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Flood Mitigation Planning using Promethee

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Abstract: The paper demonstrates the implementation of Promethee, one of the most efficient Multicriteria Decision Analysis (MCDA) outranking techniques in order to achieve the optimal flood mitigation plan for a river basin. The criteria used to rank alternatives consist of the cost of flood defence works and their maintenance cost (quantitative assessment) together with environmental and socioeconomic factors representing flood impacts to the environment and the society of the river basin district (qualitative assessment). Alternative scenarios are formulated and evaluated by different stakeholders. The Promethee method is used for aggregating the various criteria and various stakeholder evaluations and proposing the final ranking of the alternative plans.

Key words: Flood mitigation, multicriteria decision making, Promethee, stakeholders, sensitivity analysis.

1. INTRODUCTION

Floods are extreme phenomena causing significant damages to people environment. Mediterranean countries are heavily affected by floods mainly in Coastal Areas which are densely populated.

Various flood defence projects have been constructed in coastal cities to prevent severe damages from floods based mainly on economic and technical criteria. The design discharge of flood mitigation projects is traditionally estimated through the “return period” approach which in its turn is estimated empirically.

During the last 3-4 decades selected studies of flood mitigation projects were based on the relationship between flood magnitude and anticipated damage. There is a vast literature on this subject the review of which is out of the scope of this paper.

Recent approaches on flood defence planning recognize the fact that these types of projects interact with various sectors related to society economy and environment of a wider area and not only the area which is affected directly. Therefore several criteria should be used for reflecting the sectors affected.

Furthermore decisions on the magnitude of the projects and the alternatives which seem viable, involve different groups which are expected to have different opinions about the projects. At the strategic level therefore the decisions on the flood defence of an area seem to depend on many criteria and many stakeholders.

Multicriteria methods which can incorporate both various criteria and various evaluations performed by interested groups seem to be the most appropriate methods for the process of decision making at the strategic level.

It is the aim of this paper to implement one of the most powerful outranking techniques, the method of Promethee, for ranking the flood mitigation plans.

2. BASIC NOTIONS

In the recent years several decision aid methods or decision support systems have been proposed to help in the selection of the best compromise alternatives. In this paper we give emphasis on the Promethee – Gaia methodology for treating multicriteria problems.

Multicriteria problems shares common characteristics such as the presence of multiple and conflicting criteria, different units of measurement among the criteria and the presence of different alternative policies (Loucks et al., 1981; Goicoechea et al., 1982; Bogardi and Nachtenebel, 1994; Pomerol and Romero, 2000.

Several authors such as Roy (1996), Pomerol and Romero, 2000, D. Bouyssou (1984), R. Keeney (1992), Janssen (1994) and Duckstein et al. (1979) have analysed how to model a real – world multicriteria situation. Promethee methodology treats matrices similar to that of Table 1, where $a_1, a_2, \ldots a_n$ are (n) potential alternatives and $f_1, f_2 \ldots f_k$ are (k) evaluation criteria. Each evaluation $f_j(a_i)$ must be a real number. Such a matrix can model many real–world applications.

Table 1. Evaluation matrix for Promethee

	$f_1(.)$	$f_2(.)$	……..	$f_j(.)$	……	$f_k(.)$
a_1						
a_2						
…..			$f_j(a_i)$			
a_i						
…..						
a_n						

The structure of the matrix is achieved progressively and many kind of arguments could be considered such as normative, constructive, descriptive and prescriptive arguments.

Requisites can be formulated for a multicriteria procedure. Indifference or gradual degrees of preference have to be associated to the deviations observed between the evaluations. Partial rankings (including the natural avowal of incomparable alternatives) and complete rankings (without the natural avowal of incomparable alternatives) should be obtained.

Promethee requests additional information. For each criterion a specific preference function must be defined. This function is used to compute the degree of preference associated to the best action in case of pair wise comparisons.

Promethee and Gaia calculate positive and negative preference flows for each alternative. Decision Lab software has been developed to provide ways to handle easily complicated matrices.

3. THE PROMETHEE MULTICRITERIA METHOD

Based on these assumptions we laid out the evaluation table with the attribution of alternative actions (for all different groups) on the five criteria. This was realized with Decision Lab 2000 – Executive Edition, a productivity software that helps to find the best solution to problems with conflicting decisions. It is based on the methods PROMETHEE and GAIA developed at Brussels Free University (Brans et al., 1976). It is a formula which helps organizing the criteria, weighing their importance and structuring the preferences. Once the table is set up, Decision Lab compares all actions two – by – two and ranks them from best to worst. Through the use of scenarios, it gives the possibility to analyze the multiple points of view and compare and aggregate the varying perspectives of different decision – makers.

