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FUZZY MULTIGROUP CONFLICT RESOLUTION FOR ENVIRONMENTAL MANAGEMENT

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ABSTRACT

The paper provides a new methodology for conflict analysis in choice situations with multiple groups, where the information on the various choice possibilities is fuzzy in nature. The focus of the paper is on environmental conflict management. Starting from a multicriteria perspective, a fuzzy clustering technique is applied to identify possible alliances among groups with different interests. After a brief survey of coalition formation theory, the methodology is illustrated by means of an empirical land use problem in the Netherlands.

Keywords: Fuzzy sets, environmental management, multicriteria methods, coalitions, cluster analysis

1. Introduction

Evaluation models serve to judge the feasibility and desirability of alternative courses of action (plan, projects), based on political choice and plausibility criteria. Plan and project evaluation has become an important component of modern public planning and administration. It should be noted that different kinds of evaluation can be distinguished in a policy analysis; one of the important discriminating characteristics is between monetary and non-monetary evaluation. *A monetary evaluation* is characterized by an attempt to measure all effects in monetary units, whereas a non-monetary evaluation utilizes a wide variety of measurement units to asses the effects. Cost-benefit analysis and cost-effectiveness analysis are well-known examples of a monetary evaluation [31].

The history of plan and project evaluation before World War II showed first a strong tendency towards a financial and monetary trade-off analysis. Later on much attention was focussed on cost-effectiveness principles. Especially after World War II, cost-benefit analysis gained increasing popularity in public policy evaluation, by using willingness to pay notions, consumer surplus principles and shadow prices.

The hypotheses underlying monetary evaluation methodologies took for granted rational choice behaviour based on a one-dimensional well defined performance indicator. The use of such conventional optimization models has been criticized from many sides. Furthermore, in the past decades, the degraded state of the natural environment has become another key issue in evaluation, because of the externalities involved and it is increasingly taken for granted that environmental and resource problems generally have far reaching economic and ecological consequences, which cannot always be encapsulated by a market system. The limits inherent in conventional evaluation methodologies and the necessity of analyzing conflicts between policy objectives in case of (environmental) externalities have led to a need for more appropriate analytical tools for strategic evaluation [30].

Multiple criteria evaluation techniques aim at providing such a set of tools. In fact, in the last two decades, it has been understood that welfare is a multidimensional variable which includes, inter alia, average income, growth, environmental quality, distributional equity, supply of public facilities, accessibility, etc. This implies that a systematic evaluation of public plans or projects has to be based on the distinction and measurement of a broad set of criteria. These criteria can be different in nature: private economic (investment costs, rate of return, etc.), socio-economic (employment, income distribution, access to facilities, etc.), environmental (pollution, deterioration of natural areas, noise, etc.), energy (use of energy, technological innovation, risk, etc.), physical planning (congestion, population density, accessibility, etc.) and so forth [27, 31].

Generally, ecosystems are used in several ways at the same time by a number of different users. This complies with the definition of multiple use. Such situations almost always lead to conflicts of interest and damage to the environment. The consequences range from suboptimal use due to unregulated access, to degradation of resource systems due to limited knowledge of the ecological process involved. Thus, in the area of environmental and resource management and in policies aiming at an ecologically sustainable development, many conflicting issues and interests emerge. As a tool for conflict management, multicriteria analysis is then an important evaluation method, which has demonstrated its usefulness in many environmental management problems.

In the context of conflicting interests, it is also noteworthy that there is an interference from local, regional or national government agencies, while there is at the same time a high degree of diverging public interests and conflicts among groups in society. At an *intraregional level* many conflicting objectives may exist between different actors (consumers, firms, institutions, etc.), which can formally be represented as multiple objective problems and which have a clear impact on the spatial organization of a certain area (e.g. industrialization, housing construction, road infrastructure construction). At a *multiregional level* various spatial linkages exist which affect through spatial interaction and spillover effects a whole spatial system (e.g. diffusion of environmental pollution, spatial price discrimination) and which in a formal sense can be described by means of a multiple objective programming framework. At a *supraregional level* various hierarchical conflicts may emerge between regional government institutions and the central government or between regional branches and the central office of a firm, which implies again a multiple objective decision situation.

From an operational point of view, the major strength of multicriteria methods is their ability to address problems marked by various conflicting interests. Multicriteria methods can provide systematic information on the nature of these conflicts so as to make the trade-offs in a complex situation more transparent to decision makers.

2. Qualitative Multicriteria Methods for Environmental Management

During the 70's and at the beginning of the 80's a great number of multicriteria methods has been developed and used for different policy purposes in different contexts. The following distinctions can be made regarding the contexts and the scope of multicriteria evaluation methods:

1) discrete versus continuous methods;
2) multi-person versus single-person evaluation;
3) single-step versus multi-step evaluation procedures;
4) qualitative versus quantitative information.

We will elaborate the latter feature of multicriteria methods first.

It has been argued that the presence of qualitative information in evaluation problems concerning socio-economic and physical planning is a rule, rather than an exception [30, 31]. Thus there is a clear need for methods taking into account qualitative information. In multicriteria evaluation theory, a clear distinction is made between quantitative and qualitative methods. Essentially, there are two approaches for dealing with qualitative information: a direct and an indirect one. In the *direct approach*, qualitative information is used directly in a qualitative evaluation method; in the *indirect approach*, qualitative information is first transformed into cardinal one, while next one of the existing quantitative methods is used. Cardinalization is especially attractive in the case of available information of a "mixed type" (both qualitative and quantitative data). In this case, the application of a direct method would usually imply that only the qualitative contents of all available (quantitative and qualitative) information is used, which would give rise to an inefficient use of this. In the indirect approach, this loss of information is avoided; the question is of course, whether there is a sufficient basis for the application of a certain cardinalization scheme. A multicriteria method that may use mixed information is the EVAMIX procedure. Another interesting method for dealing with mixed information is the so-called REGIME method; this method is based on pairwise comparison operations.

