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Elicitation, Evaluation and Recommendation in Multi-Criteria Decision Making Process

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Abstract— Traditionnally, multi-criteria decision making (MCDM) literature has devoted its effort to the evaluation and recommendation stage of decision analysis. A MCDM problem in this context is therefore completely determined by a table where the entry at a position of this table corresponds to the value of a criterion for the corresponding action and the main purpose for the analyst is to design a procedure that derive an order or pre-order over the actions set from that data table. This framework does have some drawbacks in practice such as the necessity for actions to be evaluated through the same criteria and one objective to realize. In this communication we go further ahead to consider also elicitation and measurement stage and derive a framework that allows also inhomogeneity of attributes that will characterize actions with regard to pursued multi-objectives. A case study in infrastructures projects portfolio selection under fund constraints to enhance sustainable development is considered as an illustrative application of the developed approach.

Keywords— Decision analysis, multi-criteria, multi-objectives, BOCR analysis, Choquet integral.

I. INTRODUCTION

Many decision making problems, if not all of them, in any socioeconomic domains, necessitate to choose actions or alternative options in order to satisfy many objectives and/or to optimize many criteria. Generally, decision options are referred to as *alternatives* if they are exclusive otherwise they are known as *actions*, see for instance [13] [26]. Such problems can represent practical situations in many domains: interested readers can consults following publications [1] [2] [11] [13] [16] [19] [24] [26] and references therein for some real world applications in management, engineering, economics, finance, etc.; as well as in politics, see for instance [6] for an application in e-democracy, etc. Applications may also be found in society protection and emergency management such as decision making related to protection against fire [25] or in human-machine interface design [10]; multicriteria classification problems as decision making problems are encountered in many domains such as finance [5], in supply chain [18], among others.

Though decision making process is a multiple stages process going from:

- i) problem formulation, that is the identification of the overall goal to be satisfied; through
- ii) possibly splitting this goal into many objectives to satisfy;
- iii) identifying possible actions and/or alternatives that may realize these objectives;

- iv) identifying attributes of former actions/alternatives that will be used to measure the adequacy of actions with regards to pursued objectives;
- v) to, evaluation and recommendation stage; this later stage is the most widely studied by decision aid and operational research communities where a decision problem is completely determined by $n \times m$ table or matrix X as shown by equation (1)

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ \dots & \dots & \dots & \dots \\ x_{i1} & x_{i2} & \dots & x_{im} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \quad (1)$$

where rows correspond to actions or alternatives, columns designate criteria, and the entry $X(i, j) = x_{ij}$ corresponds to the evaluation of alternative or action i with regard to criterion j ; this evaluation is generally done over any ordered set including binary evaluation such as good/bad.

In classical approaches, the evaluation (and recommendation) problem consist in going from data of the previous table (1) and decision maker's preferences to establish an order or pre-order over alternatives/actions set. To this end, two main approaches have been proposed in the literature:

- *value type approach*: roughly speaking these techniques consider a numerical function π known as value or utility function) defined on the actions/alternatives set such that, see equation (2)

$$\pi(i) \geq \pi(l) \Leftrightarrow i \succsim l \quad (2)$$

where $i \succsim l$ stands for "action i is at least as good, with regard to decision goal, as action l " leading to an order over actions set. The evaluation modeling process then consists in building such a function based on criteria measures and decision makers preference (obtained in general by answering some particular questions of the analyst); there are many techniques employed in the literature for constructing such a function where a number of them suppose a particular form for π such as an expected utility form or an additive value function (interested reader may consult [1], [16] and references therein.

- outranking methods: in this case, a pair-wise comparison of actions is carried up under each criterion to derive a pre-order over the actions set, allowing incomparability and/or intransitivity; methods such as ELECTRE procedures and PROMETHEE techniques [3] [26] belong to this category.

Besides these two main approaches, there exists decision learning approaches where a set of decision rules are derived by a learning process from a known decision table with possibly incomplete data, see [8]. One can see that to apply such approach, it is necessary to dispose of previously collected data of similar problems to that being solved; this is generally impossible for some problems.

All these approaches do have some limitations when facing real world decision making problems, among which following issues seem important:

- in general, the main decision purpose considered by these approaches is reduced to satisfying a single common objective whereas in practice the purpose of decision process may necessitate satisfying many objectives: one may think about selecting sustainable developing projects that may satisfy social, economical and environment objectives as admitted by the definition of sustainability;
- necessity for all actions or alternatives to be evaluated over the same set of criteria;
- numerical evaluation of attributes with regards to pursued objective;
- lack of structuring framework that guide the search for necessary information.

