APPLICATION OF MULTI ATTRIBUTE DECISION MAKING METHODS TO RESOURCES ALLOCATION PROBLEMS

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ABSTRACT

Operation of over shared resources (water, gas, oil, and mineral reserves) has been one the most significant challenges of states. "*Fair*" and "*efficient*" national resources reallocation among stakeholders and states is a complex conflict problem that faces this fundamental question: which criteria and mechanisms should be taken into account for this reallocation? In this paper, we propose a risk-based Multi Attribute Decision Making (MADM) methodology to select the most appropriate mechanism for reallocation of the reserves of the Caspian Sea with respect to several quantitative and qualitative criteria. Caspian Sea is a sea with five claimants that border it, Azerbaijan, Iran, Kazakhstan, Russia, and Turkmenistan. The ordered weighted averaging (OWA) method is used to evaluate the effects of risk attitude of the decision makers on the final outcome in resources reallocation. Results indicate that risk-based MADM methods are well suited tools to resolve conflicts in natural resources reallocation problems.

Keywords: Natural resources reallocation, Ordered weighted averaging, Risk, Caspian Sea, Negotiation.

INTRODUCTION

"*Fair*" and "*efficient*" national resources reallocation including gas, oil, trans-boundary rivers, *etc.* among stakeholders and states is a complex conflict problem which is likely to depend not only upon economic attributes, but also upon other criteria such as socio-political and environmental criteria. Hence, application of multi attribute decision-making (MADM) methods are essential and useful in this field. MADM methods provide well-organized tools to reach consensus and to deal with conflict problems with more than one criterion, alternative and or decision maker (DM). The application of MADM methods to several aspects of conflict management in the natural resources management has been proven in many studies such as [1], [2], [3], and [4].

The Caspian Sea which is the largest inland sea on the earth, has been the subject of one of the world's most intractable disputes, involving the five littoral states of Azerbaijan, Iran, Kazakhstan, Russia, and Turkmenistan (Figure1). Before the collapse of the Union of the Soviet Socialist Republics (USSR) in 1991, the Caspian Sea was shared by Iran and the USSR and the only legal framework applicable to the status of the Caspian Sea

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was based on a series of treaties between Iran (Persia) and Russia (the Soviet Union) in 1813, 1828, 1921, 1935, 1940, and 1956. However, none of these treaties has any meaningful provisions for the division of the sea's resources [5]. After the collapse of the USSR at the end of 1991, there were five littoral states bordering the Caspian Sea.

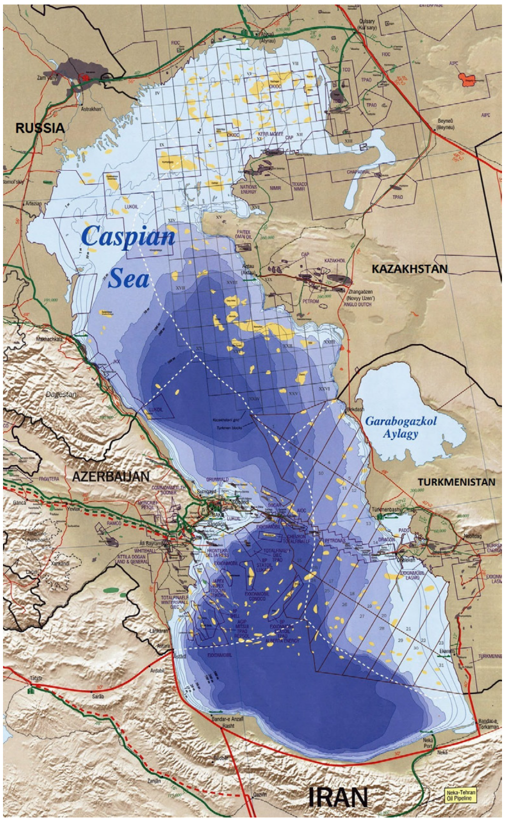

Figure 1. Oil and gas infrastructure in the Caspian Sea [6]

The last legal status of the Caspian was immediately disputed, and no division of the waters or the seabed has been agreed upon to date. In addition to the important strategic issues associated with the stalemate, energy prices are rising and the consequences of having no agreement are mounting [7]. These five states have been unable to find a solution that allows them all to exploit the sea's resources. The disputes among them remain unresolved because of the inadequate legal framework, poor delimitation, overlapping claims of ownership, and a preference for bilateral approaches [5].

