Project evaluation and selection in a network of collaboration: A consensual disaggregation multi-criterion approach

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Abstract

Project evaluation and selection are usually complex processes in large organizations, for they involve several stakeholders who are to evaluate competing alternatives with respect to a certain set of criteria and then make a choice as to which projects are to be implemented. This is particularly more so in the case of international organizations where the competing projects are proposed by units or divisions having different values and preferences. This paper discusses a project evaluation and selection methodology based on multi-criteria disaggregative approach used as an instrument rather than as a descriptive tool, as it is often the case in the literature. The proposed methodology has been developed for an international organization which has more than a dozen country members and provides them with a platform to maximize the level of consensus among the member countries, subject to some certain budgetary constraints and resentment-avoiding principles. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The globalization of economic activities, democratization of collective decisions and proliferation of business networks have turned upside down the conventional systems of decision making. In the first instance, globalization of economic activities presents the company with a multitude of political, economic and social systems in different regions of the world. The democratization of collective activities leads to a greater implication of individuals and groups in the process of decision making. The imperatives of competitiveness and the resulting necessary rationalizations lead to greater consideration of externalization strategies of activities. Finally, business networking, ranging from simple project based partnership to virtual enterprises (enterprises which conduct almost all of their activities by external agents), causes an...
explosion in the number of its partners, which have their own system of values, follow different objectives and face particular constraints (see Byrne, 1993). The enumeration of these different factors results, on one hand, in an increase in decision centres with which the company or organization must conduct business and, on the other hand, causes a significant change in the nature of these relations which become more and more transparent, democratic and cooperative (see Riggins et al., 1994).

The presence of multiple decision centres makes the decision processes more complex. Companies or organizations which are not sufficiently prepared to deal with these complexities may adopt behaviour patterns of evasion which prevents them from profiting fully from the opportunities offered to them by globalization and networking. Similar to all other strategies, individual gains depend not only on the particular objectives and the rules of the game, but also on the perception of the players with respect to these particularities and their own skills in adapting to the complexities of the environment, in understanding the rules of the game, anticipating the behaviour of the other players and profiting from opportunities of collaboration.

The partners in a network are continuously called upon to make collective decisions on new directions to follow, composition of the network, common use of resources, sharing of strategic or operational information, etc. Development of common projects is an important advantage offered by business networks. The success of such projects depends to a great extent on the degree of consensus among the partners as to the group of criteria employed, the aggregation process followed, the ranking process used and budgetary allocations imposed. The pertinent literature indicates that much has been written on group decisions (see Keeney and Buttler, 1993) as well as on evaluation and selection of projects (see Stewart, 1991). However, published research as yet does not exist on their joint consideration in a networking context.

The complexity of negotiation processes defy businessmen and academicians to design models of decision making which would take into consideration the presence of multiple stakeholders as well as conflicting objectives and which help in attaining consensus in collective decision making. With this in mind, the aim of the present article is to propose a methodology for evaluation and selection of projects (investment or R&D) with the ultimate aim of securing maximum consensus among the different stakeholders. The proposed methodology is the product of an empirical study conducted for an international organization consisting of 12 countries in order to design a framework to evaluate and select investment projects based on a multi-criteria analysis for collective decision making.

The model suggested in this paper is in essence a descriptive multiple criteria analysis model. Descriptive multiple criteria approaches can be classified into two groups: those based on statistical techniques and those based on mathematical programming. Statistical methods include, particularly, regression analysis (Beckwith and Lehmann, 1973), monotonous regression (Green and Rao, 1971) and multi-dimensional scale analysis (Caroll, 1972) whereas mathematical programming methods are represented particularly by the works of Srinivasan and Shocker (1973a,b), Pekelman and Subrata (1974), Jacquet-Lagrèze and Siskos (1982), Siskos and Zopounidis (1987) and Stewart (1990). Many studies converge to establish the superiority of approaches based on mathematical programming, notably the linear programming, in terms of their predicted power (Horsky and Rao, 1984; Shocker and Srinivasan, 1979; Jain et al., 1979; Siskos, 1985). The proposed method in this study belongs to the second group and constitutes an extension of the multi-criteria analysis methods of Kettani (1988) and Oral and Kettani (1989a,b, 1990). However, it is different in the sense that the disaggregation procedure does not have the objective simply to reproduce the historical outcome in order to understand the underlying principles of decisions made in the past, but rather to estimate the values of the parameters of the decision model that reflects the rules and characteristics of a decision making process.

The project evaluation and selection methods proposed in the literature can be classified into
two categories. One is the class of compensatory methods, which reduce a multi-dimensional evaluation into a single-dimensional one through an aggregating value function, thereby establishing a trade-off between criteria. For this class of methods, one can cite, for example, cost/benefit analysis, multi-attribute utility theory (MAUT), and analytical hierarchy process (AHP). Baker and Freeland (1975), Souder (1973a,b), Vargas (1982), Aczel and Alsina (1986), Lauro and Vepsalainen (1986) and Saaty (1986) provide good examples of these methods. The other class of methods of project evaluation and selection is that of non-compensatory methods, where trade-offs between criteria are restricted. The methods proposed by Roy (1985), Cook and Kress (1985), Cook and Seiford (1982) and Cook et al. (1988) are some examples in this class and require at least a ranking of criteria, if not the explicit values of the weights to be assigned to the criteria.