In this communication we propose a structured method that goes through important items of decision making process enumerated in the previous section in order to address as much as possible limitations of classical approaches raised in the previous items.

II. STRUCTURED MODELING: BOCR ANALYSIS

We consider a decision process to go through four main steps:

- i) definition of the overall goal of decision making;
- ii) identification of objectives to satisfy in order to realize the overall goal and possible actions to undertake; though in some cases objectives and actions may be related, here we consider them to be independent so that they can be elicited in parallel;
- iii) elicitation of attributes, that is characteristics of actions that can be used to evaluate them with regards to pursued objectives;
- iv) evaluation and recommendation, this step consists in "aggregating" information gathered in previous items to derive a selection procedure.

The two late items iii) and iv) are that considered in subsequent sections.

A. Elicitation process

We consider at this stage that the set of objectives to satisfy as well as potential actions/alternatives that can be used to satisfy these objectives are completely determined and the purpose now is to derive a framework to elicitate

attributes of actions/alternatives that can be used to evaluate the adequacy of these actions with regards to pursued objectives. In order to dispose with a structured framework for the elicitation and evaluation process of attributes, we adopt an approach that highlights the bipolarity of attributes with regards to objectives that we consider to be inherent to any decision analysis problem. We are motivated by the fact that cognitive psychologists have observed for long time that human, often, evaluate alternatives by considering separately their positive aspects and their negative aspects; that is on a bipolar basis, see for instance [3]. To this end, supporting and rejecting notions were introduced in [23] that relate attributes to objectives leading to an evaluation model in terms of two measures or indices (selectability and rejectability) for each action/alternative in the framework of satisficing game theory [17]. These notions permit to partition attributes set into three subsets given an objective: attributes that support this objective, attributes that reject this objective and attributes that are neutral with regard to this objective; of course only supporting and rejecting attributes are interesting for evaluation process. By taking into account uncertainty, authors suggest in [23], to elicitate and assess attributes in a decision analysis by partitioning them into benefit (*B*): certain attributes that support decision objective; opportunity (*O*): uncertain attributes that support decision objective; cost (*C*): certain attributes that reject decision objective; and risk (*R*): uncertain attributes that reject decision objective; leading to a framework known as BOCR analysis; this elicitation process is resumed by the following Figure 1. An action *i* is therefore completely characterized by

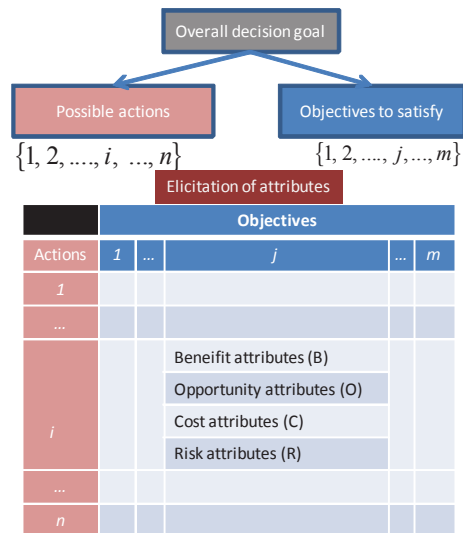


Fig. 1. Process for eliciting attributes

what we refer to as its BOCR identity card as shown by Figure 2 that corresponds to the i^{th} line of the table depicted on former Figure 1. Notice that the table given on Figure 2 is just an indication, indeed, in practice attributes may need to be decomposed until an operational and measurable level is reached.

Action/alternative (i): description and possible constraints		
Objectives	BOCR factors	Attributes
.....
Objective j	Benefit (B)	-a: description (weight $\alpha(a)$, value $v(a)$) ...
	Opportunity (O)	-a: description (weight $\alpha(a)$, value $v(a)$) ...
	Cost (C)	-a: description (weight $\alpha(a)$, value $v(a)$) ...
	Risk (R)	-a: description (weight $\alpha(a)$, value $v(a)$) ...
.....