3.1 Structure of the preferences

In most decision problems, not all criteria are considered equal; some are more important than others. The importance given to a criterion is specified by a weight. The criterion weight is a positive value, independent from the scale of the criterion: the larger that value the more important the criterion.

Every decision maker gives its weight to every criterion, structuring in this way its preferences. As each criterion is measured on a specific scale, the methodology used asks to associate to each criterion a preference function. Six different types of preference functions are available in Decision Lab: U – Shape, V - Shape, Usual, Level, Linear and Gaussian. In this paper is selected a "linear" preference function for quantitative criteria and a "level" preference function for the quantitative.

For each criterion, two additional parameters are specified: the indifference threshold Q and the preference threshold P.

The indifference threshold is the largest value that you consider negligible when comparing two actions on a single criterion. The preference threshold is the smallest value that one considers as decisive in the comparison of two actions: any lower value will introduce some hesitation in the preference that anyone can express. In our case every decision maker determined the indifference and preference thresholds for every criterion as percentages. It is assumed that percentages of indifference and preference thresholds are the same for all decision makers.

Every decision maker applying the method of pairwise comparison of actions and using the preference functions and the weights defined by him, is looking for the best alternative choice. For our case this was realized with Promethee and 2 rankings and GAIA plane.

Promethee 1 is a partial ranking. This means that it is based on strongly established preferences only. As a consequence, not all actions can be compared one–to–one. On the contrary Promethee 2 is a complete ranking: all the actions are ranked from the best one to the worst one, leaving no incomparable pair of actions. It is based on a numerical rating of the actions (called the Φ score).

GAIA plane provides the decision maker with a comprehensive graphical image of the decision problem and it thus a descriptive complement to the Promethee rankings.

3.2 Preference flows

Using the preference functions, we can compare systematically each action one– to–one with the others. We now need a way to summarize the results of all comparisons. For this purpose, preference flows are computed:

The positive flow (Φ+) of an action is the preference degree with which this action is preferred on average over the other actions. The larger the positive flow, the better the action.

The negative flow (Φ-) of an action is the preference degree with which the other actions are preferred on average to that action. The smaller the negative flow, the better the action.

The net flow (Φ), also called the Phi score, of an action is the balance between Φ+ and Φ- (Φ = Φ+ -Φ-). The larger the net flow, the better the action.

Both the positive and negative flows can be used to rank the actions from the best one to the worst one. As the two flows are based on different approaches, they usually lead to two different rankings.

The Promethee I partial ranking is defined as the intersection of the Φ+ and Φ- rankings. The Promethee II compete ranking can be used in such a case. It is directly based on the net flow Φ.

3.3 Gaia plane

GAIA is a descriptive complement to the Promethee methods. It makes use of the Principal Components Analysis method, which is popular in multivariate data analysis.

A principal components analysis is applied on the net preference flows computed separately for each criterion. The use of the preference functions acts as a normalization of the data. The GAIA plane corresponds to the two first principal components, which ensures that a maximum quantity of information is available in the plane. The elements of the problem are meaningful as follows:

- Criteria are represented by axes. Both the orientation and the length of the axes are important.
- Axes oriented in similar directions correspond to criteria that are in general agreement. Axes oriented in opposite directions correspond to conflicting criteria. Longer axes correspond to criteria for which more important deviations have been observed.
- Actions are represented by shapes. The proximity between the shapes indicates actions with similar profiles. Conversely, shapes that are apart correspond to very different actions.
- The weights of the criteria are represented by a separate axis, named the Pi decision axis. This decision axis shows the kind of compromise solution that will be proposed by Promethee. Its orientation emphasizes which criteria are predominant and which are possibly neglected.

3.4 Action profiles – Stability intervals

Action Profile is a graphical representation of the values of the unicriterion net preference flows for an action. Each bar corresponds to a criterion. Positive values denote good performance and negative values bad performance. For every alternative strategy there is a graphical representation of the performance to every criterion, taking into consideration the different weights. From the program Stability Intervals we can see the procedure that analyses the impact on the results of modifications of the weights of the criteria. Applying Walking Weights Program we can have a visual interactive weight sensitivity analysis procedure.

4. PROBLEM DESCRIPTION AND FORMULATION OF ALTERNATIVE STRATEGIES

As application of the presented methodology the flood mitigation plans for Kamaras Torrent basin were considered. Kamaras is a small torrent outskirts of Megara, a town not very far from Athens. The downstream plain is an agricultural area entirely cultivated with high productivity of fresh vegetables and fruits. Several floods over the last two decades have destroyed the entire yield production causing also damages to houses and the infrastructure of the area.