The principal features of the methodology presented here have been achieved through a certain use of different concepts from different fields. The values and preferences of stakeholders have been reflected in the evaluation process by allowing each project to have its set of weights most favourable to itself. This way each and every project-proposing unit is given the best chance possible reflecting its own values and judgments. Data envelopment analysis (DEA), which was first introduced by Farrell (1957) and then popularized by Charnes et al. (1978, 1981) and others, also permits a decision making unit (DMU) to assign most favourable weights. DEA, however, concentrates on only self-rating cases, whereas in this paper, cross-rating is also included.

The resentment-avoiding principles, the dominance and non-dominance principles, on the other hand, are based on the concept of kernel of the graph theory as defined by Roy (1985). The verbal descriptions of these principles have been converted into a mathematical model for the project selection purpose. Again, the concept of concordance of Roy (1985) has been made a part of the definition of consensus in this paper and integrated into the project selection model. With these features, the project selection model has come to represent a nonlinear combinatorial optimization problem. Through the linearization technique of Oral and Kettani (1992), a mixed-integer programming problem is repetitively solved to obtain a subset of projects for funding.

In a business network or collaboration, it is generally preferred that decisions be taken by consensus and that the decision model as well as its parameters reflect the variety of viewpoints and values, the diversity of objectives and the specific constraints of each of the partners. The proposed methodology based on the article by Oral et al. (1991) subscribes to such a philosophy of consensual decision making. At the start, three experts assign scores independently to each project under consideration with respect to a group of criteria judged to be most pertinent. Then, a process of self-rating is used to give a most favourable rating to each and every project. The cross-evaluation process, on the other hand, permits to rate each of the projects from the viewpoint of the other projects in a most favourable way. Finally, the selection phase employs the concepts of graph theory to iteratively select the projects to be financed.

2. Application context

This paper summarizes a project evaluation and selection methodology that has been developed for an international organization. The international organization in question has more than a dozen country members. Each member country has several units where certain investment needs are identified and converted into “project proposals” to improve the performance of the system the international organization represents. In this study, the number of such projects proposed by the member countries is 44. The expert valuation of each project is done with respect to a previously agreed set of eight criteria.

Obviously, in an international context, the scores to be allowed with respect to each criterion are not readily available for every project, and the task of obtaining such scores, far from being a trivial one, deserves a methodology by itself. First, one needs a group of experts who are
knowledgeable about the characteristics of the existing system of the international organization as well as about the future needs for a more effective system structure. Therefore, it is necessary to devise a mechanism through which a sufficient number of such experts can participate in determining the scores of projects. Second, the set of criteria that is considered in the evaluation process does not lend itself easily to quantification. Most of the criteria are of a qualitative nature and require the development of new and innovative measurement techniques in order to have more realistic and objective scores. The method of Delphi, for instance, or a variation of it could be a tool to reach an agreement as to the scores of projects with respect to each criterion. Third, the composition of experts should be such that the community of users, the system designers, and the planners are appropriately represented in the group of experts to reflect the values of different units.

In this application, however, we have followed a more pragmatic approach in obtaining the scores for projects. Three experts, referred to as Experts A, B, and C henceforth, were appointed to determine the scores of 44 projects with respect to the criteria chosen. Each one of the experts chosen has long been working for the international organization in question and is knowledgeable about the actual and desirable characteristics of the system it represents. Expert A is from the planning group, Expert B is a long term consultant, and Expert C is from the community of system users.

The question that most naturally arises in the case of using three experts to determine the scores of the projects is this: is it possible that these three experts will assign scores that are “consistent” with each other? This will be discussed later in the Section 4.1.

In order to comply with the decision making context of the international organization, the project evaluation and selection methodology has to satisfy the following conditions.

(1) The set of criteria or attributes that will be used to evaluate the projects proposed by different units of member countries is agreed upon. Moreover, the scores of every project with respect to every criterion is provided by a group of experts prior to project selection. The criteria are divided into two groups: several output-related criteria (measuring the contributions made to the performance of the system the international organization represents) and one input-related criterion (amount of investment needed, measuring financial requirement). Let $S_{kp}$ be the score attained by Project $k$ with respect to contribution type $p$ and $b_k$ the budget required by Project $k$.

(2) It is assumed that the importance of a given project criterion or attribute might vary from one project-proposing unit to another and therefore there is a need for using project-specific weights to reflect the values of the project-proposing units. The implication of this assumption is that every project-proposing unit will have the opportunity to determine its own weights to be assigned to the criteria in rating the projects. Such an approach engenders confidence about the methodology in the project-proposing units, and hence in the member countries.

(3) Project evaluation and selection are to be done within the context of a group of project-proposing units, each unit being a stakeholder itself in the selection process. The perception of one unit regarding the merits of the project of another unit is most relevant and therefore needs to be taken into account. Put differently, each unit should have a say in the rating of the projects of the other units. This implies that the project selection is in fact to be regarded as a collective decision making process.