Another problem related to the available information is the uncertainty contained in this information. Ideally, the information should be precise, certain, exhaustive and unequivocal. But in reality, it is often necessary to use information which does not have those characteristics and hence there is a need to face the uncertainty of a stochastic and/or fuzzy nature. In fact, if the available information is insufficient or delayed, it is impossible to establish exactly the future state of the problem faced, so that then *stochastic uncertainty* is created.

Fuzzy uncertainty does not concern the occurrence of an event but the event itself, in the sense that it cannot be described unambiguously. This situation is very common in human systems. Spatial systems in particular, are complex systems characterized by subjectivity, incompleteness and imprecision [41, 42, 43].

Therefore, the combination of the different levels of measurement with the different types of uncertainty has to be considered. Recently, a discrete multicriteria method whose impact (or evaluation) matrix may include either crisp, stochastic or fuzzy evaluations of the performance of an alternative a_n with respect to a criterion g_m has been developed by the present authors [26]. From a methodological point of view, two main issues had to be faced:

- the problem of equivalence of the used procedures in order to standardize the various evaluations (of a mixed type) of the performance of alternatives according to different criteria;
- the problem of comparison of fuzzy numbers typical of all fuzzy multicriteria methods.

This method will now briefly be described here. It can be subdivided into four main steps.

1) Definition of a Fuzzy Region of Satisfactory Alternatives

Given a "consistent family" of mixed evaluation criteria $G=\{g_m\}$, m=1,2,........., M, and a finite set $A=\{a_n\}$, n=1, 2,....., N of potential alternatives (actions), a region of satisfactory alternatives can be obtained by defining a fuzzy interval of feasible and acceptable values for each criterion.

From an operational point of view, in public decision making a single point-value solution (e.g. weights) tends to lead to deadlocks in the evolution of the decision process because it imposes too rigid conditions for a compromise. On the contrary, when a higher degree of flexibility is allowed, the definition of a fuzzy region of satisfactory solutions could in principle make more room for mutual consensus. A natural and flexible way of defining such a region is by means of linguistic propositions.

In traditional mathematics, variables are assumed to be precise, but when we are dealing with our daily language, imprecision usually prevails. Intrinsically, daily languages cannot be precisely characterized on either the syntactic or semantic level. Therefore, a word in our daily languages can technically be regarded as a fuzzy set. In order to allow a formal analysis, a mathematical translation of the linguistic propositions is needed. This can be done by means of possibility theory [21].

2) Comparison of Fuzzy Sets

In general, fuzzy approaches to multicriteria evaluation include the following limitations:

- most of them are limited to the use of triangular fuzzy numbers;
- the shape of the membership function is not taken into consideration or only a part of it is used, which gives rise to a loss of information;
- a general problem concerns the "sensitivity" (degree of discrimination[1]) of the solutions.

Some authors claim that a low degree of discrimination is a negative feature; on the contrary, others believe that in a fuzzy context, an attempt to reach a high degree of precision of the results is somewhat artificial. We share this latter position. In public decision-making in general -and in environmental problems in particular- we often face the desire not to be confronted with single unambiguous and (sometimes) imposed fixed solutions, but with a spectrum of open feasible solutions having each its own merits.

The present authors have recently developed a new distance metric that is useful in the case of continuous membership functions allowing also a definite integration. This will briefly be described here.

If $\mu_{A_1}(x)$ and $\mu_{A_2}(x)$ are two membership functions, we can write

$$f(x) = c_1\mu_{A_1}(x) \quad \text{and} \tag{1}$$

$$g(y) = c_2\mu_{A_2}(x) \tag{2}$$

where f(x) and g(y) are two functions obtained by rescaling the ordinates of $\mu_{A_1}(x)$ and $\mu_{A_2}(x)$ through c_1 and c_2, such that

$$\int f(x)\, dx = \int g(y)\, dy = 1 \tag{3}$$

Thus our semantic distance is the following:

$$S_d\,(f(x), g(y)) = \iint |x-y|\, f(x)\, g(y)\, dydx \tag{4}$$

[1] The degree of discrimination "refers to the capability of a method to differentiate between alternatives the ratings of which differ only slightly from each other [43 p.174]"

It is easy to show that this distance satisfies the properties of non-negativity and symmetry; the proof of the triangle inequality and a Monte Carlo type numerical procedure for the computation of such a distance can be found in [25]. It has to be noted that without the absolute value sign equation (4) becomes a function of the sign, thus allowing the computation of the possibility degree of a fuzzy set to be greater than another one (preference index).

From a theoretical point of view, the following main conclusions can be drawn from the above observations:

(a) the absolute value metric (simple difference) is a particular case of this type of distance (preference index);

(b) by applying this preference index, the problem of the use of only one side of the membership functions, common to most of the traditional fuzzy multicriteria methods, is overcome.

3) Pairwise Comparison of Alternatives

Evaluation requires normally a judgement of the relative performance of distinct alternatives based on dominance relationships.
Six different fuzzy relations are considered here:

1) much greater than (>>)
2) greater than (>)
3) approximately equal to (≅)
4) very equal to (=)
5) less than (<)
6) much less than (<<)

The use of such relations is inspired by the same philosophy as the definition of a "pseudo-criterion" [33], but here -according to fuzzy principles- no precise boundary is established, thus allowing a focussed use of each single evaluation criterion for different preference modelling situations. Furthermore, the decision-maker is not asked to evaluate thresholds (which is always a difficult and perhaps arbitrary process), although the choice of the membership functions contains always some degree of arbitrariness.