Several studies were performed to formulate flood defence systems for the area. The major obstacle to implement easy solutions to the flood problem is the fact that the national road cross the torrent perpendicularly and doesn’t leave enough openings for routing the flood flow.

In an attempt to demonstrate the proposed methodology a rather crude description of viable scenarios is attempted here:

Do nothing scenario (A_0)

Floods will be occurring as in the past and their anticipated damage will be estimated. No infrastructure construction is expected and no cost for the new projects is considered. However an operational and maintenance cost should be considered.

First scenario (A_1)

The scenario refers to the training of the torrent with its flood discharge, for return period T = 50 years, ranging from Qmax = 140m^3/s at the end of the first major watershed to Qmax = 220 m3/s at the mouth of the entire basin (Fig 1). The total length of the main stream is 11.25 km whereas several other branches of contributing streams with smaller design discharges (with about the same total length) are trained and routed through different bridges of the national road. Trapezoidal and double trapezoidal sections were proposed to be constructed by gabions and small closed orthogonal sections by concrete. The plan also comprises of constructing supplemental protection walls and other safety constructions. In an attempt to estimate the cost of the implementation of this plan the following figures where derived:

Construction of reclamation works	31.950 M euros
Cost of additional supplemental works	1.050 M euros
Expropriation cost	1.128 M euros
Annual Operation and Maintenance cost	1.278 M Euros

Therefore the total initial cost for the implementation of the plan is 34.128 MEuros whereas after discounting the total yearly cost is 2.270 + 1.278 = 3.548 MEuros/yr.

A flood mitigation dam is proposed at the outlet of the major watershed (point 4 in Fig. 1). The dam has the capacity of 1.7 Mm^3 and for design flood volume of 3.6 Mm^3 decrease the 50 year peak flood discharge from 140 m^3/s to 50 m^3/s.

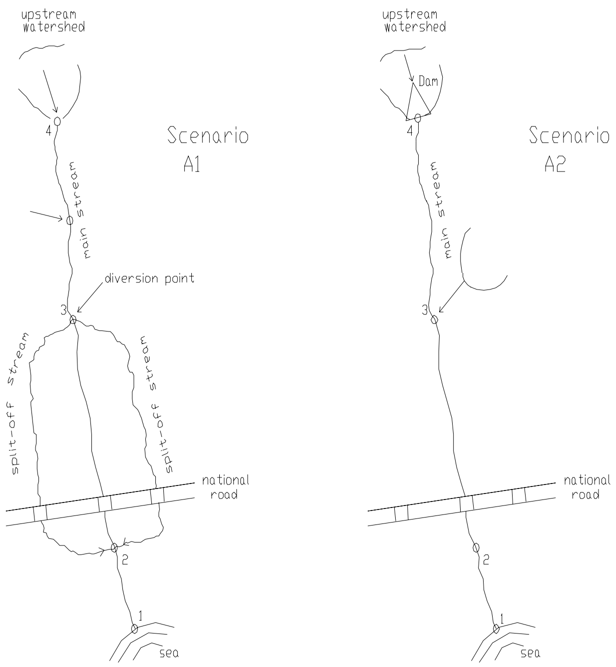

Figure 2. *Schematic representation of scenarios A1 and A2 for Kamaras flood mitigation.*

Second Scenario (A_2)

Dam Construction	7.337 M Euros
Construction of Reclamation Works	19.250 M Euros
Expropriation Cost	1.020 M Euros

Therefore the total initial cost for the implementation of the scenario is 31.457 M Euros.

Also the yearly Operational and Maintenance (O&M) cost is estimated as 1.364 M Euros.

Finally the total yearly cost after discounting and adding the O&M cost becomes 2.092 + 1.264 = 3.456 M Euros/yr.

From the above short presentation of the three viable scenarios and the calculation of the corresponding costs it is concluded that the decision cannot be taken only with a single objective which is the minimization of cost. It is necessary therefore to utilize more criteria. For simplicity reasons only the environmental and the socioeconomic criterion associated with each scenario are also examined. Flood anticipated damage is incorporated in the socioeconomic criterion

Furthermore although the cost for implementing each scenario as it is calculated previously is generally accepted by all interested parties, the other criteria are differently evaluated by each party depending on their interests and their objectives.

In the case of the above application four different stakeholders are involved; The Ministry of Environment and Public Works, The Local Authority, The Farmers Union and the Ecological NGOs in the area. Their evaluations are presented in Table 2. It should be noted that their evaluations are qualitative for environmental and socioeconomic criteria due mainly to the uncertainty of evaluations. On the contrary numerical evaluations were made for the criterion of total cost. As far as qualitative scale is concerned a 5-pointed scale is chosen, where 1 means Very Low, 2 Low, 3 Moderate, 4 High and 5 Very High.