(4) The international organization in question is sensitive to the needs of the member countries and seeks to avoid the occurrence of unwarranted resentment between its members. This requires a clear understanding between the stakeholders as to the kind of resentment that is to be avoided. Two types of resentment-avoiding principles are defined to be complied with during the process of project evaluation and selection.

Assuring the opportunity to evaluate one another and avoiding possible resentment between the stakeholders might not be sufficient to reach a perfect level of consensus when certain constraints, such as the level of available funds, are in play. In this case, one should aim at reaching the highest level of consensus possible.
3. Methodology

The evaluation and selection methodology used in the application consists of three interrelated modules: (1) project self-rating module, which assigns the most favourable rating to the project being evaluated, (2) project cross-rating module, which assigns the most favourable rating to the project being evaluated from the viewpoint of another project, and (3) project selection and consensus formation module, which identifies a set of projects for funding with the highest level of consensus possible subject to budget availability and certain types of resentment-avoiding principles. These three modules are sequentially made operational in an iterative procedure. In each iteration, a subset of projects is selected and if there are still funds available after the completion of an iteration then another iteration is performed, and this process continues until the available budget is exhausted.

3.1. The self-rating model

Given that there is one input-related criterion (amount of investment needed), it is possible to simplify the rating process by determining the contributions realized per a chosen monetary unit for every project. This is done by dividing the scores of a project by the amount of its investment requirement. Thus the “standardized score”, say for Project $k$, becomes

$$s_{kp} = S_{kp}/b_k \quad \text{for} \quad k = 1, 2, \ldots, n,$$

where $S_{kp}$ is the score of Project $k$ with respect to Criterion $p$, $b_k$ the amount of investment required by Project $k$ and $n$ is the number of projects under consideration for funding. We need to integrate now these standardized scores $s_{kp}$ into a single score so that the overall rating of a project can be attained. The conventional multiple criteria analysis suggests that the overall rating of a project is equal to the sum of the standardized scores multiplied by their corresponding importance weights. In mathematical notation, the overall rating of Project $k$, for instance, is given by

$$R_k = \sum_{p=1}^{m} w_p s_{kp},$$

where $w_p$ is the weight of Criterion $p$ and $m$ is the number of criteria. This formulation of overall rating implicitly assumes that the importance of Criterion $p$ is the same for all projects, but ignores the possibility of differences of opinion between the project-proposing units. In other words, a particular value of $w_p$ is imposed on every unit whether they agree with it or not. In fact, it is quite possible that the units might have different views regarding the level of importance of a given criterion. A unit might value one particular criterion very highly whereas another unit might consider it to be less so. If such a difference exists between the units and if it is necessary to recognize this fact while rating the projects proposed by different units then the overall rating of a project, for instance, Project $k$ can be found using the following formula:

$$R_{kk} = \sum_{p=1}^{m} w_{kp} s_{kp},$$

where $w_{kp}$ is the importance of Criterion $p$ within the context of Project $k$. Note that formula (2) allows every project to assign, if this be needed, its own weight to a given criterion. Then $R_{kk}$ can be interpreted as the rating of Project $k$ according to the values of the unit proposing Project $k$. When a unit is given the opportunity to assign its own weights to the criteria it will do so in a way that is most favourable to its own project in the rating process. Thus assigning weights to the criteria naturally becomes an optimization problem for every unit. For instance, the unit proposing Project $k$ would like to find those values of $w_{kp}$ that maximize $R_{kk}$. In this case, the following model becomes the best advocate for the unit proposing Project $k$:

Maximize $\sum_{p=1}^{m} w_{kp} s_{kp}$

subject to:

$$\sum_{p=1}^{m} w_{kp} s_{kp} \leq 1 \quad \text{for} \quad j = 1, \ldots, n,$$
\[ w_k \geq 0 \quad \text{for} \quad p = 1, \ldots, m. \] (5)

Although Project \( k \) is allowed to find the optimal values \( w_{kp} \) for itself, it needs to be consistent with the rest of the projects. This is attained by the constraints in (4), which imply that no project can have a rating greater than 1 with the weights that are optimal for Project \( k \). In another sense, the self-rating model imposes a superior limit for ratings of the projects, which is 1. It should be observed that there is no constraint requiring that the sum of the weights must be equal to unity, as usually assumed by most of the conventional multiple criteria analysis methods.

The self-rating model really is the best advocate for the unit proposing Project \( k \) since it is giving the best chance possible to Project \( k \) in the rating process. This is achieved through producing the optimal weights for Project \( k \). The favour done for Project \( k \) is also to be secured for every project under consideration to be fair to every unit. This implies that one must have a self-rating model for every project.