Given such information on the pairwise performance of alternatives according to each single criterion, it is necessary to aggregate these evaluations in order to take into account all criteria simultaneously; this is done by taking into account the degree of compensation introduced in the model, and a measure of the "incertitude" of the evaluations given by the entropy concept.

4) Evaluation of Alternatives

The information provided by a "fuzzy preference relation" can be used in different ways, e.g., the degree of truth (τ) of statements such as:

"according to most of the criteria

- **a** is better than **b**,
- **a** and **b** are indifferent,
- **a** is worse than **b**"

can be computed by means of proportional linguistic quantifiers and approximate reasoning rules.

Pairwise evaluations can be used directly by the decision-maker(s) in order to isolate a set of satisfactory solutions. Alternatively, If in a given decision environment there is a need to carry out further elaborations in order to get a ranking of the alternatives (in a complete or partial preorder), this can also be done by using further elaborations of approximate reasoning taking into account the entropy levels and the relations with all the other actions.

However, it has to be noted that all results obtained can provide "justifiable" or "defensible" decisions to policy-makers, but in real world environmental decision making, it is necessary to interact with many actors (often each single actor is represented by complex organizations like town councils, trade unions, different associations and so on) each of them having different goals and values. Therefore, since, real-world problems are generally not direct win-lose situations and a certain degree of compromise is needed, a procedure aimed at supporting real environmental policy-makers would ideally consider this problem of different (and often conflicting) evaluations. Multicriteria evaluation techniques cannot solve all these conflicts, but they can help to provide more insight into the nature of these conflicts and into ways to arrive at political compromises in case of divergent preferences in a multi-group or committee system. For this aim, the possibilities of coalitions between different interest groups whose preference patterns do not show significant differences has to be explored. This will briefly be reviewed in the next section.

3. Coalition Formation Theory: a Concise Overview

The aim of coalition formation theory is to predict a set of coalitions which are likely to be formed in a given political situation. There are two basic schools of thought among those who have applied game-theoretic principles to the study of political coalition formation. The two opposing positions can be referred to as "size theory" and "policy theory" [19].

Size theory originated from Von Neumann/Morgenstern's "minimal winning coalitions" [29], and was modified by Riker and Gamson [13, 14, 32] into "the size principle". Size theorists assert that parties prefer governments of which they are a member and which are "as small as possible". Size theorists argue that when a government coalition is voted into office it thereby gains control over a fixed sum of benefits which are then subdivided among its constituent members (with non-members receiving nothing). Therefore, the smaller the coalition, the more benefits are available per member.

"Policy theorists" such as Leiserson, Axelrod, and De Swaan [4, 11, 20] argue that the benefits to the political parties which are generated by a particular government come primarily from the policies implemented by the government. Since government policies are public goods, the benefits that a party may receive from different governments are not necessarily related to the size of the governments. Instead, these benefits are related to the preferences of that party for the policies of one government compared with those of the other.

There are two major variants of "policy theory": *"Minimal range theory"* developed separately by Leiserson and by Axelrod [4, 20], and *"Policy distance theory"* developed by De Swaan [11].

Minimal range theory asserts that a particular party will prefer a government coalition of which it is a member and which has a small "range". Range can be defined as the distance in the policy space between the policy positions of the two most extreme members of a coalition. The argument underlying the minimal range hypothesis is that the smaller the range of the government, the closer the government policy is likely to be to the policy position of any one of its members. The minimal range hypothesis predicts thus government coalitions whose range is as small as possible, given that they must form a majority.

De Swaan makes the assumption that a coalition government selects its policies by a majority rule. For instance, thinking of the policy space as a line, this assumption leads to the conclusion that the policies chosen by a particular coalition government will be the policies of the party that is at the median of the coalition. According to the policy distance hypothesis, a party will prefer to belong to a coalition for which the policy position of the median member is close to its own position.

In policy distance theories, the construction of the predicted set of coalitions proceeds in two distinct steps: first, each actor establishes his preference ordering among the various possible coalitions, and then individual preferences are used to select a subset of all possible coalitions, i.e. the set of predicted coalitions. In general, the results of policy distance theory are less clear cut than minimal range theory, because it tends to predict that any of a relatively large number of coalitions is possible in a given period, whereas minimal range theory predicts a more restricted set of possibilities.

The cornerstone of the theory of *cooperative n-person games* [22, 24, 36] is the *characteristic function*. The idea is to capture in a single numerical index the potential worth of each coalition of players (the representation of coalition's worth by a single number implies freely transferable utility). Games are defined *inessential* if no profitable grounds exist for cooperation among players. They are *essential* if some members of coalitions at least, do strictly better by sticking together. Mathematically, the characteristic function, traditionally denoted by v, is a function from subsets of players to the set of real numbers. A general property of characteristic functions is that the function v is *superadditive* (any set of players can do at least as well in coalition as in any subcoalition), formally,

$$v(S \cup T) \geq v(S)+v(T) \qquad (5)$$

which holds whenever S and T have no members in common.

