A framework for participatory group decision support using Pareto frontier visualization, goal identification and arbitration

Roman Efremov [1], Alexander Lotov [2], David Rios-Insua [1]

[1] *Rey Juan Carlos University, Spain, Madrid*

[2] *Dorodnicyn Computing Centre of The Russian Academy of Science, Russia, Moscow*

Due to the increasing demand for citizen participation in public decision processes, participatory budgets are becoming popular in many municipalities. As there is little methodology available for this type of activities and Information Technology are scarcely used in them, we provide a formalization of participatory budgets, as well as describe two models to support these processes and their corresponding web-implementation. One model is based on an iterative negotiation method that allows offering fair solutions for a participatory budget problem. The other one is based on goal identification, allowing participants to communicate their preferences comprehensively. These models were implemented to support non-sophisticated users and develop a user-friendly, yet rigorous, participatory decision support system in this application area. We describe experiments with these systems.

KEYWORDS: PARTICIPATORY BUDGET, E-PARTICIPATION, NEGOTIATION, PARETO FRONTIER VISUALIZATION, GOAL PROGRAMMING

1. Introduction

Participatory Budgets (PB) are becoming increasingly popular all over the world, see e.g. [11] for more information and references. They are an attempt to allow citizen to have a word and aid in deciding and approving how public budgets are spent. However, no formal modelling or quantification of citizen preferences is usually undertaken and no formal negotiation or group decision support tools are used, there being little methodology available in this field.

Information Technology opens up many possibilities to support stakeholders. Indeed, many authors have dwelt on how Internet is changing the way people interact with governments. However, so far, most ideas relating Internet and politics, have been directed towards facilitating traditional political methods through IT, as with voting instead of voting with a piece of paper. The most challenging goal is to actually transform public decision-making processes.

There are already several examples of systems used or about to be used for public decision support. From the analysis of such tools, a number of features that we should demand from them can be formulated. First of all, as the system will be used by the general public, we should not expect much sophistication from users. Therefore, emphasis should be placed on user-friendliness in interfaces. This does not entail, however, neglecting rigorousness of the implemented methods.

Given these prerequisites, we describe here a framework for participatory budget elaboration support. The aim of our study is to develop user-friendly procedures implementable on the web that can collect information about the stakeholders' preferences and help to transform this information into a group decision in a fair and transparent manner. The procedure should be simple enough for lay stakeholders who are not quantitatively sophisticated decision makers.

The two procedures we propose could be divided into two stages, once the problem has been formulated. First, the stakeholders express their preferences in some form. Then, the preference information is used to help stakeholders in constructing the group decision.

A successful framework for the second stage comes from bargaining theory, introduced by [7]. In particular, the balanced increment method (BIM), a method based on the discrete version of Raiffa's solution of balanced increments, see [8], is used to offer interactively to participants reasonable group solutions. We will discuss it in detail in section 3. Together with the general architecture for PB support, described in section 4 it constitutes PARBUD - a system for PB support. We then discuss the experiment run with PARBUD, which showed, on the whole, its appropriateness for PB support but also difficulties in some preference modelling concepts used there. Another approach was aimed at solving this problem through goal identification and regret analysis as discussed in section 5. We then discuss an experiment run with the preference modelling tool based on this approach that showed us its suitability for preference modelling and the need of further experiments currently on its way.

2. Participatory budget formulation

From a technical point of view, the elaboration of a participatory budget concerns a group of people that must select a subset of projects in view of multiple evaluation criteria, with group satisfaction being maximized in a certain sense. The budget available cannot be exceeded and other constraints are possible.