3.2. The cross-rating model

It is quite natural to recognize the right of a unit to rate its own project, given the fact that there exist differences in organizational values and preferences. Also quite natural, on the other hand, particularly in democratic societies, is the right to rate the projects of the others according to one’s own values and preferences. In other words, in a “group decision making” context, the perceptions of the group members need to be taken into consideration in the process of project rating. A way to achieve this is to apply the optimal weights of one project in rating the other projects. Suppose that the optimal weights for Project \( k \) are \( w_{kp}^* \), \( p = 1, \ldots, m \). Assuming that \( w_{kp}^* \)s form a unique optimal solution, the rating of Project \( j \) from the viewpoint of Project \( k \) becomes

\[ R_{jk} = \sum_{p=1}^{m} w_{kp}^* s_{jp}. \]

However, the self-rating model might produce multiple optimal solutions. In other words, different sets of optimal solutions can yield the same rating for Project \( k \). Denote by \( M_k \) the set of optimal weights yielding the same rating for Project \( k \). The question becomes then which one of these optimal sets of weights will be used in finding \( R_{jk} \). Again, we use the same principle; that is, we choose the one that is most favourable to Project \( j \). In other words, we solve the following optimization problem for Project \( j \):

Maximize
\[ \sum_{p=1}^{m} w_{jkp} s_{jp} \] (6)

subject to:
\[ \sum_{p=1}^{m} w_{jkp} s_{jp} \leq 1 \quad \text{for} \quad j = 1, \ldots, n, \] (7)
\[ \sum_{p=1}^{m} w_{jkp} s_{kp} = R_{kk}, \] (8)
\[ w_{kp} \geq 0 \quad \text{for} \quad p = 1, \ldots, m. \] (9)

Let \( w_{jkp}^* \) be the optimal values obtained from the model in (6)–(9). Then we have

\[ R_{jk} = \sum_{p=1}^{m} w_{jkp}^* s_{jp} \quad \text{for} \quad \forall j, j \neq k. \]

The constraint in (8) forces the optimization process to maintain the most favourable rating \( R_{kk} \) that was already obtained from the self-rating model for Project \( k \). Again, the cross-rating model is the best advocate for Project \( j \) when it is being rated from the viewpoint of Project \( k \).

The two ratings \( R_{kk} \) and \( R_{jk} \) obtained from the self-rating model and the cross-rating model form a square matrix, \( R = ||R_{jk}|| \). How can this rating matrix \( R \) be used in selecting a set of projects with a highest level of consensus possible subject to a budgetary constraint and certain types of resentment-avoiding principles? This is discussed below in the development of project selection and consensus formation model.
3.3. The model of project selection and consensus formation

The objective of this model is to determine a subset of projects from the set of candidate projects for funding without causing any resentment while achieving the highest possible level of consensus subject to a budgetary constraint.

Suppose, for a moment, that \( R_{ji} \geq R_{ki} \) for all \( i = 1, \ldots, n \). This implies that Project \( j \) is relatively more worthy than Project \( k \) according to every single project. In this case the level of concordance as to the superiority of Project \( j \) over Project \( k \) is a perfect score: 100% concordance. In reality such a case happens rather rarely. What happens most of the time is that \( R_{ji} \geq R_{ki} \) for some \( i \), and \( R_{ji} < R_{ki} \) for the rest. Assuming that the viewpoints of all units are equally important and legitimate, the level of concordance \( C_{jk} \) can be defined as follows.

The level of concordance. The level of concordance as to the superiority of Project \( j \) over Project \( k \) is defined as

\[
C_{jk} = \left( \frac{1}{n} \right) \sum_{i=1}^{n} \phi_{jki},
\]

where \( \phi_{jki} = 1 \) if \( R_{ji} \geq R_{ki} \) and \( \phi_{jki} = 0 \) otherwise.

According to this definition, \( C_{jk} \) is simply the ratio of the number of times the relationship \( R_{ji} \geq R_{ki} \) holds to the total number of candidate projects. Observe that the value of \( C_{jk} \) is known once the rating matrix \( R \) is given. Concordance data, more precisely the concordance matrix \( C = \left| C_{jk} \right| \), provides pairwise comparisons between projects. As such, they usually do not by themselves yield a straightforward indication as to which project is the least or most worthy. Therefore, from some detailed consensus information a more global contrasting of projects must be derived. The first step in that direction is to define a threshold beyond which the level of concordance is significant. Hence the concepts of outranking and consensus.

The outranking and the level of consensus. Project \( j \) is said to outrank Project \( k \) at the consensus level of \( \theta \) if \( C_{jk} > \theta \).

With this definition, the outranking relationship between the pairs of projects becomes a function of the level of consensus \( \theta \). A higher level of consensus will tend to decrease the number of outrankings. Also, it is to be observed that outrankings preserved by some value of \( \theta \) are not transitive. For instance, the superiority of Project \( j \) over \( k \) and the superiority of Project \( k \) over \( i \) do not necessarily imply that the superiority of Project \( j \) over \( i \) as well. Therefore, there does not exist a simple ordering of the projects on which a selection can be based. Accepting the existence of a non-transitive outranking relationship is to assume that the project selection process cannot be perfectly rational. Any selection that is not perfectly rational might create, on the other hand, some resentment between the organizations. In order to avoid possible resentments we need to introduce some principle applied in the selection process. We assume that no resentment occurs if the following two principles are strictly observed during the project selection.

Dominance principle. The set of rejected projects should include those projects each of which is outranked by at least one of the selected projects.