A special class of games, which may be thought of as "games of control" are important tools in the modelling of organizational and group decision processes. They are called *simple games* and are distinguished by the property of having just two kinds of coalitions, namely, winning and losing. In the presence of transferable utility, they are c-games, and after suitable normalization they give rise to a special single type of characteristic function:

$$v(S)= \begin{cases} 0 & \text{if S is losing} \\ 1 & \text{if S is winning} \end{cases} \qquad (6)$$

4. Fuzzy Cluster Analysis in Coalition Formation Theory

Any political situation is characterized by an *information set.* composed by *descriptive data* and actors' *behavioural rules,* represented by assumptions that describe the way each actor uses the descriptive information in order to establish his own preferences.

Since, generally real-world problems are not direct win-lose situations (simple games), but a certain degree of compromise is needed, the assumption typical of voting theory, that actors' preferences are fixed can be relaxed, and also strategic aspects may be introduced.

In real world situations of public decision analysis two main cases can be distinguished [38]:

1) *Broad Commonality of Goals* (i.e., differences among parties are revealed through various trade-offs which they perceive to be most in their interest).

2) *Direct Conflict of Goals* (i.e., a case where public policy involves an explicit division of resources among different sectors of the society or where attitudes have led to unreconcilable strong antagonies (e.g. environmentalists versus industrialists).

Given these considerations, it is possible to construct a model (performing as a "simulation model") whose main aim is to give relevant information on the structure of the decision problem at hand. For example, the authority in charge of a decision can try to forecast the possible behaviour of the relevant interest groups.

The following main assumptions are made:

1) only a set of well defined actions has to be taken into account;
2) the actors evaluate the different actions by means of "linguistic declarations" (good, not very good, etc.);
3) the actors are often groups too, but we take for granted that it is possible to have their evaluations independently from the way they are derived, (in any case, to give a linguistic evaluation of each action can be easier than to supply a complete ranking of all actions);

Given a conflict indicator, a fuzzy cluster algorithm can be used in order to have an idea of the coalitions (minimizing such an indicator) that are "possible". It should be noted that the formal structure of the model is:

units=actors attributes=actions.

Thus we have to evaluate the similarity among actors given the evaluations of the different actions. By using the semantic distance described in section 2 as conflict indicator, a similarity matrix (achieved by means of the simple transformation $s=1/1+d$) for all possible pairs of actors can be obtained, so that the following clustering procedure is meaningful.

On an axiomatic basis, cluster analysis can be distinguished in deterministic, stochastic and fuzzy. By taking into consideration the "clustering criteria", the following distinction exists [1, 7, 17]:

- hierarchical methods,
- graph theoretic methods,
- objective functional methods.

The hierarchical clustering approach, in particular, allows an evolutionary view of the aggregation process and can easily be dealt within fuzzy terms.

However, in a fuzzy environment a problem exists, i.e. the relation between the concepts of *partition* and *equivalence class.* In a crisp environment, the choice of treatment of data in terms of partitions or equivalence relations is a matter of convenience, since the two models are fully equivalent (philosophically and mathematically). On the contrary, fuzzy equivalence relations and partitions are philosophically similar, but their mathematical structures are not isomorphic (e.g. the notion of transitivity is unique for crisp relations but has taken several proposed forms in the fuzzy case). In Appendix 1 we present the technical details of a fuzzy clustering procedure which can be used for an analysis of coalition formation.

In the next section, the applicability of this procedure for the analysis of possible coalitions in conflicting environmental management problems will be illustrated by means of a real world land use planning problem.

5. Environmental Management and Fuzzy Conflict Analysis: Illustration by means of a Land Use Problem

The application used in this section is based on a previous case study which was using ordinal information and multidimensional scaling techniques [30]. It concerns a study on environmental management in the Netherlands.

The southern part of Limburg (a province in the south-eastern part of the country) is the major centre of the Dutch cement industry owing to the special physical structure and condition of the soil in this area. The production of cement is based on the raw material marl. The marl winning takes place by extracting this raw material from so-called marl-pits. This is an open-air activity which destroys more or less completely the original physical structure of the area concerned. There is a company having almost absolute dominance in the Dutch cement industry. This company has a concession to extract marl on one of the hills in south Limburg, but this concession may finish in the near future; thus alternative areas have to be explored. Among the new possible areas, the most appropriate one is the Plateau van Margraten; this is a rather flat area which is used for agriculture and for some recreation. It has a unique physical structure and it is a rather characteristic area in the landscape of the region. Designation of this area for marl winning would fundamentally affect its social and ecological value; on the other hand, if the authorities would refuse to grant permission for marl winning to the company, this would lead to an almost total destruction of the national cement industry and to serious unemployment effects for this already weak economic region. This situation clearly demonstrates the sharp conflicts between environmental and economic interests.

A first meaningful step toward an evaluation analysis for this land use problem is to identify a set of feasible and relevant alternatives. These alternatives are:

(1) An implementation of the original plans of the company (i.e. a concession for the total area). This guarantees the future position of the national cement industry and also favours the employment and welfare in the region. Agriculture suffers from some negative impacts, while the negative social impacts (for recreation, etc.) are rather high. Finally, the environmental damage is very high.

(2) The use of an alternative area (the Rasberg area, in the same region) for marl winning. But this area is much smaller and the physical condition of the soil hampers a profitable cement production against current prices. On the other hand, the ecological damage is less serious.

(3) The provision of a concession for one half of the area (Plateau van Margraten). This leads to less agricultural losses, while the environmental damage is also lower. The economic impacts are less favourable than those of the first alternative.

(4) A new concession for marl winning on the present area. This is only a short-term solution which is less attractive from an economic point of view (note that in this case, one would need a multi-period approach, but this is too complex for illustrative purposes).