There are five discussed ways during negotiations to resolve the legal status of the Caspian Sea. These ways are denoted as *C*, *Dm, De, Ds, DC* [7]:

C: Condominium status applying to both the surface and the seabed
Dm: Division based on the International Law of the Seas
De: Equal Division: 20% of the sea, and the seabed, to each littoral state
Ds : Division based on Soviet maps
DC: Division of the seabed based on the International Law of the Seas, with condominium status on the surface.

It should be mentioned that "Equal Division" indicates equal area and does not mean equal shares in the sources. Table 1 shows the ordinal preferences orderings of the states over the alternatives and their relative weights [7], [8].

Table 1. *The ordinal preferences of the states and their relative weights* [7], [8].

Regional States	*Relative Weight*	*Dm*	*C*	*Ds*	*De*	*DC*
Azerbaijan (A)	4.91	2	5	1	4	3
Iran (I)	4.55	3	1	5	2	4
Kazakhstan (K)	4.48	2	4	1	5	3
Russia (R)	9.98	4	1	3	5	2
Turkmenistan (T)	3.26	3	5	2	1	4

The general objective of this study is to select the most appropriate legal status of the Caspian Sea among a set of alternatives. One of the remarkable parameters in negotiations is DM's risk level. Risk and its effects on the final results are obviously significant for this complex conflict problem that should be considered in analyzing. In this paper, we use OWA risk-based MADM method to select the most appropriate legal status to divide the resources of Caspian Sea by considering different risk level of DMs.

METHODOLOGY

OWA operator

An *aggregation operator* is a function $F: I^n \to J$ where I and J are real intervals, $I, J \neq \phi$. I denotes the set of values to be aggregated and J denotes the corresponding result of the aggregation [9]. OWA operator was introduced in 1988 by Yager [10–12]. An OWA operator is an aggregation operator with an associated vector of weights $\sum_{i=1}^{n} w_i = 1, w \in [0,1]^n$ such that:

$$F_w(x) = \sum_{i=1}^{n} w_i . b_i \quad , \quad x \in I^n \tag{1}$$

with b_i denoting the ith largest element in $x_1; \ldots; x_n$.

An important characteristic of OWA operator is that we can produce solutions based on decision makers' risk level. In other words, OWA is able to involve risk management in providing the best selection considering subjective characteristics of decision-makers and evaluates the effect of being risk aversion/risk prone DMs on decision making process.

One significant issue in the using of OWA aggregation operator is how to obtain the associated weighting vector. There are various approaches to calculate the weighting vector w. One of the most used approaches is that the weighting vector w is calculated by using linguistic quantifiers. In this method which was introduced by Yager, the weighting vector is calculated as follow [11], [13]:

$$w_i = Q(\frac{i}{n}) - Q(\frac{i-1}{n}) \quad , \quad i = 1, \ldots, n \tag{2}$$

Q is a linguistic quantifier that represents concept of fuzzy *majority*. Zadeh (1983) introduced the concept of linguistic quantifiers [14]. The concept of fuzzy quantifiers enhances the conversion between natural language and formal mathematical expressions that can be used in multi criteria decision making problems. To calculate the function Q, the equation (3) having many applications in calculation of membership function of a quantifier can be used which α is optimistic coefficient [13]. If α >1, it indicates a pessimistic or risk-averse decision-maker. α<1, represents an optimistic or risk-prone decision-maker and α=1 means the decision-maker is neutral.

$$Q(r) = r^{\alpha}, \alpha > 0 \tag{3}$$

The behavior of the OWA operators can be described in two dimensions [15]: (1) the degree of *ORness* (or risk) and (2) *tradeoff*. The measure of *ORness* is defined as follows [10], [13]:

$$OR\ ness = \int_0^1 Q(r)dr = \frac{1}{n-1}\sum_{i=1}^{n}(n-i).w_i \quad , \quad 0 \le OR\ ness \le 1 \tag{4}$$

The degree of *ORness* indicates the position of OWA on a continuum between the AND or OR operators. There are both theoretical and empirical evidences to show that DMs with optimistic (or risk-prone) attitudes tend to emphasize good properties of alternatives while pessimistic or risk-averse decision-makers tend to focus on bad properties of alternatives [15–17]. The greater the *ORness* value, the higher level of the decision maker's optimism.