Put differently, the project that is not included in the set of selected projects has to be outranked by at least one of the projects included in the set of selected projects. This principle implies that a project that is not a clear dominating competitor should be given the benefit of doubt. It also asserts that being outranked, as long as this outranking is not originated from a selected project, is not a cause for exclusion. This is a graph theory concept that was first introduced by Roy (1985) to the context of decision making and termed as external consistency. As an example, consider the following situation. There are six projects under consideration for funding. At the consensus level of \( \theta \) they have the following outranking relationship (see also Fig. 1):

- Project A outranks Project D,
- Project B outranks Projects D and E,
- Project E outranks Project D,
- Project D outranks Project C.

Suppose we have decided to fund Projects A and B, and reject the others. This of course violates the dominance principle. In this situation, what will be the position of the units whose projects are rejected? The units proposing Projects D and E will
not have much to say since their projects are outranked by at least one of the selected projects. However, the units who are proposing Projects C and F will resent the selection made for the following reasons. The promoter of Project C will argue that his project should have been selected since none of the selected projects (Projects A and B) outranks his project. Although Project C is outranked by a rejected project (Project D), the promoter will compare his project only with those projects that are selected. The promoter of Project F has even a stronger case to make against the selection process. His project in fact is not outranked by any project, selected or rejected, implying Project F has no clear dominating competitor.

A strict observation of the dominance principle is therefore necessary to avoid the occurrence of the type of resentment discussed above.

Non-dominance principle. The set of selected projects should include only those projects that are not outranked by any selected project.

The non-dominance principle implies that the set of selected projects should not include any project that is outranked by another project in itself. Again, this concept was first introduced by Roy (1985) and termed as internal consistency in the multi-criteria analysis. The violation of this principle might mitigate certain kinds of resentment among the project-proposing units. As an example, consider the following situation. There are five projects under consideration for funding. At a certain level of consensus, suppose that the outranking relationship between the projects is as given below (see also Fig. 2).

Project A outranks Projects B, D, and E,
Project B outranks Projects C and D.

Assume that Projects A and B are selected for funding and the others are rejected. This is a clear violation of the non-dominance principle since one of the selected projects (Project B) is outranked by another selected project (Project A). Now what will be the position of the units whose projects are rejected? The unit promoting Project D will not have much to say since its project is outranked by both of the projects selected. The promoter of Project C is not in a position to bring an argument against the way the selection is made. Project C, although not outranked by Project A, is outranked by Project B, which is outranked by Project A. The argument of Project E’s promoter, however, will be different. The promoter will compare Project E with the selected Project B, rather than with rejected projects, and will make the following legitimate point: why is Project B selected and not Project E, given the fact that they are both in the same position (that is, both being outranked by the same selected project, Project A). There is no satisfactory response to this and therefore it becomes a source of resentment.

Again, the non-dominance principle needs to be strictly observed if one wishes to avoid the kind of resentment discussed above.

The dominance and non-dominance principles are both satisfied if the following rule is observed:

Fig. 1. A violation of the dominance principle.

Fig. 2. A violation of the non-dominance principle.
“a project is rejected if and only if it is outranked by a selected project”. This rule is particularly easy to apply when the number of projects is relatively small. This task becomes difficult as the number increases. Therefore we need to formalize the application of these principles through mathematical formulations. For this purpose, we first define an outranking indicator for a given level of consensus and provide its equivalent formulation in linear expressions. After this, we shall give mathematical formulations for the above verbally described dominance and non-dominance principles.

Let 
\[ a_{jk} = \begin{cases} 1 & \text{if } C_{jk} \geq \theta, \\ 0 & \text{otherwise}. \end{cases} \]  
(10)

With this definition, if Project \( j \) outranks Project \( k \) at the consensus level of \( \theta \) then \( a_{jk} = 1 \). This permits us to identify the pairs of projects between which there is an outranking relationship at the consensus level of \( \theta \). In other words, for a given value of \( \theta \), \( a_{jk} \) completely determines all the existing outranking relationships between the projects. The totality of these outranking relationships is equivalently given by the following linear expressions:

\[ \theta + a_{jk} \leq C_{jk} + 1 \quad \forall (j, k), \ j \neq k, \]  
(11)

\[ \theta + a_{jk} \geq C_{jk} + \varepsilon \quad \forall (j, k), \ j \neq k, \]  
(12)

\[ a_{jk} = 0 \text{ or } 1 \quad \forall (j, k), \ j \neq k, \]  
(13)

where \( \varepsilon \) is a sufficiently small positive number, actually introduced to enforce a strict equality. An interval for \( \varepsilon \) can be easily defined by observing that the only values \( C_{jk} \) can take on are \( 0, 1/n, 2/n, \ldots, 1 \) when the number of projects under consideration is \( n \). Therefore, a value in the interval \( (0, 1/n) \) is appropriate for \( \varepsilon \).