It is important to note that using Promethee the stakeholder views were considered as having the same weight. However the stakeholders give different weights to the various criteria dependent on their interest. The weights attributed to the criteria by each stakeholder appear in the last column of Table 2. Finally the objective of each criterion used is to minimize total cost, environmental and socioeconomic criterion. The information gathered and was used by the presented methodology are in Table 2.

From the reports of the program (Promethee Partial and Complete Rankings, Gaia plane and Stability Intervals) the choice of Flood Dam construction seems to be the best solution in almost all cases.

As can be seen from Gaia plane in Figure 2, the solution A1 is good on the criterion of Socioeconomic criterion and A2 is better for environmental criterion. The axis points towards Flood Dam which is ranked first in the two Promethee rankings corresponds to a solution weak on criteria Total Cost and Environment.

Table 2. Evaluation of the criteria by the stakeholders

Stakeholders	Scenarios			Criteria	Weights
	A0	A1	A2		
Ministry	0.5	3.548	3.456	Total Cost	35%
	High	Very Low	Moderate	Environmental	30%
	High	Low	Very Low	Socioeconomic	35%
Municipality	0.5	3.548	3.456	Total Cost	25%
	High	Very Low	Moderate	Environmental	35%
	High	Low	Very Low	Socioeconomic	40%
Farmers' Union	0.7	3.548	3.456	Total Cost	20%
	High	Very Low	Moderate	Environmental	30%
	High	Low	Very Low	Socioeconomic	50%
Ecological NGOs	0.7	3.548	3.456	Total Cost	10%
	High	Very Low	Moderate	Environmental	50%
	High	Low	Very Low	Socioeconomic	40%

5. CONCLUDING REMARKS

Flood control plans cannot be evaluated from a single point of view. The technical performance of these measures, in terms of preventing inundation and the resulting damage, should be weighted against social and environmental benefits which are important for an overall appraisal of the acceptability of each alternative. For evaluating each alternative a systematic way for deriving the views of all the stakeholders should be conceived. As French (1988) says: 'despite our natural inclination to believe in the ability of the human mind to make well-considered judgments and decisions, much evidence has been accumulated by many psychologists to make such a belief untenable. It appears that unguided, intuitive decision making is susceptible to many forms of inconsistency'.

The Promethee multicriteria approach which was used in this work for evaluating flood control measures proved to be appropriate, flexible and sufficiently broad to be applied to similar environmental problems. The advantage of Promethee for decision aid is not limited therefore to its technical ability as aiding in the construction of single value functions and the weighting of criteria. The ultimate goal of Promethee is therefore to facilitate the systematic process of learning about the implications of flood problems and the viable mitigation alternatives, by enabling people to think about their preferences from several points of view.

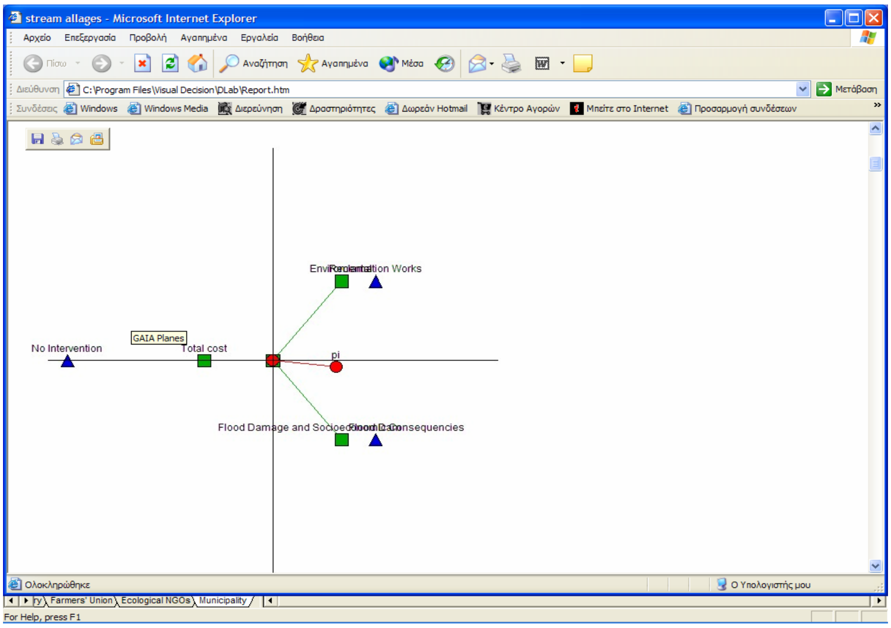

Figure 3. Gaia Plane Report

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