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Resolving hydro-environmental conflicts under uncertainty using Fallback Bargaining procedures

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***Abstract*—Fallback bargaining methods seek minimizing the maximum dissatisfaction of the bargainers involved in group decision making problems. These methods are suitable for predicting the outcomes of water and environmental resources management problems where a group of stakeholders, often with competing objectives, are present. This paper intends to provide insights into one of the most important hydro-environmental disputes in California, namely the Sacramento-San Joaquin Delta problem. The Sacramento-San Joaquin Delta is a multi-benefit system which serves Californians as a major hub of water supply and is central to the ecosystem of many threatened species. The Delta is currently in crisis as a result of unsustainable water exploitation strategies. While different strategies to avoid a dramatic future for the Delta have been proposed, the stakeholders have failed to develop a consensus, given their different preference orders over the suggested strategies. This study uses Fallback bargaining procedures to predict the possible outcomes of the Sacramento-San Joaquin Delta conflict over selecting a new water exports strategy. Given the uncertainty about the performance of each given strategy, the study suggests a novel method for finding the possible outcomes of negotiations when bargainers are uncertain about their gains from the possible outcomes.**

Keywords- Fallback Bargaining; negotiations; Multi-Objective Decision Making (MODM); uncertainty; Monte-Carlo; Sacramento-San Joaquin Delta; California

I. INTRODUCTION

The California's Sacramento-San Joaquin Delta serves as a major water supply system for California and is a home to a range of native endangered and threatened species. The Delta supplies water to 25 million urban residents and roughly two million acres of farmland, and is a unique ecosystem with more than 750 species of flora and fauna [1]. Today's Delta is encountered with some serious problems, making continuation of the present governing policies a threat to its reliable and sustainable future. The water export from the Delta is an important driver of the problem, decreasing Delta's reliability. The problem exacerbates by growing urbanization, increasing agricultural demands, unreliable aged levees, floods, earthquakes, subsiding Delta islands, and climate change [2-3].

Adopting new strategies to secure the Delta against current threats and to prevent tragic outcomes for Delta's future would not be convenient, given the variety of interests in the Delta. Lund et al. [3] suggested four central water export options for solving the Delta problem: 1) Continuing the Delta exports as usual (CDE); 2) constructing a peripheral canal to convey water around the Delta (PC); 3) constructing a dual conveyance system for water transfers (DC); and 4) stopping the water exports (SE). Details of these methods are provided in [3].

To evaluate the four suggested options economic performance and environmental sustainability were suggested as the two important criteria which can represent the main interests of the Delta stakeholders [3, 4]. Table 1 indicates the performances of the suggested options under the two mentioned criteria. Cost of each alternative, the major concern for the Delta water exporters, includes the construction, maintenance, and failure costs of that alternative [5] and is considered as a good indicator of the economic performance of each option. The survival rate of fish under each alternative has been considered as the major concern of the Delta environmentalists and a reasonable indicator of the environmental sustainability performance of each water exports option.

The uncertainties in the performance ranges of the water exports alternatives together with the trade-offs between the economic and environmental performances make selection of the optimal water exports strategy challenging. This paper develops an innovative method for dealing with uncertainty in making group decisions based on Fallback Bargaining methods [6, 7]. Under Fallback Bargaining, bargainers start by indicating their preference orders over the alternatives. Then they fall back, in lockstep, to less and less preferred alternatives until they find an alternative on which all bargainers agree. This common agreement, which becomes the outcome of the procedure, maximizes the bargainers' minimum satisfaction [6]. Fallback Bargaining methods reasonably simulate the decision making process when multiple decision makers are present. Therefore, they are suitable for mathematical simulation and reliable interpretation of stakeholders' behaviors in hydro-environmental management problems which usually involve conflicts [8, 9]. This study employs 3 different Fallback Bargaining methods, namely Unanimity Fallback Bargaining, q-Approval Fallback Bargaining, and Fallback Bargaining with Impasse to find the possible resolution to the California's Sacramento-San Joaquin Delta conflict over selection of an appropriate water exports strategy.