Fig. 2. BOCR structured identity card of an action or an alternative

Finally in this framework, each action or alternative i , will be characterized by four measures, its benefit measure $B(i)$, its opportunity measure $O(i)$, its cost measure $C(i)$, and its risk measure $R(i)$, which can be considered as criteria in the classical way of MCDM; these measures are obtained by aggregating the corresponding measures over the set of objectives which are obtained by aggregating attributes measure of each category. Given the homogeneity of attributes obtained from BOCR structuring that creates synergy between measure to aggregate, a synergetic aggregation operator such as Choquet integral associated with a weighted cardinal fuzzy measure (WCFM), see [22], that leads to a straightforward formula for this integral, is used at any level that needs aggregation.

This model allows actions/alternatives to be characterized by heterogeneous attributes and incomparability between alternatives in terms of Pareto-equilibrium. Indeed, decision making situations where alternatives are characterized by attributes of different nature are pervasive in real world applications. One may think about a government evaluating projects that belong to different domains such as health, infrastructures, social, economics, etc. with the main objective to enhance a country developing process or an enterprise planning to invest in projects of different nature. In these situations, though attributes characterizing projects may be completely different, the important thing is their adequacy with regards to the pursued objectives, so that alternative projects can be ultimately compared on the same basis (decision maker desires).

Once attributes are elicited comes the step of assessment of their quantitative strength with toward the realization (for supporting attributes) of pursued objectives or against (for rejecting attributes) the achievement of these objectives.

B. Assessment of parameters

The normalized value $v(a)$ of attribute a for a given BOCR component can be obtained by normalization of row measure, by expert elicitation for operational attributes or by aggregating sublevel attributes measures; it represents how well this attribute contribute to the corresponding BOCR component achievement; the weight $\omega(a)$ in con-

trary represents the relative importance degree of this attribute in comparison of other attributes of the same category and level that can easily be determined by methods such as analytic hierarchy process (AHP), see [14], by answering questions like “how important is the contribution of attribute a in comparison of its counterparts in the realization of upper level attribute”. Uncertain components, opportunity and risk, identification and assessment approach may build on well known risk assessment approach, see [9], [20].

Normalizing row measures is important in order for aggregation to operate efficiently; in the literature, normalizing scheme encountered are dominated by the form given by equation (3)

$$v(a_i) = \frac{a_i}{\max_i(a_i)} \text{ or } v(a_i) = \frac{a_i - \min_i(a_i)}{\max_i(a_i) - \min_i(a_i)} \quad (3)$$

these normalization schemes do rise some problems in applications, such as:

- necessity to numerically evaluate attributes; this is not always the case in practice;
- necessity to know the measurement range at advance whereas in practice and mainly in the case of dynamic behavior of problem data, one does not know this range in advance;
- independence with regards to decision makers attitude or feeling though it is obvious that value accorded by a decision maker to an attribute given its row measure on some scales will depend on his/her feeling, habit, situation, etc.;
- etc.

In this communication, we consider a value type normalization scheme; in this scheme a decision maker will be asked to map actual measurement of an attribute to a value between 0 and 1 possibly using graphical support (where the shape of a curve depends on decision maker feeling) as shown on Figure 3 that displays some possible shapes; thus, the measure $v(a)$ shown on the previous Figure 2 will be a normalized value obtained by this normalization scheme. One should notice that this scheme of normaliza-

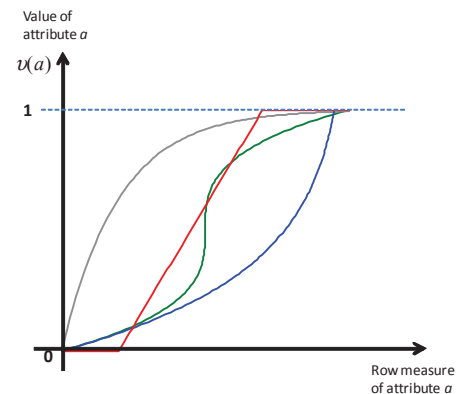


Fig. 3. Value type normalization scheme

tion works even if possible measures of an attribute belong

to an ordered discrete set; this normalization scheme also may integrate the nature (positive or negative) of the attribute.

