A Web Application for Group Decision-Making based on Combinatorial Optimization

Ivan Mustakerov[1] and Daniela Borissova[1]

[1] Department of Information Processes and Decision Support Systems
Institute of Information and Communication Technologies – BAS,
Sofia – 1113, Bulgaria
mustakerov@iit.bas.bg, dborissova@iit.bas.bg

Abstract. Many applications of operations research are used to support managers in making intelligent decisions. Designing of reliable and effective decision making is a prerequisite for effectiveness of business intelligence. In the current paper, a Web-based framework of group decision support application is proposed. It uses multi-attribute decision making approach that is based on combinatorial optimization. The described modeling approach takes into account weightings of criteria of different decision makers and their evaluations for each alternative. A single criterion mixed integer optimization task is formulated whose solution defines an optimal alternative. The proposed framework of Web-based application for group decision support implements XHTML, JavaScript, XML, AJAX technology and mixed-integer programming optimization modules. The described combinatorial optimization approach and Web-based framework are tested and results show their applicability for group decision making.

Keywords: multi-attribute group decision making, combinatorial optimization, web-based application.

1 Introduction

A common problem in business organizations is the need for decision making in the light of the organizational objectives. Nowadays the reasonable business decision making is associated with the term “business intelligence”. Based on the assumption that management should get more out of data, business intelligence mixes data mining, algorithms, visualization and other approaches to help businesses make better decisions [1-5]. Over the years many applications of operations research (OR) methods under different names like “management science”, “decision engineering”, “analytical decision making” and others are used as business intelligence tool to support managers in taking decisions [6, 7]. Nevertheless that some researchers point out certain limitations in using of OR [8], the growing interest to business intelligence leads to mix of mathematical and statistical techniques that are usually used by operations researchers. [9-11]. It is recognized that there exists some lack of interaction of the business intelligence and OR and this is acknowledged as a necessity to evolve business intelligence to become more decision-oriented [12].

In many organizations group decision making has become a part of everyday organizational life. It could be argued that group provides better decisions by developing a greater number of more creative potential options (alternatives and criteria) to be used in the decision process. Another positive effect of group decision making is the fact that persons who contributed to the decision tend to feel more involved in the proper implementation of that decision. It is assumed that the individuals participating in making a group decision face the same common problem and are all interested in finding a solution. The decision making problems when the number of the criteria and alternatives is finite, and the alternatives are given explicitly are called multi-attribute decision making problems (MADM) [13]. Group decision problems are multidimensional and the decision has to be based on procedures that explicitly require the integration of a broad set of various and conflicting points of view by means of Group Decision Support Systems (GDSS) defined as a class of electronic meeting systems [14-16]. If various decision makers' (DMs) points of view are different but not contradictory the decision support system has to incorporate properly the DMs' perceptions to assist making proper solution.

In this paper a framework of Web-based group decision support application is described. It uses combinatorial optimization modeling approach leading to mixed integer programming task formulation. The solution of the optimization task defines an optimal alternative while considering different decision makers' points of view about the criteria weightings and alternatives evaluations.

2 Decision Making Process

In general, the decision-making is a process resulting to the selection of a single alternative among set of alternatives. The decisions are taken by manager or group of decision makers that has certain experience and background and are responsible for reaching of organizational objectives. It is known that DMs have their own specific way of using the available information. Some DMs take decisions based on quantative analysis while others prefer using intuition based on experience [17]. The decision making process is illustrated graphically on Fig. 1.

The process of decision making starts with awareness that there exist problem requiring proper decision. Then the data related to this problem have to be found, derived, collected and processed to become information compatible with the DM cognitive style and personal background. This is an important specificity of decision making process should not be ignored because if the information is not consistent with the mental way the DM absorbs, appreciates and uses information, it could be worthless for decision making. The next step is to define the set of alternative decisions and their implications to the problem solution. The choice of particular decision is based on analysis of different alternatives and/or using of mathematical reasoning methods.

