MULTIPLE CRITERIA DECISION MAKING USING VIKOR METHOD. APPLICATION IN IRRIGATION NETWORKS IN THE THESSALONIKI PLAIN

ZORMPA D.[1], TZIMOPOULOS C.[1], EVANGELIDES C.[1] and SAKELLARIOU M.[2]

[1]Laboratory of Hydraulics and Environmental Management, Aristotle University of Thessaloniki, 54124, Greece, [2] University of Thessaly, Department of Agronomy, Volos, 38354, Greece
E-mail: dzormpa@yahoo.gr

ABSTRACT

A multicriteria model is developed for analyzing the planning strategies for reducing future social, economic and environmental costs. The developed multicriteria decision-making procedure consists of generating alternatives, establishing and ranking criteria, assessing criteria weights, and application of the compromise ranking method.

In the present paper the Multiple Criteria Decision Making (MCDM) is applied, using compromise programming and specific the VIKOR method, in order to obtain the optimal irrigation network among a finite number of networks in the area of Thessaloniki plain.

The method VIKOR is applied here to determine compromise solution with noncommensurable and conflicting criteria including economic, environmental and social criteria. It focuses on selecting and ranking from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision makers to reach a final decision.
The VIKOR method is based on $L_{1,j}$ *and* $L_{\infty,j}$ norms, where $j = 1, 2, ..., J$ is the number of alternatives. The solution norm Q_j is introduced as a linear combination of the $L_{1,j}$ *and* $L_{\infty,j}$ norms and the final solution is min Q_i, where $\min L_{1,j}$ represents the maximum ‘‘group utility’’ (majority rule) and $\min L_{\infty,j}$ represents the minimum individual regret of the ‘‘opponent’’.

As an application a finite number of networks in the area of Thessaloniki plain is selected for obtaining the optimal irrigation network .The networks should be graded for certain evaluation criteria in order to be incorporated in the Economic Plan of the General Land Reclamation Organisation (G.L.R.O.) of Thessaloniki – Lagadas. The criteria have been selected for each alternative and as optimal solution the network satisfying mostly the selected criteria was considered. In the present paper, the method of the Analytic Hierarchy Process was applied, which was introduced in 1980 by Saaty. This method was applied for the alternative proposals, as well as for the weights for the determination of the weights, in order to objectify the weights as much as possible.

Keywords: Multi-criteria analysis, compromise programming, VIKOR method, Thessaloniki plain, irrigation networks, A.H.P..

1. Introduction

Land and waters in the world are under increasing pressure from the continuous growth in demand for many different purposes, and the allocation of water in the river basin is a complex management problem, with conditions that may foster conflicts. Conflict over the management of a shared water resource arises mostly because of differing objectives among different interest groups.

The agricultural sector in Greece is the largest water consumer and essentially it has the lion's share in the management of water. All modern land reclamation projects started at the beginning of the second half of the 20th century. The organized collective irrigation networks in Greece were mainly built during the decade of 1960 (Konstantinides, 1989; Balioti, 2009). They are characterized by age but also by an old technology and the design does not take into account the factor of protection of both water and the environment. It is difficult today to characterize the functioning of an irrigation network, taking into account only one criterion. For the management of irrigation water and repair of irrigation systems, knowledge of a set of criteria is required that will help the sustainable disposal of water.

The design of an irrigation management system is characterized by: a) a large degree of uncertainty, b) sophisticated subject design with often multidimensional objectives, c) difficulty in determining the individuals or groups that contribute to the decision and d) sophisticated structure alternatives which combine in sequence several elementary actions and planning horizons (Netto *et al*., 1996).

To solve a problem for MCA, many methods were developed, but in this article the Vikor method is used, as analyzed by Opricovic and Tzeng (2002; 2004; 2006) and Opricovic (2009). In the area of water resources management, management problems have been addressed by Duckstein and Opricovic (1980); Opricovic (1993); Maraveas (1998); Karasavvidis (2003), Baka (2006); Zarghami (2006); Zormpa (2010); Schiau and Wu (2006); Karasavvidis (2009) etc.

2. MCDM

Multicriteria optimization (MCO) is considered as the process of determining the best feasible solution according to established criteria which represent different effects. However, these criteria usually conflict with each other and there may be no solution satisfying all criteria simultaneously. Thus, the concept of Pareto optimality was introduced for a vector optimization problem (Pareto, 1896; Kuhn and Tucker, 1951; Zadeh, 1963). Pareto optimal solutions have the characteristic that, if one criterion is to be improved, at least one other criterion has to be made worse. In such cases, a system analyst can aid the decision making process by making a comprehensive analysis and by listing the important properties of the Pareto optimal (noninferior) solutions. However, in engineering and management practice there is a need to select a final solution to be implemented. An approach to determine a final solution as a compromise was introduced by Yu (1973), and other distance-based techniques have also been developed (Chen and Hwang, 1992).