Now, the verbally described dominance and non-dominance principles need to be expressed in mathematical formulations as well. First, let \( P \) be the set of selected projects and define \( \beta_i = \begin{cases} 1 & \text{if Project } i \in P, \\ 0 & \text{otherwise}. \end{cases} \)

Then the dominance and non-dominance principles will be observed if the following constraints are respected:

\[ \sum_{j \neq j} x_{ij} \beta_i + \beta_j \geq 1 \quad \text{for } j = 1, \ldots, n, \]  
(14)

\[ \sum_{j \neq j} x_{ij} \beta_i + (n-1) \beta_j \geq n-1 \quad \text{for } j = 1, \ldots, n, \]  
(15)

\[ x_{ij} = 0 \text{ or } 1 \quad \forall ij; \quad \beta_i = 0 \text{ or } 1 \quad \forall i. \]  
(16)

Constraints (14) and (15) imply that the number of projects in \( P \) will be between 1 and \( n-1 \), which is the basic condition for the existence of a selection program. In other words, the possibility of selecting all the projects or rejecting all the projects is excluded from consideration. For a detailed mathematical development of constraints (14)–(16), the reader is referred to Oral et al. (1990).

We are now ready to state the model of project selection and consensus formation as follows:

Maximize \( \theta \)

subject to:

outranking relationships : (11)–(13),

definition of kernel : (14) and (15),

binary conditions : (16),

budgetary constraint : \[ \sum_{i=1}^{n} b_i \beta_i \leq B. \]  
(17)

We shall now use this application algorithm to identify the projects that should be funded. The process will be repeated three times, one application for the scores provided by each of the three experts, in order to find out the consistency level of scoring process.
4. Results and their interpretation

The summaries of the application algorithm, step by step, are given in Tables 1–3. We shall however provide explanation for only Table 1 since the other tables can be interpreted in the same manner.

Step 1 of the algorithm identifies Projects #3 and #14 as the projects that should be funded first; that is \( K_1 = \{ \#3, \#14 \} \). The budget required

<table>
<thead>
<tr>
<th>Step number, ( i )</th>
<th>Projects selected, ( K_i )</th>
<th>Budget required, ( b_i )</th>
<th>Funds available, ( B_i )</th>
<th>Consensus level, ( \theta_i )</th>
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<tr>
<td>0</td>
<td>– { #3, #14 }</td>
<td>– 219</td>
<td>– 30,000</td>
<td>–</td>
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<td>{ #1, #5, #23, #30, #40 }</td>
<td>6321</td>
<td>20,946</td>
<td>1.00</td>
</tr>
<tr>
<td>5</td>
<td>{ #10, #34 }</td>
<td>2093</td>
<td>14,625</td>
<td>1.00</td>
</tr>
<tr>
<td>6</td>
<td>{ #28, #29, #37, #39 }</td>
<td>9365</td>
<td>13,700</td>
<td>1.00</td>
</tr>
<tr>
<td>7</td>
<td>{ #24 }</td>
<td>2500</td>
<td>4,335</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Remaining funds (1835) are no longer sufficient to finance any project.

<table>
<thead>
<tr>
<th>Step number, ( i )</th>
<th>Projects selected, ( K_i )</th>
<th>Budget required, ( b_i )</th>
<th>Funds available, ( B_i )</th>
<th>Consensus level, ( \theta_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>– { #3, #14 }</td>
<td>– 219</td>
<td>– 30,000</td>
<td>–</td>
</tr>
<tr>
<td>1</td>
<td>{ #2, #26 }</td>
<td>386</td>
<td>29,781</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>{ #6, #19, #21, #22, #27 }</td>
<td>1985</td>
<td>29,395</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>{ #12, #44 }</td>
<td>1462</td>
<td>27,410</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>{ #7, #11, #15, #16, #40 }</td>
<td>3683</td>
<td>25,948</td>
<td>1.00</td>
</tr>
<tr>
<td>5</td>
<td>{ #8, #9, #34 }</td>
<td>2703</td>
<td>22,265</td>
<td>1.00</td>
</tr>
<tr>
<td>6</td>
<td>{ #23, #29, #39, #43 }</td>
<td>8398</td>
<td>19,562</td>
<td>1.00</td>
</tr>
<tr>
<td>7</td>
<td>{ #1, #10, #25, #30, #41 }</td>
<td>8780</td>
<td>11,164</td>
<td>1.00</td>
</tr>
<tr>
<td>8</td>
<td>{ #28 }</td>
<td>1900</td>
<td>2,384</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Remaining funds (484) are no longer sufficient to finance any project.