EVALUATION OF THE ALTERNATIVES

In this step, we select the most preferred alternative to reallocate Caspian Sea reserves using OWA method and considering the relative weights of states. Since the evaluation of states about alternatives is preference ordering; hence, we should firstly transform the ordering of alternatives expressed by states (Table 1) to *fuzzy preference relations* (FPR) to be able to aggregate the assessments. A fuzzy preference relation is expressed by k_{sm}^i, where $k_{sm}{}^i \subset X * X$ with membership function $\mu_{ki} : X \times X \to [0,1]$, and $\mu_{k^i}(x_s, x_m) = k_{sm}^i$, that $X = \{x_1, ..., x_n\}$ is a finite set of alternatives. Value of k_{sm}^i denotes the preference degree or intensity of alternative x_s over x_m. Here k_{sm}^i=0.5 indicates indifference between x_s and x_m, $k_{sm}^i = 1$ indicates that x_s is unanimously preferred to x_m, and $k_{sm}^i > 0.5$ indicates that x_s is preferred to x_m. It is usual to assume that $k_{sm}^i + k_{ms}^i = 1$ and k_{ss}^i=0.5 [18].

The preference ordering of the states over the legal status alternatives expressed in Table 1 are represented by O_s^i.It defines preference-ordering evaluation given by DM^i to alternative x_s. The transformation function for preference ordering mode into fuzzy preference relationship is as follow [19]:

$$K_{sm}^i = \frac{1}{2}\left(1 + \frac{o_m^i - o_s^i}{n-1}\right) \tag{5}$$

By using this function, the transformed fuzzy preference relations of the alternatives are as follow:

$$A\begin{bmatrix} & Dm & C & Ds & De & DC \\ Dm & .5 & .875 & .375 & .75 & .625 \\ C & .125 & .5 & 0 & .375 & .25 \\ Ds & .625 & 1 & .5 & .875 & .75 \\ De & .25 & .625 & .125 & .5 & .375 \\ DC & .375 & .75 & .25 & .625 & .5 \end{bmatrix} \quad I\begin{bmatrix} & Dm & C & Ds & De & DC \\ Dm & .5 & .25 & .75 & .375 & .625 \\ C & .75 & .5 & 1 & .625 & .875 \\ Ds & .25 & 0 & .5 & .125 & .375 \\ De & .625 & .375 & .875 & .5 & .75 \\ DC & .375 & .125 & .625 & .25 & .5 \end{bmatrix}$$

$$K\begin{bmatrix} & Dm & C & Ds & De & DC \\ Dm & .5 & .75 & .375 & .875 & .625 \\ C & .25 & .5 & .125 & .625 & .375 \\ Ds & .625 & .875 & .5 & 1 & .75 \\ De & .125 & .375 & 0 & .5 & .25 \\ DC & .375 & .625 & .25 & .75 & .5 \end{bmatrix} \quad R\begin{bmatrix} & Dm & C & Ds & De & DC \\ Dm & .5 & .125 & .375 & .625 & .25 \\ C & .875 & .5 & .75 & 1 & .625 \\ Ds & .625 & .25 & .5 & .75 & .375 \\ De & .375 & 0 & .25 & .5 & .125 \\ DC & .75 & .375 & .625 & .875 & .5 \end{bmatrix}$$

$$T\begin{bmatrix} & Dm & C & Ds & De & DC \\ Dm & .5 & .75 & .375 & .25 & .625 \\ C & .25 & .5 & .125 & 0 & .375 \\ Ds & .625 & .875 & .5 & .375 & .75 \\ De & .75 & 1 & .625 & .5 & .875 \\ DC & .375 & .625 & .25 & .125 & .5 \end{bmatrix}$$

The weighted transformed values are calculated as follow:

$$\overline{K}^i_{sm} = w_i . K^i_{sm} \quad , \forall s \neq m, \quad \overline{K}^i_{ss} = 0.5 \tag{6}$$

Where w_i is the normalized weights of states which was shown in Table 1 and K^i_{sm} is the transformed fuzzy preference relations of options. We have $w_{(A,I,K,R,T)}$=(0.181, 0.167, 0.165, 0.367, 0.12).