(5) Import of marl from the Plateau van Vroenhoven, an area in Belgium. This solution may be attractive from a social and environmental point of view (at least from a national stand-point), but it is less attractive from an economic point of view. For simplicity, we ignore the environmental impact of transport of marl.

(6) A restructuring of the company so that it becomes a trade and research organization for cement instead of a production unit for cement. This will lead to a certain loss of employment, while the future need for such an organization is unclear.

(7) A close-down of all productive activities of the company. This may be favourable from the viewpoint of environmentalists and recreationers, but it will lead to serious economic problems for the region.

These alternatives are to be judged on the basis of various evaluation criteria. Three main groups of criteria can be distinguished, viz. economic, social and environmental. These three classes can be subdivided into various components.

A) Economic Criteria

1) employment in agriculture,
2) employment in cement industry (including marl winning),
3) agricultural production,
4) national production of marl,
5) value added in cement industry

B) Social Criteria

6) residential attractiveness,
7) recreational attractiveness (daily),
8) tourist attractiveness,

9) congestion created in transportation infrastructure.

C) Environmental Criteria

10) quality of physiological structure,
11) diversity and scarcity of eco- and bio-components,
12) consistency with existing landscape components,
13) consistency with existing cultural-historical components.

It appears that the information concerning the diverse plan impacts is rather inaccurate; the degree of uncertainty on the impacts of the plans is high, so that quantitative information on these impacts is often not available. A representation of such impacts in fuzzy terms seems very appropriate. A multicriteria fuzzy evaluation matrix related to the above-mentioned 7 alternatives and 13 criteria is presented in Table 1.

	Alternatives						
Criteria	a_1	a_2	a_3	a_4	a_5	a_6	a_7
g_1	moderate	moderate	good	good	excellent	excellent	excellent
g_2	excellent	excellent	moderate	moderate	good	moderate	bad
g_3	moderate	moderate	good	good	excellent	excellent	excellent
g_4	excellent	excellent	moderate	moderate	moderate	bad	bad
g_5	excellent	moderate	bad	bad	good	good	bad
g_6	moderate	moderate	bad	bad	good	good	bad
g_7	good	good	good	excellent	excellent	excellent	excellent
g_8	moderate	moderate	good	excellent	excellent	excellent	excellent
g_9	moderate	moderate	moderate	excellent	excellent	excellent	excellent
g_{10}	moderate	moderate	moderate	excellent	excellent	excellent	excellent
g_{11}	good	good	good	excellent	excellent	excellent	excellent
g_{12}	bad	moderate	good	excellent	excellent	excellent	excellent
g_{13}	moderate	good	good	excellent	excellent	excellent	excellent

Table 1. Evaluation matrix for a fuzzy land use problem

Interest groups	Alternatives a_1	a_2	a_3	a_4	a_5	a_6	a_7
1	very good	good	moderate	bad	fairly good	fairly bad	very bad
2	very good	good	moderate	bad	fairly good	very bad	very bad
3	very bad	fairly bad	moderate	good	very good	good	moderate
4	very bad	fairly bad	fairly bad	good	fairly good	good	very good
5	very bad	bad	fairly bad	moderate	fairly good	good	very good
6	very bad	good	bad	good	good	good	very good

Table 2. Fuzzy evaluations of alternatives according to each interest group

In addition to this fuzzy evaluation matrix, an assessment of the priority structures of the diverse interest groups is required. The number of interest groups distinguished in this study is six. These groups are:

1) the board of directors of the company,
2) the employees of the company,
3) the farmers' association in Limburg,
4) the recreational association for South Limburg,
5) the environmental federation in Limburg,
6) the residents of the area around the Plateau Margraten.

In Table 2 the linguistic evaluations of the alternative plans according to each interest group are presented. These evaluations were assessed on the basis of personal inquiries, interviews, talks with interest groups and study of available material.

By applying our fuzzy multicriteria procedure for each pair of actions, the following degrees of truth of a linguistic evaluation are obtained:

a_1 is better than a_2	$\tau=0$	a_1 is better than a_3	$\tau=0$
a_1 and a_2 are indifferent	$\tau=1$	a_1 and a_3 are indifferent	$\tau=0$
a_1 is worse than a_2	$\tau=0$	a_1 is worse than a_3	$\tau=0$

a_1 is better than a_4	τ=0	a_1 is better than a_5	τ=0
a_1 and a_4 are indifferent	τ=0	a_1 and a_5 are indifferent	τ=0
a_1 is worse than a_4	τ=1	a_1 is worse than a_5	τ=1
a_1 is better than a_6	τ=0	a_1 is better than a_7	τ=0
a_1 and a_6 are indifferent	τ=0	a_1 and a_7 are indifferent	τ=0
a_1 is worse than a_6	τ=1	a_1 is worse than a_7	τ=1
a_2 is better than a_3	τ=0	a_2 is better than a_4	τ=0
a_2 and a_3 are indifferent	τ=0	a_2 and a_4 are indifferent	τ=0
a_2 is worse than a_3	τ=0	a_2 is worse than a_4	τ=1
a_2 is better than a_5	τ=0	a_2 is better than a_6	τ=0
a_2 and a_5 are indifferent	τ=0	a_2 and a_6 are indifferent	τ=0
a_2 is worse than a_5	τ=1	a_2 is worse than a_6	τ=1
a_2 is better than a_7	τ=0	a_3 is better than a_4	τ=0
a_2 and a_7 are indifferent	τ=0	a_3 and a_4 are indifferent	τ=0
a_2 is worse than a_7	τ=1	a_3 is worse than a_4	τ=1
a_3 is better than a_5	τ=0	a_3 is better than a_6	τ=0
a_3 and a_5 are indifferent	τ=0	a_3 and a_6 are indifferent	τ=0
a_3 is worse than a_5	τ=1	a_3 is worse than a_6	τ=1
a_3 is better than a_7	τ=0	a_4 is better than a_5	τ=0
a_3 and a_7 are indifferent	τ=0	a_4 and a_5 are indifferent	τ=1
a_3 is worse than a_7	τ=1	a_4 is worse than a_5	τ=0
a_4 is better than a_6	τ=0	a_4 is better than a_7	τ=0
a_4 and a_6 are indifferent	τ=1	a_4 and a_7 are indifferent	τ=1
a_4 is worse than a_6	τ=0	a_4 is worse than a_7	τ=0
a_5 is better than a_6	τ=0	a_5 is better than a_7	τ=0
a_5 and a_6 are indifferent	τ=1	a_5 and a_7 are indifferent	τ=1
a_5 is worse than a_6	τ=0	a_5 is worse than a_7	τ=0