Assume, then, that a group of K persons has to decide how to spend a budget b. There is a set of Q projects, $A = \{a_1, \ldots, a_Q\}$. Project a_q has an estimated cost c_q. Assume that the total cost of all the projects from A is greater than b. Otherwise there would be no discussion. A *feasible budget* for the participatory budget problem is a subset of projects, $x \subseteq A$, which satisfies the budget constraint, and other constraints that might appear. Let X be the set of all possible feasible budgets. We assume that every feasible budget can be assessed with respect to d criteria: the performance of each feasible decision $x \in X$ is described by a d-dimensional vector $y = f(x)$. The set $Y := f(X)$ is called the *feasible criterion set*. Without loss of generality, we assume that the criteria must be maximized. The Pareto frontier of Y is defined as

$$P(Y) := \left\{ y \in Y : \left\{ y' \in Y : y' \geq y \text{ and } y' \neq y \right\} = \emptyset \right\}. \qquad (1)$$

We shall assume that the participants are multiattribute value function maximizers, see [9]. We can associate with each feasible budget x the value $v^k(x)$ that the individual k give to x. Let

$$x_k = \text{argmax}\{v^k(x) : x \in X\}. \quad (2)$$

Should $x_1 = x_2 = \ldots = x_K$, this feasible solution would obviously be the group decision. However, typically, various individuals will reach different optimal solutions. Consequently, an agreement should be sought as a joint decision. Consider the vectors $v(x) = (v^1(x), \ldots, v^K(x))$, associated with each feasible budget x. The set X of feasible budgets can be transformed to the participants' value set $S = v(X) = \{v(x), x \in X\}$.

The disagreement point is a vector $d = (d_1, \ldots, d_K) \in \mathbf{R}^K$, whose k-th coordinate represents the value level that the k-th participant would receive if the negotiation breaks down. Mathematically, given (S,d), the problem of selecting a reasonable nondominated point in S is known as a bargaining problem and it has been studied, e.g. under arbitration schemes. Therefore, the participatory budget problem is represented through (S,d), where S is a finite, but potentially very large, set. Let $P(S,d)$ be the set of participants' values of nondominated budgets which are better than the disagreement point:

$$P(S,d) = \{z \in S \mid (z \geq d \text{ and } z \neq d) \text{ and } (z' \in S, z' \geq z \text{ and } z' \neq z)\}$$

Hence, $v^{-1}(P(S,d))$ is the set of nondominated feasible budgets, within which an agreement should be sought.

3. The balanced increment method

For a bargaining problem (S,d), the highest value that the k-th participant can get from the disagreement point d without worsening the value of the other participants is known as the dictatorial solution for this participant, $D_k(d)$, and his most optimistic expectation. This is $D_k(d) = \max\{z_k \mid z \geq d \text{ and } z \neq d\}$. Given d, the bliss point will be $B(d) = (D_1(d), \ldots, D_k(d))$ and represents an ideal point, as participants can rarely get these values jointly through a feasible solution.

The Kalai-Smorodinsky solution $K(d)$ lies where the diagonal linking the disagreement point and the bliss point crosses the set of nondominated solutions. The direction of this diagonal represents a compromise direction in which joint value improvements are proportional to the participant's most optimistic expectation. [8] proposed to compute a reasonable solution by beginning at the status quo and making step by step improvements of the participants' values in the direction joining the current solution with its bliss point, until a nondominated solution is reached. This limiting solution is known as balanced increment solution.

In [12], it was proposed such approach with the modification that, at each iteration, we offer parties the nondominated solution closed to the diagonal to see whether they accept it. Initially, individuals are proposed to reach an agreement in the participatory budget problem using the balanced increment method (BIM), whose status quo shall be the solution which includes no proposals. To avoid enumeration that can be extremely costly from a computational point of view, some heuristics are used to screen almost all dominated alternatives, see [12]. In the i-th iteration, the system offers K^i, the Kalai-Smorodinsky solution from x^i. If participants do not accept unanimously the offered solution, another solution is offered that involves a concession in the participants' most optimistic expectation. It may happen, that negotiators do not reach an agreement through negotiations. In such case, we would allow them, as usual in participatory budgets, to proceed through voting.

4. Developed tool and experiment

4.1 PARBUD

We describe PARBUD, a web system for supporting groups in budget elaboration, based on BIM. For more implementation details see [10]. The kernel of the system consists of a negotiation module described in section 3. Nevertheless, some preliminary steps should be undertaken before negotiations take place. Moreover, some arrangements should be provided for the case in which negotiations fail.