Many papers have proposed analytical models as aids in conflict management situations. Among the numerous approaches available for conflict management, one of the most prevalent is multicriteria decision making. Multicriteria decision making (MCDM) may be considered as a complex and dynamic process including one managerial level and one engineering level (Duckstein and Opricovic, 1980). The managerial level defines the goals, and chooses the final ‘‘optimal’’ alternative.

The multicriteria nature of decisions is emphasized at this managerial level, at which public officials called ‘‘decision makers’’ have the power to accept or reject the solution proposed by the engineering level. These decision makers, who provide the preference structure, are ‘‘off line’’ from the optimization procedure done at the engineering level.

Very often, the preference structure is based on political rather than only technical criteria. In such cases, a system analyst can aid the decision making process by making a comprehensive analysis and by listing the important properties of noninferior and/or compromise solutions (Yu, 1973). The engineering level of the MCDM process defines alternatives and points out the consequences of choosing any one of them from the standpoint of various criteria. This level also performs the multicriteria ranking of alternatives.

3. VIKOR method

The VIKOR method was developed for multicriteria optimization of complex systems. It determines the compromise ranking-list, the compromise solution, and the weight stability intervals for preference stability of the compromise solution obtained with the initial (given) weights. This method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria. It introduces the multicriteria ranking index based on the particular measure of ‘‘closeness’’ to the ‘‘ideal’’ solution (Opricovic, 1998).

Assuming that each alternative is evaluated according to each criterion function, the compromise ranking could be performed by comparing the measure of closeness to the ideal alternative.

The multicriteria measure for compromise ranking is developed from the L_p-metric used as an aggregating function in a compromise programming method (Yu, 1973; Zeleny, 1982).
The various J alternatives are denoted as $a_1, a_2, \ldots, a_j$. For alternative a_j, the rating of the i aspect is denoted by f_{ij}, i.e., f_{ij} is the value of i criterion function for the alternative a_j; n is the number of criteria.

Development of the VIKOR method started with the following form of L_p-metric:

$$L_{p,j} = \left\{ \sum_{i=1}^{n} \left[w_i \left(f_i^* - f_{ij} \right) / \left(f_i^* - f_i^- \right) \right]^p \right\}^{1/p}, \; 1 \leq p \leq \infty \text{ ; j=1.2….j.}$$

Within the VIKOR method $L_{1,j}$ =S_j and $L_{\infty,j}$ = R_j are used to formulate ranking measure. The solution obtained by $\min_j S_j$ is with a maximum group utility (“majority” rule), and the solution obtained by $\min_j R_j$ is with a minimum individual regret of the “opponent”.
The compromise solution F^c is a feasible solution that is the “closest” to the ideal F*, and compromise means an agreement established by mutual concessions, as is illustrated in Figure 1 by $\Delta f_1 = f_1^* - f_1^c$ and $\Delta f_2 = f_2^* - f_2^c$.

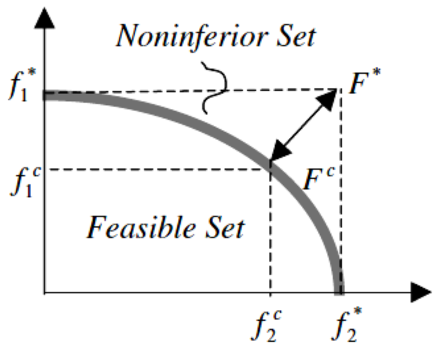

Figure 1: Ideal and compromise solution.

The compromise ranking algorithm VIKOR has the following steps:

(1)Determine the best f_i^* and the worst f_i^- values of all criterion functions, i = 1,2,. . . , n;

$$f_i^* = \max_j f_{ij}, \; f_i^- = \min_j f_{ij} \text{ if the i-th function represents a benefit;}$$

$$f_i^* = \min_j f_{ij}, \; f_i^- = \max_j f_{ij} \text{ if the i-th function represents a cost.}$$

(2) Compute the values S_j and R_j, j = 1,2,. . . ,J, by the relations

$$S_j = \sum_{i=1}^{n} w_i \left(f_i^* - f_{ij} \right) / \left(f_i^* - f_i^- \right)$$

$$R_j = \max_i \left[w_i \left(f_i^* - f_{ij} \right) / \left(f_i^* - f_i^- \right) \right]$$

where w_i are the weights of criteria, expressing the DM’s preference as the relative importance of the criteria.
(3) Compute the values Q_j, j = 1,2,. . . ,J, by the relation

$$Q_j = v\left(S_j - S^*\right)/\left(S^- - S^*\right) + (1-v)\left(R_j - R^*\right)/\left(R^- - R^*\right),$$

where $S^* = \min_j S_j$, $S^- = \max_j S_j$, $R^* = \min_j R_j$, $R^- = \max_j R_j$ and v is introduced as a weight for the strategy of "the majority of criteria" (or "the maximum group utility"), whereas 1 − v is the weight of the individual regret.