a_6 is better than a_7 $\tau=0$
a_6 and a_7 are indifferent $\tau=1$
a_6 is worse than a_7 $\tau=0$

It is clear that almost all linguistic evaluations are quite unambiguous. This is caused by four factors:

- the number of criteria in favour of an action;
- the degree of compensation allowed in the aggregation process;
- definition of the membership function of the linguistic operators;
- aggregation operator chosen for the approximate reasoning operations (in this application we have used the "min" operator which is known as a representation of the logic "and", and therefore it is completely non interactive (since a high value cannot compensate[2] a low one)).

It has to be noted that between actions a_1 and a_3, and a_2 and a_3, none of the possible situations satisfies the minimum requirement requested by the linguistic operator "most"; this can be interpreted as a difficulty in the comparison which might bring about an incomparability relation.

On the basis of the above pairwise comparison between alternatives, we arrive at the following final ranking of alternatives:

$$\{a_4, a_5, a_6, a_7\} > \{a_1, a_2, a_3\}.$$

This means that we obtain two subsets of alternatives. The best subset contains a_4, a_5, a_6 and a_7. On the basis of the pairwise comparison results, it is not possible, however, to rank the alternatives within the two subsets.

An higher degree of discrimination (on the basis of technical grounds) can be obtained by means of a complex procedure whose details can be found in [26]. The result of such a procedure is the following

$$a_6 \rightarrow a_5 \rightarrow a_4 \rightarrow a_7 \rightarrow a_1 \rightarrow a_2$$
$$\searrow$$
$$a_3$$

However, since a weighting of criteria is not assumed and no consideration is given to the "minority principle" (like the discordance index in the ELECTRE

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[2] By compensation in the context of aggregation operators for fuzzy sets is meant the following: "Given that the degree of membership to the aggregated fuzzy set is $\mu_{Agg}(x_k) = f(\mu_A(x_k), \mu_B(x_k)) = k$, f is compensatory if $\mu_{Agg}(x_k) = k$ is obtainable for different $\mu_A(x_k)$ by a change in $\mu_B(x_k)$ [42 p. 36]".

methods) such a procedure must be integrated with conflict minimization methods which allow policy-makers to seek for "defensible" decisions that could reduce the degree of conflict (in order to reach a certain degree of consensus) or that could have a higher probability of being accepted by certain groups of decision-makers.

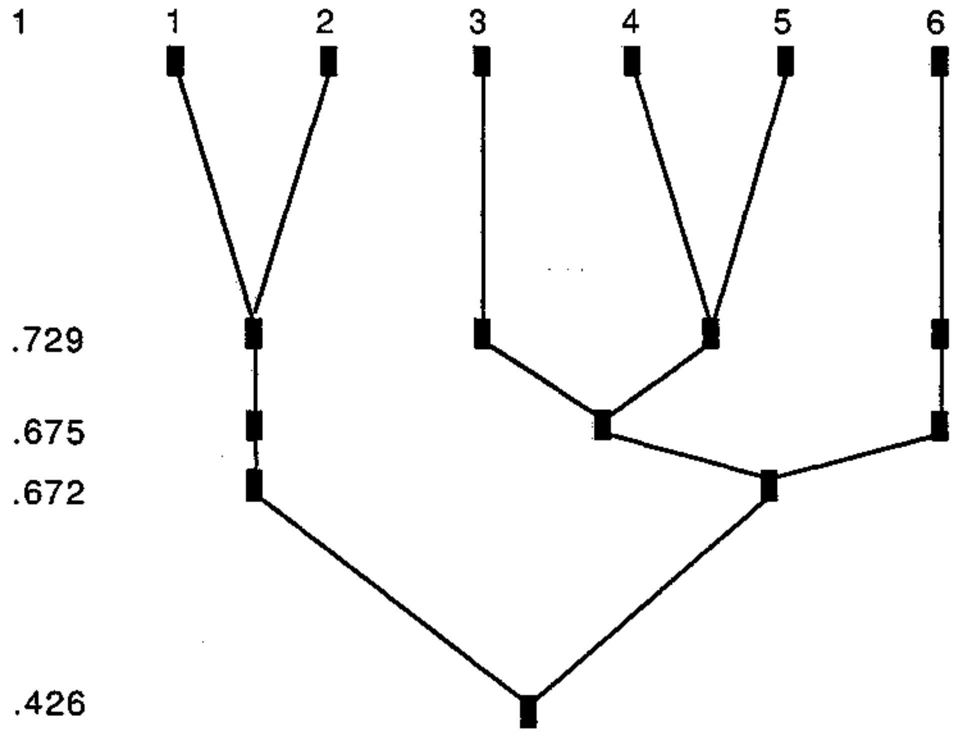
Taking into consideration the possibility of coalitions among the different interest groups, the following results can now be obtained.