The implementation consists of the following functional modules:

- A module for proposal elaboration allows the problem owner to structure the problem. The module allows for defining the number of alternatives, specify the alternatives and associated costs and specify the budget.
- A value function assessment module allows users to build their preference model, assessing their value functions, which are assumed to be weighted additive. The system allows for:
    - Specification of basic properties of (multiple) objectives by the problem owner: number of objectives, their scale and range, whether the objective is to be minimised or maximised. All participants will share these objectives. Some participants may disregard some of them by giving them zero weight.
    - Assessment of each component value function and component weights. For each objective, and each user, the value of some attribute values is assessed directly or with the probability equivalent method.
- Once the preferences of a participant are assessed, his preferred budget can be privately computed solving the corresponding optimization module. If not all participants prefer the same budget, the system proceeds to the negotiating module. We use negotiation by posting at this stage.

As negotiations may end up in a deadlock, the system includes a voting model for approval voting, see [1].

A post-settlement module is needed for the case in which the system detects that the outcome is dominated. In this case, the agreement is renegotiated with the aid of BIM, taking the outcome as disagreement point.

4.2 Experiment

As an illustration, we sketch an experiment with PARBUD over a participatory budget problem. It was conducted with a group of lecturers and students from the Statistics and

Decision Science Group of the Rey Juan Carlos University who wanted to participate in deciding how to spend an annual departmental grant of 10,000 Euros.

4.2.1 Description of the example problem

A preliminary study was carried out by the department head to identify possible proposals. In addition to the budgetary constraint, proposals were also subject to other constraints. This preliminary study also identified appropriate criteria for proposals evaluation. The initial draft of the budget problem was formally debated with lecturers and students who wanted to participate, including a brainstorming process to extend the set of proposals. This process was carried out through a physical meeting. Participants proposed new proposals and the criteria were discussed guided by an analyst to consolidate the final list of proposals and criteria. Finally, proposals were evaluated in view of the following criteria: Expected number of students directly benefiting, Expected number of researchers directly benefiting, Expected number of papers in the next two years, directly related with such proposal. A detailed description of the problem can be found in [10]. Performance of the proposals with regards to each criterion is shown in Table 2.

	Attributes			
Proposals	Cost	Students	Researchers	Papers
ILOG-CPLEX	2,000	50	6	2
ED-Taylor	3,000	60	4	0
Extend	2,000	60	4	0
DreamWeaver	1,500	10	10	0
DPL	1,000	35	2	0
Data Mining Software	2,000	15	4	0
Netica	400	35	4	0
Laptop	1,700	15	10	0
Projector	600	15	20	0
Multimedia equipment for the lab	500	20	5	0
New equipment for the lab	5,600	20	5	0
Negotiation course	2,000	10	5	4
Markov Random Fields course	900	10	12	1
Combinatorial Optimisation course	1,200	10	7	1
Operations research course	2,200	10	7	0

Figure 2. Proposal performance against the criteria

4.2.2 Experiment with PARBUD

The value function of each of the five individuals finally participating were elicited in the preference communication phase. The problem has 7090 feasible budgets, but only 3 of them are nondominated. In the negotiation phase, the BIM offered at its first iteration one of these 3 nondominated budgets to participants as an equitable budget for possible acceptance. As all participants agreed on accepting that offer, this budget was finally implemented and participants were pleased with the experiment. Participants found quite useful the offer evaluation support because of the complexity of the intuitive budget evaluation. Although a budget was chosen in the negotiation phase, to illustrate the participants the voting phase, a voting session was run through approval voting over the proposals. Interestingly enough, the winning budget in the voting phase, obtained by the usual mechanism to decide participatory budgets, was dominated, specifically, in this case, by the agreed budget. See [10] for more details. Nevertheless, initial experiments pointed to the potential difficulties of non-sophisticated users with the preference concepts used. Partly motivated by this, another approach based on single-step identification of a participant's goal was proposed in [2], which we discuss next.