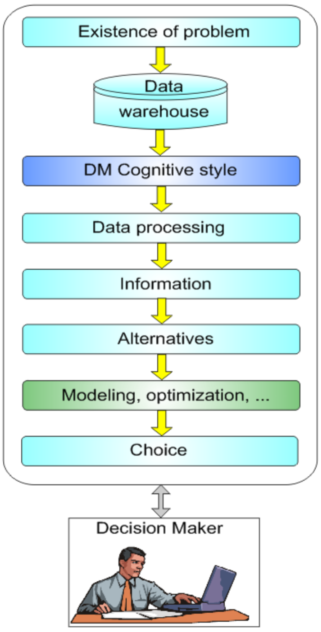

Fig. 1. Decision making process

On this step methods of operations research, artificial intelligence, soft computing, etc., can be used to support the DM to make his final decision. What method and tool could be used depends on the type of available information – structured, semi structured, unstructured, detailed, quantified and so on.

3 Combinatorial Optimization Approach for Group Decision Making

A standard feature of multi-attribute decision making methodology is representation of the input data as decision table [13] also known as weighted decision matrix (WDM) [10, 18-20]. WDM structure example is shown in Table 1.

Table 1. WDM structure example [10]

Factors *(Criteria)*	***Weight***	***Option 1*** *(Alternative 1)* ***Score on Factor***	…	***Option m*** *(Alternative m)* ***Score on Factor***
Factor 1	w_1	$s_{1,1}$	**…**	$s_{m,1}$
Factor 2	w_2	$s_{1,2}$	…	$s_{m,2}$
…	…	…	…	..
Factor n	w_n	$s_{1,n}$	…	$s_{m,n}$

In general, two main directions in the multi-attribute decision making methods exist [13] – methods based on the Multi-Attribute Utility Theory (MAUT) and Outranking methods. The family of MAUT methods consists of aggregating the different criteria into a function, which has to be maximized. The concept of outranking is based on pair-wise outranking assessments that can be combined into a partial or complete ranking of alternatives.

There are a variety of types of group meetings for decision making or problem solving but in the majority of cases there exist individual who is assigned a position of the process leader, or facilitator with some specific responsibilities. In the paper, it is assumed that there exist a single facilitator or supra decision maker (SDM). SDM is responsible to organize the decision making process, to negotiate the phrasing of the key factors (criteria) and possible alternatives, to collect everyone's evaluations, and publish the final results. The SDM is usually a manager who is responsible to propose a final decision at a higher level of management or has the right to make the final decision by himself. The finite number of alternatives and criteria weightings is defined by a group of DMs. The structure of investigated in the paper multi-attribute group decision making process is shown in Fig. 2.

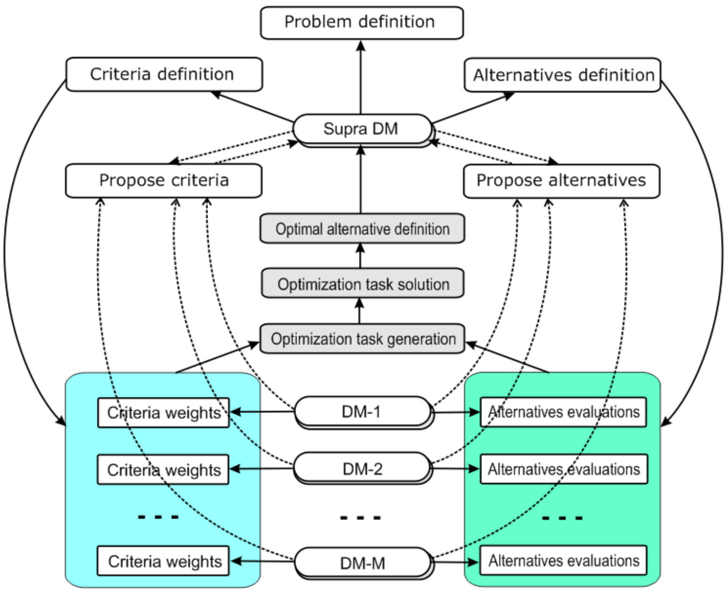

Fig. 2. Group decision making process

MAUT methods assume that weights reflecting the relative importance of criteria to the decision are represented by a single vector i.e. it is assumed to consider the opinion of a single decision maker or the synthesized opinion of a group of experts. A more complex is the case when each DM has different idea about the importance of criteria and these different points of view have to be considered explicitly. In current paper a more flexible MAUT approach ensuring the implementation of this requirement by using of combinatorial optimization is proposed. For the goal, a structure of the WDM as shown in Table 2 is used.