<table>
<thead>
<tr>
<th>Step number, ( i )</th>
<th>Projects selected, ( K_i )</th>
<th>Budget required, ( b_i )</th>
<th>Funds available, ( B_i )</th>
<th>Consensus level, ( \theta_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>– { #3, #14 }</td>
<td>– 219</td>
<td>– 30,000</td>
<td>–</td>
</tr>
<tr>
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<td>{ #2, #12, #26 }</td>
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<td>29,781</td>
<td>1.00</td>
</tr>
<tr>
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<td>{ #6, #16, #22, #27 }</td>
<td>1491</td>
<td>28,995</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>{ #4, #7, #15 }</td>
<td>2208</td>
<td>27,304</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>{ #1, #5, #9, #10, #11, #21, #34, #44 }</td>
<td>7914</td>
<td>25,296</td>
<td>1.00</td>
</tr>
<tr>
<td>5</td>
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<td>7796</td>
<td>17,382</td>
<td>1.00</td>
</tr>
<tr>
<td>6</td>
<td>{ #20, #29 }</td>
<td>4045</td>
<td>9,603</td>
<td>0.72</td>
</tr>
<tr>
<td>7</td>
<td>{ #23, #25 }</td>
<td>3933</td>
<td>5,558</td>
<td>0.81</td>
</tr>
<tr>
<td>8</td>
<td>{ #30 }</td>
<td>838</td>
<td>1,625</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Remaining funds (787) are no longer sufficient to finance any project.
for the realization of Projects #3 and #14 is
\[ b_1 = \text{MU 219}, \]  
MU being an internally defined monetary unit. Since the available funds (MU 30,000) exceed the amount of the required budget we select Projects #3 and #14. As to the first level worthiness of these two projects the stakeholders has a consensus of 100%. For Step 2, after excluding Projects #3 and #14 from the original set of projects \( R \) and deducting the required budget MU 219 from the original available funds \( B \), we have as the total fund available for the next step
\[ B_2 = B_1 - b_1 = 30,000 - 219 = \text{MU 29,781}. \]

Step 2 identifies Projects #2, #26, and #27 for funding. Again the available funds (MU 29,781) far exceed the required budget (MU 621) for the realization of the three projects identified as worthy at the second level. Therefore, we select these three projects for funding. The level of consensus reached at Step 2 is again 100%. And so on. Step 8 is different from the previous ones in the sense that the level of consensus is no longer 100%, but only 60%. The application algorithm stops after Step 8 since no feasible solution can be obtained with the funds remaining (MU 1835) without violating the dominance and non-dominance principles. Thus, the model solution consists of 30 projects out of 44 candidates for funding. If we let \( P_A \) be the set of projects selected by using the scores of Expert A, then
\[
P_A = K_1 \cup K_2 \cup K_3 \cup K_4 \cup K_5 \cup K_6 \cup K_7 \cup K_8,
\]
and
\[
P_B = \{\#1, \#2, \#3, \#4, \#5, \#6, \#7, \#8, \#9, \#10, \#11, \#12, \#14, \#15, \#16, \#19, \#21, \#22, \#23, \#24, \#26, \#27, \#28, \#29, \#30, \#34, \#37, \#39, \#40, \#44\},
\]

respectively.

The question is now which one of these three sets will be eventually chosen. Several ways can be considered. One way to resolve this is to first finance those projects which have appeared in the solution set based on the assessment by all three experts at the same time, then fund those projects which have appeared in the solution set of two of the three experts and, finally, if there are still funds available, some of the projects that have appeared in the solution set of one of the experts. If such a procedure is applied to the results in Tables 1–3 we have the following situation. First, observe that the number of projects that appear in the solutions based on the assessment of three experts is 24, two experts is 4 and one expert is 7.

The total amount of funds required by the first group is MU 19,765, an amount which is much less than the available funds of MU 30,000. We can also finance projects in the second group since the required amount MU 6167 is less than the remaining amount MU 10,235 after financing 24 projects in the first group. However, we cannot finance all of the projects in the third group since the required amount MU 14,380 is far above the remaining available funds MU 4068. The experts in this case may be asked to reconsider their scores for the projects in the third group as well as for those not selected and then reapply the algorithm with the new scores to allocate the unused funds.

Another way to attain a high level of consistency is to finance only those projects that have appeared in the solution sets of all three experts at the same time. The projects not falling in this group are returned to the experts for re-scoring. The algorithm is then reapplied to these projects with their new scores to allocate the funds remaining after financing the projects that are initially selected by all three experts.
It might be of interest to know the extent to which the experts are consistent with one another in their scores. For this, we need an index to indicate the consistency level of expert scores within the context of project selection. This is discussed below.

4.1. Consistency of expert scoring system

As before, let $P_A$, $P_B$, and $P_C$ be the sets of projects selected using the scores of Experts A, B, and C, respectively. Given the definitions of $P_A$, $P_B$, and $P_C$ we can form the following sets:

\[
\begin{align*}
T & = P_A \cap P_B \cap P_C, \\
S & = (P_A \cap P_B) \cup (P_A \cap P_C) \cup (P_B \cap P_C) - T, \\
U_A & = P_A \cap \overline{P_B} \cup P_C, \\
U_B & = P_B \cap P_A \cup \overline{P_C}, \\
U_C & = U_A \cup U_B \cup U_C.
\end{align*}
\]

With these definitions, $T$ becomes the set of those projects which have appeared in the model solutions of all three experts, $S$ the set of those projects which have appeared in the model solutions of two of the three experts and $U$ the set of those projects which have appeared in the model solution of one of the three experts. We define the scoring consistency index $\lambda$ among the three experts as follows:

\[
\lambda_{ABC} = \frac{3/3|T| + 2/3|S| + 1/3|U|}{|P_A \cup P_B \cup P_C|}
\] (18)

where [“set”] is the number of projects in the “set”. We apply this formula now using the results given Tables 1–3. First, we rewrite

\[
P_A = \{#1, #2, #3, #4, #5, #6, #7, #8, #9, #10, #11, #12, #14, #15, #16, #19, #21, #23, #25, #26, #27, #28, #29, #30, #34, #39, #40, #41, #43, #44\},
\]

\[
P_B = \{#1, #2, #3, #4, #5, #6, #7, #8, #9, #10, #11, #12, #14, #15, #16, #19, #21, #23, #25, #26, #27, #28, #29, #30, #34, #39, #40, #41, #43, #44\},
\]

\[
P_C = \{#1, #2, #3, #4, #5, #6, #7, #8, #9, #10, #11, #12, #13, #14, #15, #16, #19, #20, #21, #22, #23, #25, #26, #27, #28, #29, #30, #34, #40, #44\}.
\]