Let us now, denote by $b_k^o(i)$, $o_k^o(i)$, $c_k^o(i)$, and $r_k^o(i)$ the normalized values of benefit, opportunity, cost and risk attribute k of action i with regard to objective o ; and by $\mathbf{b}^o(\mathbf{i})$, $\mathbf{o}^o(\mathbf{i})$, $\mathbf{c}^o(\mathbf{i})$, and $\mathbf{r}^o(\mathbf{i})$ vectors gathering normalized benefit, opportunity, cost and risk measures respectively. Let us suppose now that decision maker is able to supply for benefit, opportunity, cost and risk attributes normalized relative degrees vectors in terms of $\omega_{\mathbf{b}}$, $\omega_{\mathbf{o}}$, $\omega_{\mathbf{c}}$, and $\omega_{\mathbf{r}}$ then the overall benefit ($B^o(i)$), opportunity ($O^o(i)$), cost ($C^o(i)$), and risk ($R^o(i)$), measures of action i for objective o are given by equations (4) and (5)

$$\begin{aligned} B^o(i) &= C_{\omega_{\mathbf{b}}}^{wcfm}(\mathbf{b}^o(\mathbf{i})); O^o(i) = C_{\omega_{\mathbf{o}}}^{wcfm}(\mathbf{o}^o(\mathbf{i})); & (4) \\ C^o(i) &= C_{\omega_{\mathbf{c}}}^{wcfm}(\mathbf{c}^o(\mathbf{i})); R^o(i) = C_{\omega_{\mathbf{r}}}^{wcfm}(\mathbf{r}^o(\mathbf{i})) & (5) \end{aligned}$$

where $C_{\omega}^{wcfm}(x)$ stands for Choquet integral of numerical vector x associated to weighted cardinal fuzzy measure with weight vector ω , see [22].

Let us now denote by $\mathbf{b}(\mathbf{i})$, $\mathbf{o}(\mathbf{i})$, $\mathbf{c}(\mathbf{i})$, and $\mathbf{r}(\mathbf{i})$ vectors gathering benefit, opportunity, cost and risk measures with regard to all objectives and by ω^o , the relative importance vector of objectives with regard to overall goal, then the overall opinion decision maker regarding the action i is captured by the benefit measure $B(i)$, opportunity measure $O(i)$, cost measure $C(i)$, and risk measure $R(i)$, that are given by equations (6) and (7)

$$B(i) = C_{\omega_{\mathbf{b}}}^{wcfm}(\mathbf{b}(\mathbf{i})); O(i) = C_{\omega_{\mathbf{o}}}^{wcfm}(\mathbf{o}(\mathbf{i})); \quad (6)$$

$$C(i) = C_{\omega_{\mathbf{c}}}^{wcfm}(\mathbf{c}(\mathbf{i})); R(i) = C_{\omega_{\mathbf{r}}}^{wcfm}(\mathbf{r}(\mathbf{i})) \quad (7)$$

C. Recommendation

Recommendation procedure will depend on the problem to solve (selecting, ranking, sorting, or classification, etc. of actions/alternatives in order to satisfy some purposes); let us illustrate the case of forming portfolio of actions that is selecting a subset of actions in order to optimize BOCR components of the portfolio when respecting some resources limitation conditions. Let us designate by f_i the numerical quantity of resource needed by action i to be implemented and by f the available resource level. Given the structure of BOCR analysis, we propose two approaches to solve this problem: binary multi-objectives programming (BMOP) and bipolar measures approach for short list (BMSL) selection in the framework of satisficing game [17].

C.1 BMOP: binary multi-objectives programming

Given the description presented in above paragraph, the problem, here, is to form a portfolio that maximize global benefit and opportunity and minimize global cost and risk when respecting limited resource condition. Let us denote by x_i a binary variable indicating whether action i is included or not in the portfolio, thus $x_i = 1$ if i is included

in the portfolio and $x_i = 0$ if not. The problem to solve is therefore a multi-objectives programming problem given by following formulation (8)

$$\left\{ \begin{array}{l} \max \left\{ \sum_{i=1}^n (B(i))x_i \right\} \\ \max \left\{ \sum_{i=1}^n (O(i))x_i \right\} \\ \min \left\{ \sum_{i=1}^n (C(i))x_i \right\} \\ \min \left\{ \sum_{i=1}^n (R(i))x_i \right\} \\ \sum_{i=1}^n f_i x_i \leq f \\ x_i \in \{0, 1\} \end{array} \right. \quad (8)$$

To solve this problem, different algorithms developed in multi-objective optimization literature such as genetic algorithms, evolutionary algorithms, constraint satisfaction algorithms, etc., see for instance [4] [27] and references therein, can be used.