By applying the semantic distance as defined in (4), after the transformation s= 1/1+d, the following similarity matrix for all possible pairs of interest groups is obtained:

	1	2	3	4	5	6
1	1	0.729	0.426	0.399	0.403	0.403
2	0.729	1	0.410	0.386	0.390	0.390
3	0.426	0.410	1	0.675	0.584	0.569
4	0.399	0.386	0.675	1	0.729	0.672
5	0.403	0.390	0.584	0.729	1	0.595
6	0.403	0.390	0.569	0.672	0.595	1

This means for example that the highest similarity occurs for interest groups 1 and 2. These interest groups have a relatively high correspondence of goals, accordingly. The reverse holds true for interest groups 2 and 4 where the lowest degree of similarity is found.

Application of the clustering procedure presented in Appendix 1 leads to the following results. As long as the similarity degree α required for a coalition is higher than .729, there will be no coalition formation. Two coalitions will be formed when α is between .729 and .675 (1 and 2), and (4 and 5). When the similarity degree is reduced to .675 and .672, interest groups 3 and 6 join the last coalition, respectively. The conflict of interest between the remaining coalitions (1, 2) versus (3, 4, 5, 6) is considerable as can be inferred from the low similarity degree associated with a grand coalition.



These results are quite well in agreement with prior expectations about the attitudes and behaviour of the interest groups. The interests of the company and of its employees seem to run fairly parallel. The agricultural interest group seems to take an intermediate position, but it joins quite soon the coalition made by the recreation and environmental groups. The priority patterns of the recreation group and the environmental group bear a very close correspondence. The residential group presents a more individualistic character since it can be considered a clear case of a "NIMBY" (never in my back yard) syndrome; in any case, it is closer to the interests of the recreation and environmental groups than to those of the economic groups.

It is interesting to note that the alternatives strongly supported by interest groups 1 and 2 (a_1, a_2) have bad environmental impacts. All the alternatives considered "good" from an environmental point of view are more or less well-accepted by interest groups 3, 4, 5, 6. Among the actions of this group, a_6, a_5, and a_4 are clearly compromise solutions in nature while a_7 is a too extreme solution (closedown of all productive activities) but which clearly presents a high performance from a social and environmental point of view; a_5 is the only alternative which minimizes the conflicts. Both a_6 and a_4 will strongly be rejected by interest groups 1 and 2.

Up till now a weak element in this analysis is the lack of strategic considerations leading to new coalitions or alliances. In fact, the clustering algorithm only indicates the groups whose interests are close in comparison to the other ones. This is more or less in agreement with the hypotheses underlying the "minimal range theory". This theory is quite plausible in the case of "broad commonality of goals". On the contrary, in the case of "direct conflict of goals", game-theoretic elements such as the notion of "power" need to be introduced. Furthermore, attaching to each interest group the same weight can be an oversimplification of a real-world situation. Such an introduction of strategic elements in this analysis of coalitions should be undertaken in future research.

6. Concluding Remarks

In this contribution we have illustrated how qualitative multicriteria methods can be used in evaluation problems with conflicting objectives related to economic and environmental impacts. It is shown how fuzzy set approaches can be used to generate a ranking of alternatives in order of attractiveness according to the preference of a decision-maker. As long as there is only one decision-maker, this approach is directly applicable. In this case, multicriteria methods have a normative orientation in the sense that they are an aid to the decision-maker to find out which alternative is most attractive given his or her preference structure.

In the case of more than one decision-maker such a normative approach is still useful for each decision-maker or interest group to determine the most preferred alternative. But the final decision to be taken cannot be determined in this case only on technical grounds. It depends among others on relative power, and decision rules and practices. The second part of this paper no longer has a normative orientation. It addresses the question to what extent decision-makers have different evaluations of the alternatives. This gives the approach an analytical orientation: the analysis of similarity of interests is an input for the analysis of the formation of coalitions. In this paper we have shown that fuzzy cluster analysis is a useful tool to study the coalition formation process.

APPENDIX 1

We start the discussion on fuzzy cluster analysis with the definition of a *crisp equivalence relation.*

Let $X=\{x_1, x_2,....,x_n\}$ be any finite set. Then an nxm matrix $R=[r_{ij}] = [r(x_i, x_j)]$ is a crisp equivalence relation on XxX if

$r_{ii}=1$ $\quad 1\leq i\leq n$ (reflexivity)

$r_{ij}=r_{ji}$ $\quad 1\leq i\neq j\leq n$ (symmetry)

$$\left\{\begin{array}{l} r_{ij}=1 \\ r_{jk}=1 \end{array}\right. \Rightarrow r_{ik}=1 \quad \forall i,j,k \qquad \text{(transitivity)}$$

Let R be a fuzzy binary relation with $\mu_R(x_i, x_j)$ indicating the degree to which two elements x_i and x_j are similar (similarity matrix). The relation R is obviously reflexive and symmetric, thus it is called a *resemblance relation.*

A fuzzy relation is a *similitude relation* if it has the following properties:

$\mu_R(x_i, x_i)=1 \quad \forall (x_i, x_i) \in XxX$ (reflexivity)

$\mu_R(x_i, x_j)=\mu_R(x_j, x_i) \quad \forall (x_i, x_j) \in XxX$ (symmetry)

$\mu_R(x_i, x_k) \geq \max \min [\mu_R(x_i, x_j), \mu_R(x_j, x_k)]$

$\forall (x_i, x_j), (x_j, x_k), (x_i, x_k) \in XxX$ (max-min transitivity)

Note that compared to the notion of transitivity in conventional analysis, the present notion defines a weak transitivity of similarity.