Then we have

\[
T = \{#1, #2, #3, #6, #7, #8, #9, #10, #11, #12, #14, #15, #16, #19, #21, #23, #26, #27, #28, #29, #30, #34, #40, #44\},
\]

\[
S = \{#4, #5, #25, #39\},
\]

\[
U = \{#13, #20, #24, #37, #38, #41, #43\}.
\]

Therefore, $|T| = 24$, $|S| = 4$, $|U| = 7$, and $|P_A \cup P_B \cup P_C| = 35$. Substituting these values in (18), we obtain

\[
\lambda_{ABC} = \frac{3/3|T| + 2/3|S| + 1/3|U|}{|P_A \cup P_B \cup P_C|} = \frac{24 + (2/3)4 + (1/3)7}{35} = 0.82.
\]

The meaning of $\lambda_{ABC} = 0.82$ is simply that the three experts agree with one another 82% of the time in scoring within the context of project selection. Corollary to this, the variance among the expert scores causes a disagreement level of only 18%.

This concept of consistency of the expert scoring can be also applied to the case where two experts are considered at a time. Let $\lambda_{AB}$, $\lambda_{AC}$, and $\lambda_{BC}$ be the consistency indices when two of the three experts are considered at a time. Using the modified version of formula (18) for two experts, we obtain

\[
\lambda_{AB} = 0.88, \quad \lambda_{AC} = 0.92, \quad \lambda_{BC} = 0.81,
\]
which indicate the consistency levels are higher when the number of experts is smaller. This is an intuitively appealing conclusion since it is most natural that the level of disagreement will be higher as the number of experts increases. Moreover, Experts A and C seem to be more in agreement (with \( \lambda_{AC} = 0.92 \)) compared to the other two pairs (\( \lambda_{AB} = 0.88 \) and \( \lambda_{BC} = 0.81 \)).

The complex nature of the proposed projects and the presence usually of a large number of stakeholders in the context of the international organization suggest that several experts are to be involved in the scoring process. In the presence of several experts, on the other hand, the consistency level introduced above will probably be rather low. In this case, one needs a procedure by which high levels of scoring consistency are attained. Delphi method or a variation of it could be effectively used in order to reach an agreement as to the most likely scores of projects with respect to the criteria chosen.

The formula given in (18) can be easily generalized to the case of \( N \) experts as follows:

\[
\lambda = \frac{\sum_{i=0}^{N-1} ((N - i)/N) J_{N-i}}{N} \bigg| \bigcup_{j=1}^{N} P_j
\]

where \( \lambda \) is the consistency index of expert scores, \( T_{N-i} \) is the set of those projects which are selected by \( (N - i) \) experts, \( P_j \) is the set of projects selected by Expert \( j \).

4.2. The impact of the level of available funds

It might be of interest to study the impact of the availability level of funds on the way the project selection is made. Let the level of available funds be \( B = \text{MU} 12,000 \), for the same set of 44 projects. Again using the scores provided by the three experts we obtain the results summarized in Tables 4–6.

First, compare Table 1 with Table 4. The first four steps in both tables are identical, as might be expected. The difference starts with Step 5 when...
the available funds become an active constraint. In Table 1, the project set \{#1, #5, #23, #30, #40\} is selected in the fifth step since the available funds (MU 20,496) are higher than the amount needed to finance the selected projects. When the initial funds are only MU 12,000, there is only MU 2946 available, as can be observed from Table 4, for the projects to be selected in the fifth step. Therefore, we cannot finance all the projects in the set \{#1, #5, #23, #30, #40\} with MU 2946. A choice is to be made. And the choice is \{#5, #40\}, which requires only MU 2117, an amount less than MU 2196.

Similar statements can be made for Table 2 versus Table 5 and Table 3 versus Table 6. These observations indicate that one can perform a sort of sensitivity analysis to study the impact of the level of available funds on project selection.

### 5. Concluding remarks

This paper has presented a project evaluation and selection methodology and summarized its test application in an international organization. The methodology has been discussed in connection with a decision context which has the following distinct properties: (1) it is a group decision making process in which different, and sometimes conflicting, values and preferences of stakeholders are to be taken into account, (2) there exist principles to be complied with during the process of project selection in order to avoid the occurrence of certain types of resentment among the stakeholders, and (3) a maximum level of consensus is to be achieved in selecting projects for funding.

Although interactions between the projects is not discussed in this paper, this can be easily incorporated into the formulations, as was done in Oral et al. (1990). Moreover, extensions to cover multi-period cases as well as contingency requirements between the projects can also be included as constraints in the project selection model.

### References