TABLE I. PERFORMANCE RANGE OF DELTA WATER EXPORTS STRATEGIES UNDER THE THE ECONOMIC AND ENVIRONMENTAL SUSTAINABILITY CRITERIA [5]

Water Export Alternative	*Cost (Billion \$/year)*	*Fish Survival (%)*
CDE	0.55 – 1.86	5 - 30
PC	0.25 – 0.85	10 - 40
DC	0.25 – 1.25	10 – 40
NE	1.25 – 2.5	30 - 60

The paper's structure is as follows: In the next section the Delta problem is formulated as a deterministic bargaining problem with two bargainers. Fallback Bargaining methods are then introduced and applied to find the possible outcome(s) of the bargaining procedure. To ensure the reliability of the predicted outcome in face of the given uncertainties in the performance values, in section 3, a Monte-Carlo Fallback Bargaining method is suggested and applied to examine if the outcomes differ when uncertainties are involved. The paper ends with conclusions and suggestion of the most possible outcome of the Delta conflict in Section 4.

II. DETERMINISTIC FALLBACK BARGAINING

Taking performance averages is a conventional method to deal with the uncertainty in performance ranges [4, 10]. Performance averages imply how decision makers rank the alternatives on average. The following matrix indicates the decision making problem in cardinal form. Each number in the matrix indicates the row alternative's average performance under the column criterion, where each column criterion represents the main interest of one group of decision makers (the water exporters and the environmentalists in this problem).

$$\text{Performance}_{\text{cardinal}} = \begin{array}{c} \\ \text{CDE} \\ \text{PC} \\ \text{DC} \\ \text{SE} \end{array} \begin{array}{c} \begin{array}{cc} \text{Cost} & \text{Fish Survival} \end{array} \\ \begin{pmatrix} 1.205 & 17.5 \\ 0.550 & 25.0 \\ 0.750 & 25.0 \\ 2.000 & 45.0 \end{pmatrix} \end{array}$$

Since Fallback Bargaining methods can determine the outcomes based on ordinal information, the above cardinal matrix can be simplified to the following ordinal matrix illustrating stakeholders' preferences over the possible Delta exports alternatives. In the ordinal preference matrix, a higher rank of an alternative under a criterion indicates its more desirability for a stakeholder represented by that criterion.

$$\text{Preference}_{\text{ordinal}} = \begin{array}{c} \\ \text{CDE} \\ \text{PC} \\ \text{DC} \\ \text{SE} \end{array} \begin{array}{c} \begin{array}{cc} \text{Cost} & \text{Fish Survival} \end{array} \\ \begin{pmatrix} 3 & 3 \\ 1 & 2 \\ 2 & 2 \\ 4 & 1 \end{pmatrix} \end{array}$$

Considering the Delta problem as a bargaining problem in which stakeholders bargain based on their preferences over the water exports alternative, Fallback Bargaining methods can be applied for predicting the plausible outcome(s) [7]. Stakeholders always begin the bargaining process with their most preferred alternatives. However, to develop a compromise they have to fall back in lockstep to their less preferred alternatives until reaching the alternative with sufficient support [6]. The definition of sufficient support varies based on the Fallback Bargaining method applied. Next, different Fallback Bargaining methods are defined and applied to the deterministic Delta decision making problem, represented by the ordinal preference matrix, developed based on average performance values.

A. Unanimity Fallback Bargaining

Unanimity Fallback Bargaining (FB) [6] selects the alternative(s) which receive all stakeholders' support in the highest possible quality as the possible bargaining outcome(s). The selected outcome(s) may differ if a decision rule other than unanimity is used. While the outcome of Unanimity FB is not necessarily unique, it is always Pareto-optimal. The alternative(s) selected under Unanimity FB is at least middling in each bargainer's ranking order [6]. The compromise set under the Unanimity FB method exactly include the alternatives which maximizes the minimum satisfaction over all bargainers [6, 7].

Table 2 indicates the quality of support for the water exports alternatives in the Delta problem. In this problem SE is the most preferred alternative by the Environmentalists. In the second level of preference, they prefer PC and DC equally. On the other hand, the water exporters place PC at their first preference level and DC at their second preference level. Therefore, alternatives PC and DC are suggested as the most possible outcomes of the Delta bargaining problem under the Unanimity FB method.

B. q-Approval Fallback Bargaining

q-Approval FB [6] selects the alternative(s), receiving the support of q stakeholders ($1 \leq q \leq n$, where n is the number of bargainers), at the highest possible level, as the most possible bargaining outcome(s). In fact, this method maximizes the minimum dissatisfaction of q most satisfied bargainers. Under q-Approval FB, ties are broken according to the quality of support [6]. Thus, when more than one alterative receive the minimum required level of support at a given preference level, the alternative with the strongest quality of support (highest number of supporters) is the winner under q-Approval FB.