If one wants to derive a set of equivalence classes (and not simple partitions) there is a need for the similarity matrix being at least max-min transitive. As it is known [21], a method to transform an intransitive similarity matrix into a transitive one is to derive the transitive closure $\mathcal{R}$ of R. The *max-min transitive closure* of a fuzzy binary relation R is

$$\mathcal{R}= R \cup R^2 \cup R^3 \cup..........$$

where $R^2= R\circ R$ is the max-min composition of R.

The element $\mu_{\mathcal{R}}(x_i, x_j)$ indicates the max-min transitive similarity of x_i and x_j.

A standard operation for two fuzzy relations is the *max-min composition*: given two relations R(x, y), S(y, z) defined on XxY and YxZ, respectively, the max-min composition of R and S, denoted as R∘S, is defined by

$$\mu_{R\circ S}(x, z)= \max_{y\in Y} \min [\mu_R(x, y), \mu_S(y, z)]$$

$x\in X$, $y\in Y$ and $z\in Z$.

By using the notion of max-min composition, one is allowed to derive new fuzzy relations. A transitive closure can be obtained by means of the following theorem.

Let R be any fuzzy binary relation. If for some k, the max-min composition $R^{k+1}=R^k$, then the max-min transitive closure is

$$\mathcal{R}= R \cup R^2 \cup R^3 \cup .... \cup R^k$$

Knowing that a fuzzy set A can always be decomposed into a series of α-level sets A_α, the similitude relation $\mathcal{R}$ can be decomposed into

$$\mathcal{R}= \bigcup_{\alpha\in[0, 1]} \alpha\cdot\mathcal{R}_\alpha$$

where

$$f_{\mathcal{R}}(x_i,x_j)= \begin{cases} 1 & \text{if } \mu_{\mathcal{R}}(x_i,x_j)\geq\alpha \\ 0 & \text{if } \mu_{\mathcal{R}}(x_i,x_j)<\alpha \end{cases}$$

and $\alpha_1>\alpha_2 \Rightarrow \mathcal{R}_{\alpha_1}\subset \mathcal{R}_{\alpha_2}$

Since $\mathcal{R}_\alpha$ is reflexive, symmetric and transitive in the sense of ordinary sets, then it is an *equivalence class of level α*. Within each α-level equivalence class, the similarity of any two units is no less than α.

Note that the equivalence classes obtained are ordinary disjoint sets. In fact, in order to have non-mutually exclusive equivalence classes, it is necessary to assume the use of a *min-addition transitive distance matrix* (which is a stronger assumption than max-min transitivity).

It can be proved that the following four algorithms generate the same partition [23 pp. 157-167]:

- the single linkage method,
- the connected components of an undirected fuzzy graph,
- the transitive closure of a reflexive and symmetric fuzzy relation, and
- the maximal spanning tree of a weighted graph.

Then the following consequences can be drawn:

1) since the connected components are independent of the numbering of the vertices, the algorithm is independent of the ordering of the inputs, and therefore it is *stable*;
2) no *reversal* exists in the dendrogram (reversal meaning that the merging levels are not monotonically decreasing, and thus a cut of the dendrogram may produce ambiguous results);
3) one is not obliged to use only the Euclidean metric (e.g. like in the "centre of gravity" procedures), but any distance measure (even if it does not respect the triangular inequality property) can be used; thus the method is quite *general*.

As an illustration of the application of the max-min composition we use the following similarity matrix as a starting point:

	1	**2**	**3**	**4**	**5**	**6**
1	1	0.729	0.426	0.399	0.403	0.403
2	0.729	1	0.410	0.386	0.390	0.390
3	0.426	0.410	1	0.675	0.584	0.569
4	0.399	0.386	0.675	1	0.729	0.672
5	0.403	0.390	0.584	0.729	1	0.595
6	0.403	0.390	0.569	0.672	0.595	1

By using the notion of max-min composition, the following new fuzzy relations are derived:

R^2

	1	2	3	4	5	6
1	1	0.729	0.426	0.426	0.426	0.426
2	0.729	1	0.426	0.410	0.410	0.410
3	0.426	0.426	1	0.675	0.675	0.672
4	0.426	0.410	0.675	1	0.729	0.672
5	0.426	0.410	0.675	0.729	1	0.672
6	0.426	0.410	0.672	0.672	0.672	1

R^3

	1	2	3	4	5	6
1	1	0.729	0.426	0.426	0.426	0.426
2	0.729	1	0.426	0.426	0.426	0.426
3	0.426	0.426	1	0.675	0.675	0.672
4	0.426	0.426	0.675	1	0.729	0.672
5	0.426	0.426	0.675	0.729	1	0.672
6	0.426	0.426	0.672	0.672	0.672	1

R^4

	1	2	3	4	5	6
1	1	0.729	0.426	0.426	0.426	0.426
2	0.729	1	0.426	0.426	0.426	0.426
3	0.426	0.426	1	0.675	0.675	0.672
4	0.426	0.426	0.675	1	0.729	0.672
5	0.426	0.426	0.675	0.729	1	0.672
6	0.426	0.426	0.672	0.672	0.672	1

Since in the series of max-min compositions $R^3=R^4$, the transitive closure is

$$\mathfrak{R} = R \cup R^2 \cup R^3 = R^3$$

Since $\mathfrak{R}$ is a similitude relation, it can be decomposed into equivalence classes with respect to the degree of similarity α.

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