Now, the *collective fuzzy preference relation* (CFPR) to the above weighted transformed information $(\overline{K}^i_{sm})$ is found out. OWA operator and quantifier equation $Q(r) = r^{\alpha}$ are used to calculate CFPRs or to aggregate the weighted transformed values $(\overline{K}^i_{sm})$. To measure the extent to which the final value of each option is affected by risk aversion and risk proneness of decision-maker, values α=0.1(indicative of risk prone decision-maker), α=1 (indicative of neutral decision-maker), and α=5 (indicative of risk averse decision-maker) are studies. For example, the collective fuzzy preference opinion for α=0.1 is as follow:

$$\textit{collective fuzzy preference}\,(CFRP)_{\alpha=0.1} = \begin{bmatrix} & Dm & C & Ds & De & DC \\ Dm & .5 & .1477 & .1302 & .2117 & .1106 \\ C & .2841 & .5 & .2459 & .3248 & .2089 \\ Ds & .2092 & .1691 & .5 & .2522 & .134 \\ De & .1287 & .1131 & .1338 & .5 & .118 \\ DC & .2437 & .1319 & .2053 & .2868 & .5 \end{bmatrix}$$

The final aggregated value and rank of each alternative are calculated using OWA operator and $Q(r) = r^{\alpha}$ and previously used α value. The final value and order of alternatives are shown in Table 2 and Figure 2.

The comparison of results shows that the final outcome strongly depends on the risk attitude of states. The *condominium status applying to both the surface and the seabed* (C), *Division based on Soviet maps* (*Ds*), and *Division based on the International Law of the Seas* (*Dm*) methods are the most appropriate solutions for Caspian Sea resources reallocation under risk prone, risk neutral and risk averse situations, respectively. To make the final decision in determining the most appropriate method for reallocation of Caspian Sea reserves, it is necessary to analyze the problem under more different risk levels and investigate their effects on the final outcome in future studies.

Table 2. *Final values for the Caspian Sea legal status alternatives under different risk attitudes.*

Methods	*Risk Prone* (α=0.1)		*Risk Neutral* (α=1)		*Risk Aversion* (α=5)	
	Value	*Rank*	*Value*	*Rank*	*Value*	*Rank*
Dm	0.4502	4	0.1795	4	0.0474	1
C	0.4677	1	0.1876	2	0.0133	5
Ds	0.4567	3	0.1919	1	0.0352	2
De	0.4445	5	0.1591	5	0.0158	4
DC	0.461	2	0.1820	3	0.0319	3

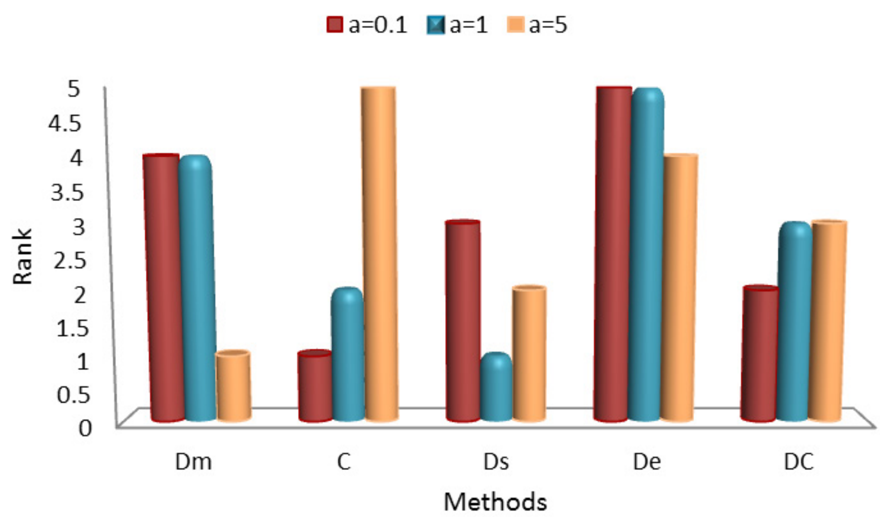

Figure 2. *Ranking of the Caspian Sea legal status alternatives under different risk levels*

CONCLUSION

The objective of this study was to represent the application of risk-based multi attribute decision making (MADM) methods in the natural resources reallocation problems such as gas, oil, trans-boundary rivers, *etc*. Planners and decision makers must be aware of creative system analysis as a powerful tool for "fair" and "efficient" reallocation. OWA method was used to select the most appropriate methods for reallocation of the Caspian Sea reserves which is common between five states: Azerbaijan, Iran, Kazakhstan, Russia, and Turkmenistan. Moreover, we evaluated the best outcome under the different risk prone, risk neutral and risk averse situations. The results reveal that the outcome strongly depends on the risk attitude of the negotiators and it may differ with respect to their risk level that should be taken into account in decision making.

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