(4) Rank the alternatives, sorting by the values S, R and Q in decreasing order. The results are three ranking lists.

(5) Propose as a compromise solution the alternative [$F^{(1)}$] which is the best ranked by the measure Q (minimum) if the following two conditions are satisfied:
C_1. "Acceptable Advantage":

$$Q(F^{(2)} - F^{(1)}) \geq DQ$$

where: $F^{(2)}$ is the alternative with second position in the ranking list by Q and $DQ = 1/(m-1)$.

C_2. "Acceptable stability in decision making":

The alternative $F^{(1)}$ must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when v > 0.5 is needed), or "by consensus" v ≈ 0.5, or "with veto" (v < 0.5). Here, v is the weight of decision making strategy of maximum group utility.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives $F^{(1)}$ and $F^{(2)}$ if only the condition C_2 is not satisfied.
- Alternatives $F^{(1)}$, $F^{(2)}$,. . . , $F^{(M)}$ if the condition C_1 is not satisfied. The $F^{(M)}$ is determined by the relation $Q\left(F^{(M)}\right) - Q\left(F^{(1)}\right) < DQ$ for maximum M (the positions of these alternatives are "in closeness").

4. Choice of optimal irrigation network

4.1. Description of problem

The study area consists of 16 irrigation networks of the plain of Thessaloniki, specifically: F_1=irrigation networks of Agios Athanasios, F_2=irrigation networks of Akrolimnis, F_3=irrigation networks of Braxias, F_4=irrigation networks of Brisaki, F_5=irrigation networks of Zervoxori, F_6=irrigation networks of Klidi, F_7=irrigation networks of Korifis, F_8=irrigation networks of Malgara, F_9 = irrigation networks of Nisi, F_{10}=irrigation networks of Jexasmeni, F_{11}=irrigation networks of Prasinada, F_{12}=irrigation networks of Stauros, F_{13}=irrigation networks of Trikala, F_{14}=irrigation networks of Chalastras, F_{15}=irrigation networks of Chalkidona and F_{16}=irrigation networks of *Ex Lake of Giannitsa (*E.L.G.).

A common feature of sixteen irrigation networks (options / scenarios) is that they are supplied with water from the rivers Axios, Aliaknonas, Galikos and Loudias for the crop water requirements. Additionally, the construction took place during the first phase of land reclamation projects in the plain of Thessaloniki during the decade of 1960, in the first fifteen irrigation networks (Konstantinidis, 1989). Therefore, the problem is reduced to the calibration and classification of these networks in terms of financial planning.

To find the ideal solution to the problem, it is necessary to establish criteria that will cover both the economic-environmental and productive part of the evaluation of each scenario. Thus, we use the following basic criteria: a) C_1 = water that is drained by G.L.R.O. Thessaloniki, b) C_2 = productivity per acre based on the crop, c) C_3 = cost of production, d) C_4 = cost of maintenances, e) C_5= mechanical composition of the soil, f) C_6 = products' availability.

The calibration criteria was partially made using the A.H.P method (Analytic Hierarchy Process) which was introduced in 1980 by Saaty, for both scenarios and for weights. The worst score is 1 and the maximum 9. The main reason this calibration was used was to achieve as much objectification of compensatory weights and criteria as possible.

4.2. Evaluation of the problem

The F (I, J) is the matrix whose elements indicate the value of different scenarios for different criteria. The index I accounts for different scenarios (alternatives), while the index J for the different criteria shows the 'calibration' or evaluation of each scenario based on various criteria. For finding the dimensionless of each criterion and the weights by Saaty (1980) the normalization of problem initially took place and for this reason the program Matlab was used, which resolved the 16*16 matrix for each criterion and a matrix 6*6 for the weights. Table 1 shows the dimensionless assessment of the problem for the study area.