5. The goal identification model for preference modelling

5.1 Interactive Decision Maps

In [2] another model for participatory budget support was proposed, based on the ideas of goal programming. First of all, each participant is advised to choose his goal on the Pareto frontier, $P(Y)$, represented visually. To visualize the Pareto frontier for more than two criteria, the Interactive Decision Map (IDM) technique is used, see e.g. [5]. In IDM, the *convex Edgeworth-Pareto Hull* of Y (CEPH(Y)) that is the convex hull of the set containing $P(Y)$ and all points dominated by $P(Y)$, is represented using *decision maps*, see left picture on Figure 3.

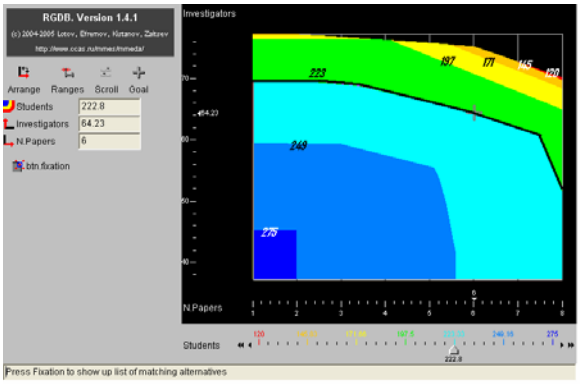
A user can select any point on a decision map by mouse-clicking. This point is called a *reasonable goal*. Note that it may not correspond to any feasible alternative, but can be used to describe users' preferences. These preferences can be formalized as regrets of a user about the coordinatewise deviation from the bliss point, see [13]. Therefore, preference modelling is restricted to the goal that each participant chooses on the Pareto frontier, represented visually. In [2] it is argued that this is an intelligible, yet rigorous way for preference modelling. Preferences elicited in such a way can be written in a form of value functions, which can then be used within any arbitration scheme. Such idea makes it possible to integrate the goal identification supported by the IDM technique with various arbitration schemes, e.g. BIM.

5.2 Some implementation issues of IDM-based preference modelling tool

In implementations of IDM, $\mathrm{CEPH}(Y)$ is approximated in advance. Moreover, the approximation of $\mathrm{CEPH}(Y)$, which requires up to 99% of the computing time, is separated from the human-computer exploration of decision maps and can be performed automatically. At the same time, slices of the approximation of $\mathrm{CEPH}(Y)$ can be quickly computed. This feature of the IDM technique facilitates implementation on computer networks, where decision maps may be depicted and animated on-line, see [5], [6].

To run experiments a simple Web service was designed that permitted participants to independently enter the system and communicate their preferences. Also a simple goal-based arbitration rule was designed, see [2] for details. The arbitration solution can be taken as definite solution of the problem or be the reference point for the posterior voting. For more details on the implementation see [6].

Before the experiment started, the feasible criterion set of the problem was built, i.e. all feasible budgets were generated in the form of a table, its rows corresponding to budgets, while columns corresponding to different criteria. All constraints except budgetary were excluded from this experiment problem, there were 26 nondominated budgets. Furthermore, CEPH of the feasible criterion set was approximated and stored on the server-side. Participants could access to the server and request the CEPH along with the IDM Java applet. The applet displays a decision map (as it were only three criteria under consideration) and can be used to explore them and identify the goal, see left picture on Figure 3. After fixing a goal, it is transmitted to the web-server and a new arbitration point is generated. The experiment is available at http://bayes.escet.urjc.es/refremov/rgmas/pp_gecd/index.html.



Name	Students	Investigators	N.Papers
Your goal	*210*	*66*	*7*
The group decision goal	*175*	*67*	*6*

To your goal correspond the following alternatives:	To the group goal correspond the following alternatives:
Gregory Kersten	Simon Wilson
Simon Wilson	multimedia para el lab PFC
P. Toth	DPL decision tree solver
multimedia para el lab PFC	Extend
Extend	ED-Taylor
ED-Taylor	DreamWeaver - Macromedia
DreamWeaver - Macromedia	H.A. Taha
H.A. Taha	Ampliar lab PFC (incluido multimedia)

There are 8 persons voted.

Figure 3. The IDM applet and the page that the user can enter to get a reference of his goal and current group goal.