C.2 BMSL: bipolar measures for short list selection

Given the way the identity card of each action is structured in terms of positive incentives (benefit and opportunity) and negative impacts (cost and risk), bipolar analysis approach developed by the authors, see ([18] [19] [21] [23]), where an action in decision analysis is characterized by its *selectability degree* and its *rejectability degree* is well suited for forming a portfolio of actions; it means that one avoid immediate compensation between positive incentives and negative impacts. Selectability measure $\mu_S(i)$ and rejectability measure $\mu_R(i)$ of action i in the point of view of decision maker can finally be obtained by equations (9) and (10)

$$\mu_S(i) = \frac{\phi B(i) + (1 - \phi) O(i)}{\sum_l \{\phi B(l) + (1 - \phi) O(l)\}} \quad (9)$$

$$\mu_R(i) = \frac{(1 - \phi) C(i) + \phi R(i)}{\sum_l \{(1 - \phi) C(l) + \phi R(l)\}} \quad (10)$$

where $0 \leq \phi \leq 1$ is the risk averse index of decision maker; this index permits to adjust the attitude of a decision maker toward uncertainty; for instance a risk averse decision maker, for who $\phi \rightarrow 1$, will balance immediate benefit (B) with potential harm (R) regardless of potential opportunity (O) and immediate cost to pay (C).

To select the final portfolio, following steps (building on satisficing games theory [17]) can be used.

- Form the satisficing equilibrium set S_q of actions that is given by equation (11)

$$S_q = \Sigma_q \cap E \quad (11)$$

where E is the equilibrium set (actions for which there is no other actions having less rejectability degree and at least the same selectability degree or having more selectability and at most the same rejectability degree; this set is always no empty by construction) and Σ_q is the satisficing set, see [17], at the boldness or caution index q , given by equation (12) below

$$\Sigma_q = \{i : \mu_S(i) \geq q \mu_R(i)\} \quad (12)$$

- Compute the corresponding resource level $f(S_q)$ as given by equation (13)

$$f(S_q) = \sum_{i \in S_q} f_i \quad (13)$$

– If $f(S_q)$ is less than f , all satisficing equilibrium actions are included in the portfolio; if the remaining resource $f - f(S_q)$ is sufficient for at least one project, it will be used in a second selection step where the actions already included in the portfolio are excluded; the process is repeated until no action can get resource with the remaining resource or available resource is completely used. One may alternatively decrease caution index in order to include as much as equilibrium actions (if any) in the portfolio until resource is completely used.

– If $f(S_q)$ is greater than the available resource f , then increase caution index q to reduce the number of satisficing actions and repeat previous steps.

III. CASE STUDY

3. Description of the problem

Authorities of a rural area in a developing country are confronted to difficulties related to a quick population growing of this area in terms of lack of infrastructure facilities for the well-being of the population. Furthermore, they are sensible to facilities that enhance sustainable development which is considered as the most important issue for the future of this area in particular and national development in general. For this purpose and after largely consulting population and experts, five developing projects have been identified (see [19] for more details):

• **Project 1 (build and operate a waste management facility):** as population is quickly growing, the issue of managing waste became important because actually waste is being thrown everywhere causing by the way health problems, soil pollution, sanitary conditions degradation, etc.. Necessary amount for this project is $F(P_1) = 75$ million MU where MU stands for monetary unit.

• **Project 2 (build and maintain a bridge that connects the area to a main national road):** the considered rural area is supplied in different goods from main towns of the country via a rural road that across a river; so that during raining periods, accessibility is rendered difficult causing many troubles for the population of this area; a bridge over this river would be a great advancement towards developing process. Necessary amount for this project is $F(P_2) = 63$ million MU.

• **Project 3 (install and operate a wind farm to supply electricity to this area):** at the moment, there is no electricity facility in this area; and its isolated condition render its connection to national power supply infeasible, which power supply, is actually insufficient for that nation. Necessary found of this project is $F(P_3) = 72$ million MU.

• **Project 4 (build and operate a water supply facility):** actually, water used by inhabitants of the considered area for different activities of their domestic life comes from the river where children and women went to fetch water. Therefore having a modern water supply facility in this area will be very important for the population in differ-

ent viewpoints. The project consists therefore in making a drill in some points to get drinking water from underground. Necessary amount for this project is $F(P_4) = 55$ million MU.