Table 1: Decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6
F_1	0.0106	0.0276	0.0494	0.1916	0.1564	0.1495
F_2	0.0646	0.1096	0.0096	0.0165	0.0220	0.0098
F_3	0.0140	0.0202	0.0709	0.1247	0.0909	0.0718
F_4	0.0375	0.0903	0.0355	0.0537	0.0377	0.0308
F_5	0.1768	0.1528	0.0139	0.0144	0.0195	0.0086
F_6	0.0186	0.0093	0.0273	0.0488	0.0335	0.1223
F_7	0.0910	0.0382	0.1137	0.0452	0.0810	0.0361
F_8	0.0125	0.0130	0.0317	0.1072	0.1260	0.1010
F_9	0.0467	0.0653	0.0903	0.0414	0.0172	0.0261
F_{10}	0.0300	0.1259	0.0121	0.0383	0.0293	0.0172
F_{11}	0.1051	0.0461	0.0603	0.0353	0.0711	0.0534
F_{12}	0.0530	0.1957	0.0176	0.0325	0.0151	0.0797
F_{13}	0.1340	0.0112	0.1823	0.0297	0.0460	0.0454
F_{14}	0.0083	0.0241	0.0241	0.1393	0.1159	0.1301
F_{15}	0.0248	0.0170	0.1318	0.0203	0.0957	0.0939
F_{16}	0.1727	0.0538	0.1294	0.0612	0.0427	0.0243

Table 2: Eigenvectors of weights

W_1	W_2	W_3	W_4	W_5	W_6
0.39	0.17	0.22	0.07	0.05	0.11

Table 3: Classification by VIKOR method

	S	*Sorting S*	R	*Sorting R*	Q	*Sorting Q*
F_1	0,707	*0,396*	0,385	*0,129*	0,829	*0,000*
F_2	0,784	*0,452*	0,260	*0,166*	0,673	*0,135*
F_3	0,789	*0,482*	0,377	*0,168*	0,903	*0,257*
F_4	0,795	*0,603*	0,322	*0,199*	0,805	*0,319*
F_5	0,482	*0,625*	0,215	*0,215*	0,257	*0,358*
F_6	0,855	*0,664*	0,366	*0,260*	0,954	*0,593*
F_7	0,603	*0,707*	0,199	*0,287*	0,358	*0,673*
F_8	0,821	*0,712*	0,380	*0,301*	0,944	*0,707*
F_9	0,742	*0,742*	0,301	*0,322*	0,707	*0,771*
F_{10}	0,829	*0,784*	0,340	*0,340*	0,876	*0,805*
F_{11}	0,625	*0,789*	0,166	*0,352*	0,319	*0,829*
F_{12}	0,664	*0,795*	0,287	*0,366*	0,593	*0,876*
F_{13}	0,452	*0,798*	0,168	*0,377*	0,135	*0,903*
F_{14}	0,798	*0,821*	0,390	*0,380*	0,938	*0,938*
F_{15}	0,712	*0,829*	0,352	*0,385*	0,771	*0,944*
F_{16}	0,396	*0,855*	0,129	*0,390*	0,000	*0,954*

According to Table VIKOR ranking in the ranking is as follows:

$$F_{16} \succ F_{13} \succ F_5 \succ F_{11} \succ F_7 \succ F_{12} \succ F_2 \succ F_9 \succ F_{15} \succ F_4 \succ F_1 \succ F_{10} \succ F_3 \succ F_{14} \succ F_8 \succ F_6$$

• Under the condition C_1 we have:

$$Q(F^{(2)}) - Q(F^{(1)}) \geq DQ \Rightarrow \text{(0.276-0) > 1/(16-1)=0.067.}$$

• According to the second condition rankings of S, R coincides with the classification of Q and thus fulfilled the condition F_{16}.

The optimal irrigation network, according to the research is E.L.G. (alternative activity 16), it follows Trikala (alternative activity 13), while the worst of all is Chalastra (alternative activity 14), Malgara (alternative activity 8) and Klidi (alternative activity 6) with very little difference concerning evaluation points .

In this evaluation the criteria that predominate in these results are the irrigated water that is drained from the General Land Reclamation Organisation (G.L.R.O.) of Thessaloniki – Lagadas (w_1 criterion) crop productivity (w_2 criterion) and cost of production (w_3 criterion). These three criteria make up 78% of the total sum of the weights, while criterion w_1 is the only one that makes up 39% of the total.

5. Conclusion

The VIKOR method introduces the ranking index based on the particular measure of ‘‘closeness’’ to the ideal solution. The VIKOR method is using linear normalization and the normalized value in the method does not depend on the evaluation unit of a criterion function, whereas other MCDM methods may depend on the evaluation unit.

The results of the program are close to reality, because the irrigation network of E.L.G. is using sprinkle and drip irrigation. These irrigation methods are much better than open irrigation networks in relation to water consumption and losses.

Additionally, although the irrigation network of E.L.G. contains the largest number of pumping stations compared to the rest of the networks, these pumping stations have low operational costs, because they are more recent. Summarizing all the above, the method leads the user to rank the networks, thus enabling the recipient of the decision(The General Land Reclamation Organisation-G.L.R.O. of Thessaloniki – Lagadas) to make a rational planning of upgrading the irrigation networks.

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