Once all participants select their goals, each of them may access the page where he can inform himself about the goal he specified and about the final arbitration point, see right picture on Figure 3. The information about the user's goal consists of the feasible vector of criteria values that is nearest to his goal and the corresponding budget, i.e. the list of items. The information about the group goal consists of the arbitration point and the corresponding budget. This page can serve each participant as a reference about his own preferences and preferences of the group.

5.3 Experiment with the IDM-based tool

We recorded information such as the participants' goals, the arbitration points after every goal selection and the time participants needed to understand the instructions on how to use the IDM applet and fix their goal.

Of special interest were the messages that participants left, as they were given such an opportunity. Among other comments, they observed that the alternatives are selected according to their representation in the criteria space, i.e. items that correspond to alternatives are not seen, until a particular alternative is chosen. In their opinion, it is fairer than the situation when the choice is made directly over the items because in the last case some participants might be interested in particular items rather than in improving criteria values.

Furthermore, as the experiment was informal, some participants permitted us to be present at their IDM sessions, so we could make some observations about the course of decision making. Some participants had some biases before they studied the decision map. For example, one of the participants had a position that could be formulated as follows: "favour investigators and give students what remains". Nevertheless, they could see with IDM that their strong wish to follow their principled position, that is, a single criterion optimization, would bring them to an unreasonable solution.

6. Conclusions and plans for future

Two models for participatory decision support have been presented. The model based on balanced increments arbitration and the probability equivalent method for preference modelling is theoretically well defined but may be too sophisticated for some users. It was shown that the model based on goal programming may be used for preference modelling, the experiment has showed that this approach can be implemented in an intelligible way for stakeholders. Technically it permits constructing a surrogate value function that can be used, particularly, in the BIM negotiation scheme. We shall integrate the goal-based preference modelling as an alternative implementation and run further experiments with different preference modelling and arbitration tools in the near future.

References

[1] Brams, S.J. and Fishburn, P.C. (1983) *Approval Voting* Birkhauser, Boston.

[2] Efremov R., Ríos Insua D., Lotov A.(2006) *A framework for participatory group decision support over the web based on Pareto frontier visualization, goal identification and arbitration*: Rey Juan Carlos University Technical Reports on Statistics and Decision Sciences.

[3] Efremov R., Rios-Insua D. (2006) *An experimental study of a web-based framework for group decision support with applications to participatory budget elaboration:* Rey Juan Carlos University Technical Reports on Statistics and Decision Sciences.

[4] Kalai, E. and M. Smorodinsky (1975) *Other solutions to Nash's bargaining problem*, Econometrica, 43, 3, 513-518.

[5] Lotov A.V., Bushenkov V.A., and Kamenev G.K. (2004a) *Interactive Decision Maps. Approximation and Visualization of Pareto Frontier*: Kluwer Academic Publishers.

[6] Lotov A., Kistanov A., and Zaitsev A. (2004b) *Visualization-based Data Mining Tool and its Web application*// In: Y. Shi, W. Xu, and Z. Chen (Eds.), Lecture Notes in Artificial Intelligence, Springer-Verlag Berlin Heidelberg, 3327, XIII, 263.

[7] Nash J. F. (1950). *The bargaining problem.* Econometrica 18: 155-162

[8] Raiffa, H. (2002) *Negotiation Analysis*, Harvard University Press.

[9] French, S (1986) *Decision theory. An Introduction to the Mathematics of Rationality.* Willey: Chichester.

[10] Ríos J. (2005) *Supporting group decisions through the web: E-democracy and E-participatory budgets*: PhD thesis, Rey Juan Carlos University.

[11] Ríos J., Ríos-Insua D., Fernandez E., Rivero J. A.(2005a) *Participatory Budget Formation Through the Web*: Lecture Notes in Computer Science, Springer, 268-276.

[12] Ríos J, Rios-Insua D and Kim J B (2005b). *Arbitration and Mediation Schemes: Balanced Increment and Balanced Concession.* Tech. Report, Rey Juan Carlos University.

[13] Yu, P.L. (1985) *Multiple-criteria Decision Making: Concepts, Techniques and Extensions*, Plenum Press.