any kind of measurable and non-measurable parameters can be included
- (iii) Calculating evaluation score with the ratio system
- (iv) Simplest calculation procedure using MS Excel
- (v) Better decision making based on preferred evaluation scores
- (vi) A better ranking model for oil spill cleanup

The possibility of combining the MOORA process with other MCDM methods should be explored to achieve better results. In addition, the selection problem must be defined in terms of many other options for cleaning methods in different marine ecosystems. A decision support system shall be developed based on the proposed AHP-MOORA method to make the decision faster and accurate.

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CONFLICT OF INTEREST STATEMENT

Authors do not have any conflict of interest, financial or academic, for publication of this work.

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