TABLE II. THE NUMBER OF SUPPORTS FOR EACH ALTERNATIVE AT DIFFERENT PREFERENCE LEVELS

Alternative	*1st*	*2nd*	*3rd*	*4rth*
CDE	0	0	2	2
PC	1	2	2	2
DC	0	2	2	2
SE	1	1	1	2

In the Delta problem q can be either 1 or 2. When q= 1, the alternative(s) which receive at least one support at the highest quality should be selected based on 1-Approval FB. SE is the most preferred alternative for the environmentalists and PC is the best alternative for the water exporters (Table 2). Therefore, SE and PC are the most likely outcomes of the Delta problem under the 1-Approval FB method. In this case, since both alternatives have the same quality of support (1 supporter) there is no need for breaking ties and both alternatives should be selected as winners.

When q= 2, the alternative(s) which receive at least two supporters at the highest possible quality should be selected based on 2-Approval FB. Since n= 2, receiving more than 2 supporters is not possible here. When q= n= 2, the q-Approval FB is similar to Unanimity FB. Thus, PC and DC are the most likely bargaining outcomes under the 2-Approval FB method.

C. *Fallback Bargaining with Impasse*

Permission to "Impasse" introduces a new alternative (IMP) to the bargainers, beside the other alternatives to agree upon. Impasse could be an outcome itself, foreclosing any possibility to develop a compromise [6]. In fact, Impasse is defined as an arbitrary point below which a bargainer would not descend because he prefers "no agreement" to agreement over any less preferred (lower level) alternative [6, 7]. Therefore, when a stakeholder realizes that descending from a specific alternative is not beneficial, he selects IMP or no agreement. IMP can be ranked at any level after the most preferred alternative (starting from the second preference level). After letting the parties add IMP to their preference matrices, the problem can be solved using Unanimity FB or q-Approval FB. In fact, the Fallback Bargaining with Impasse method produces a set of Pareto-optimal alternatives, or IMP, that maximize the minimum satisfaction of the bargainers. However, with addition of IMP, the selected Pareto-optimal excludes certain alternatives that, without IMP, might have been considered satisfactory [6].

In the Delta problem, there is no reliable information about how the stakeholders might rank IMP in their preference matrix. Therefore, it is assumed that IMP may be placed at any level lower than the first preference level. Since IMP can rank from 2 to 4 under the fish survival criterion and 2 to 5 under the cost criterion in this problem, 12 different ordinal preference matrices can be generated to represent the Delta decision making problem based on different possible combinations of the preference orders of the two bargainers over the 5 possible alternatives under consideration (CDE, PC, DC, SE, and IMP).

Here, the most likely outcomes of the 12 generated problems (matrices) were solved using the Unanimity FB method. Table 3 shows the results of the analysis of the Delta bargaining problem under the FB with Impasse. Assuming that the most likely outcome(s) under the FB with Impasse method are those which have the highest chance of being selected, PC (selected 11 out of 12 times) and DC (selected 9 out of 12 times) are suggested as the most likely bargaining outcome when Impasse is permitted.

TABLE III. LIKELY OUTCOMES OF THE DELTA BARGAINING PROBLEM UNDER THE FALLBACK BARGAINING WITH IMPASSE METHOD

Alternative	Probability of Being an Outcome (%)
CDE	0
PC	92
DC	75
SE	0
IMP	17

TABLE IV. LIKELY OUTCOMES OF DETERMINISTIC FALLBACK BARGAINING

Fallback Bargaining Method	Identified Likely Outcome
Unanimity FB	PC, DC
1-Approvall FB	PC, SE
2-Approvall FB	PC, DC
FB with Impasse	PC, DC

Table 4 summarizes the results for analyzing the deterministic bargaining game under different Fallback Bargaining methods applied so far. According to this table, PC and DC are the most likely bargaining outcomes. The 1-Approval FB may not be a reliable method in predicting the outcome of the Delta bargaining game as it does not simulate the bargaining process realistically. In fact, in a bargaining problem with two bargainers with equal powers, reaching an agreement is possible only when both parties support the final resolution. Therefore, SE is not likely to be the final outcome of the Delta bargaining problem.