• **Project 5 (build and operate a dam for agriculture irrigation):** principal activity of population of the considered area is agriculture; but it is noticed that the productivity of cultivated lands is very low due in part to insufficient raining. The idea is therefore to build and operate a dam in order to retain rain water to be used for irrigation by farmers. Necessary amount for this project is $F(P_5) = 30$ million MU

As the available fund of $F = 150$ million MU cannot fund all projects, they must be evaluated in order to select projects that must constitute the most sustainable projects portfolio. It is well accepted, from the definition of sustainable development paradigm (development that meets the needs of the present without compromising the ability of future generations to meet their own needs) given by former Norwegian Prime Minister Gro Harlem Brundtland in 1987, that sustainability of a project must be assessed through three main objectives, social objective, economical objective and environmental objective; so this three objectives are those used to evaluate each project and BOCR factors values of these projects are shown on the following Table I (detailed calculations are omitted here because of lack of place, interested readers can consult [19] to this end).

Projects	$B(P_i)$	$O(P_i)$	$C(P_i)$	$R(P_i)$
P_1	0.56	0.61	0.67	0.61
P_2	0.62	0.54	0.65	0.54
P_3	0.58	0.64	0.73	0.44
P_4	0.46	0.56	0.61	0.45
P_5	0.54	0.72	0.65	0.68

Table I: BOCR evaluation of projects

A. Results

From data of previous Table I, portfolio forming problem has been considered in two levels, by varying the risk averse index ϕ from risky decision making ($\phi = 0$); mean risk taking ($\phi = 0.5$) and risk averse decision making ($\phi = 1$); and following Figure 4 shows obtained results in the case of BMSL recommendation model with a boldness index of $q = 1$.

For $\phi = 0$, $S_1 = \{P_5\}$, that is, only project 5 is a satisficing equilibrium (comparison of opportunity to immediate cost); by disregarding project P_5 , projects P_1 , P_3 and P_4 become equilibriums for a total amount of 202 million MU that cannot simultaneously be funded by the remainder of $150 - 30 = 120$ million MU; furthermore one can easily see that only one of these projects can be funded with the remainder fund; by reasoning on maximum boldness index basis, the next project to fund is project P_4 with a remainder fund of 65 million MU that can cover financial amount of project P_2 (that becomes equilibrium when P_4 is disregarded) so that in this case the portfolio consists in $\{P_2, P_4, P_5\}$ with a remainder of 2 million MU. For

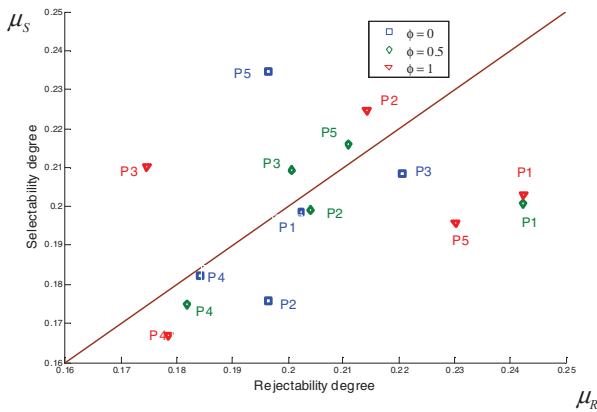


Fig. 4. Representation of results in the plan (μ_R, μ_S)

$\phi = 0.5$, the satisficing equilibrium set at boldness index $q = 1$ is $S_1 = \{P_3, P_5\}$ which total fund is 102 million UM and the remainder fund of 48 million UM cannot finance any of the rest of projects. For risk averse decision making, $\phi = 1$, the satisficing equilibrium projects set is $\{P_2, P_3\}$ that is funded for 135 million MU and the remainder of 15 million MU cannot fund a further project.

IV. CONCLUSION

A structured framework for multi-criteria decision making processes has been considered in this communication. The main contribution of this communication concerns the clarification of objectives notion, attributes notion and criteria notion compared to existing approaches in the literature. The proposed approach permit to characterize actions by heterogeneous attributes with regard to pursued objectives. Indeed, in this communication, an objective is something decision maker seeks to achieve to attain some ultimate goal, an attribute is a feature of an action that may act toward or against the realization of some objectives and a criterion is obtained by "aggregating" the strength of some attributes over all objectives to represent an indicator of how well or resistant is an action with regard to overall decision goal. Furthermore the proposition to assess the strength of attribute by a value function permits enlarges possibilities of scales and ways of measurement of row data.

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