III. STOCHASTIC FALLBACK BARGAINING

Although taking performance averages can simplify the analysis, the final results based on the average values may not be reliable due to ignorance of uncertainty. In fact, average taking can be a source of uncertainty by itself because of omitting a wide range of [4]. To deal with the uncertainty in performance ranges of the alternatives under the decision criteria [4] suggested a Monte-Carlo game theory approach under which random preference matrices are first generated based on a Monte-Carlo selection method and then are solved based on non-cooperative game theoretic concepts. Similarly, a Monte-Carlo social choice making method was suggested by [10] to account for uncertainty in performance ranges. Based on the same concept, here a Monte-Carlo Fallback Bargaining approach is developed to account for the uncertainty in the decision making problem's input variables.

In this problem in each round of Monte-Carlo selection random numbers are selected out of the performance ranges of each alternative under each criterion, using a continuous uniform probability distribution as done in [4] and [10]. Selection occurs numerous times (here 60,000 rounds of selection). In each round 4 equally probable numbers are generated out of the performance ranges of the 4 alternatives under the fish survival criterion and 4 numbers out of the performance ranges under the cost criterion. Therefore, in every round of selection, 8 numbers are selected (total number of selections= 480,000) to generate one deterministic bargaining problem, represented by an ordinal preference matrix. Each generated deterministic bargaining problem is then solved using the introduced Fallback Bargaining methods to find the possible bargaining outcome(s) for that generated Delta bargaining problem. If N is the total rounds of random selections (here N= 60,000), and n_i represents the number of times that alternative i is found as the likely outcome of the bargaining game under a given Fallback Bargaining method, ni/N indicates the likelihood of alternative i being the outcome of the bargaining problem under that Fallback Bargaining method.

Table 5 indicates the results of the Monte-Carlo Fallback Bargaining analysis of the Delta problem. This table shows the probability of selection as the final outcome for each water exports alternative under different Fallback Bargaining methods. Based on this table, one can find that the summation of selection probabilities of the alternatives under a given Fallback Bargaining method may exceeds one. That is because of the fact that, in every analysis round, the selected outcome by a Fallback Bargaining method is not necessarily unique.

According to Table 5, PC is the most likely outcome for the Delta bargaining problem. After PC, alternative DC has the highest chance of being the bargaining outcome. Although alternative SE has a high likelihood of being the final outcome under the 1-Approval FB method, its selection probability is minimal under the other Fallback Bargaining methods. Furthermore, due to fact the 1-Approval FB method is not a reliable method in predicting the Delta bargaining game, SE cannot be considered as a likely outcome. The probability of IMP being the final bargaining outcome is not significant. Therefore, "no agreement" is not very likely in the Delta bargaining problem and the parties are expected to agree on one of the suggested water exports alternatives eventually.

TABLE V. LIKELY OUTCOMES OF STOCHASTIC FALLBACK BARGAINING

Stochastic Fallback Bargaining	**Probability of Being an Outcome (%)**				
	CDE	***PC***	***DC***	***SE***	***IMP***
Unanimity FB	14	55	50	1	-
1-Approvall FB	3	69	33	90	-
2-Approvall FB	1	55	50	1	-
FB with Impasse	1	48	42	1	16

IV. CONCLUSIONS

To explore the most likely outcome of the Sacramento-San Joaquin's Delta decision making problem in which parties have to agree over an alternative for continuation of water exports from the Delta, this problem was modeled as bargaining procedure in which two bargainers, representing the main Delta interests, have to reach an agreement over a water exports alternative. The problem was solved under two different approaches, namely the deterministic Fallback Bargaining and the stochastic Fallback Bargaining approaches. Under the first approach, performance averages were used as the required input information to solve the Fallback Bargaining problem. To ensure the reliability of the obtained results under the deterministic approach, a stochastic Fallback Bargaining approach was then adopted for better representation of uncertainties in the decision making process by combining a Monte-Carlo selection with Fallback Bargaining methods.

Both approaches identified building a peripheral canal as the most likely outcome of the Delta problem. After peripheral canal, building a dual conveyance system is the most likely outcome of the Delta bargaining problem. Neither continuation of Delta exports as usual, nor stopping the water exports is likely for taking the Delta out of crisis. When parties were allowed to choose "no agreement" as an additional option, this option was not found very likely.

These results are consistent with findings of [4] and [10] who used game theory solution concepts and social rules, respectively, for determining the possible resolution to the Delta conflict. The consistency approves the reliability of Fallback Bargaining methods in finding the optimal outcomes of multi-criteria multi-decision-makers problems.

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