Table 2. WDM Combinatorial Structure

Criteria	***Weights***			***Alternative 1***			***Alternative 2***			**….**	***Alternative* J**		
	DM¹	…	***DMᴷ***	***DM¹***	**…**	***DMᵏ***	***DM¹***	**…**	***DMᵏ***	**…**	***DM¹***	**…**	***DMᵏ***
c_1	w_1^1	…	w_1^K	$a_{1.1}^1$	…	$a_{1.1}^K$	$a_{1,2}^1$	…	$a_{1,2}^K$	…	$a_{1,J}^1$	…	$a_{1,J}^K$
c_2	w_2^1	…	w_2^K	$a_{2,1}^1$		$a_{2,1}^K$	$a_{2.2}^1$	…	$a_{2.2}^K$	…	$a_{2,J}^1$	…	$a_{2.J}^K$
…		…			…			…		…		…	
c_M	w_M^1	…	w_M^K	$a_{M,1}^1$	…	$a_{M,1}^K$	$a_{M,2}^1$	…	$a_{M,2}^K$	…	$a_{M,J}^1$	…	$a_{M,J}^K$

Here, c_i are criteria (i = 1,2,…,M), DM_k are group of decision makers (k = *1, 2, … ,* K), w_i^k are weighting coefficients representing relative importance of criteria as evaluated by different DMs, $a_{i,j}^k$ are evaluation scores of DMs for performance of alternative j (j = 1, 2,…,J) against criterion c_i. A higher scores values mean a better performance and the final goal is to maximize the outcome of decision (any goal of minimization can be transformed into a maximization goal).

Using the described structure of WDM a combinatorial optimization model is formulated as follows:

$$\text{maximize} \sum_{i=1}^{M} \sum_{k=1}^{K} w_i^k A_i^k \tag{1}$$

subject to

$$\forall i = 1, 2, \ldots, \mathrm{M} : (\forall k = 1, 2, \ldots, \mathrm{K} : A_i^k = \sum_{j=1}^{J} a_{i,j}^k \; x_j \;) \tag{2}$$

$$\sum_{j=1}^{\mathrm{J}} x_j = 1, \;\; x_j \in \{0, 1\} \tag{3}$$

The binary integer decision variables x_j are used to perform the choice of a single alternative. This modeling approach allows formulation of a single criterion mixed integer optimization task. In contrast to other known MAUT methods, thus formulated optimization problem defines solution that takes into account simultaneously all points of view of different DMs about the criteria weightings and alternatives evaluations.

4 Numerical Illustration

To illustrate the applicability of the proposed approach to group decision making a numerical example for software engineering problem adapted from [10] is solved. A group of 6 decision makers have to take a decision about software engineering problem with 19 criteria and 3 alternatives as shown in Table 3 and Table 4.

Table 3. Decision makers' weightings for 19 criteria

Criteria	Description	DM1	DM2	DM3	DM4	DM5	DM6
c_1	*Enforces process accountability*	2	4	8	8	6	10
c_2	*Addresses horizontal reporting*	10	8	8	8	8	4
c_3	*Addresses vertical reporting*	10	10	8	4	8	10
c_4	*Reinforces standards of practice*	6	2	6	6	6	6
c_5	*Effectively handles the gathering of local requirements*	10	4	10	10	10	8
c_6	*Effectively handles the gathering of Enterprise requirements*	10	2	8	6	6	8
c_7	*Provides project visibility to contract PMO*	6	6	6	8	8	6
c_8	*Provides project visibility to Gov't PMO*	10	8	10	8	8	10
c_9	*Provides visibility to local site leads*	6	10	8	10	10	8
c_{10}	*Provides project management oversight for projects*	4	2	8	6	6	6
c_{11}	*Provides mechanism to efficiently assign resources*	8	8	10	10	10	10
c_{12}	*Enforces requirements management*	10	4	10	6	8	10
c_{13}	*Provides specific requirements approval and prioritization*	10	2	10	6	8	10
c_{14}	*Promotes de-confliction of requirements*	8	6	8	10	10	8
c_{15}	*Aligns work to Software resources*	4	8	6	8	10	10
c_{16}	*Manages and operates resources more efficiently*	4	4	8	10	10	10
c_{17}	*Will be supported by local customers*	6	6	10	10	10	6
c_{18}	*Development environment is reachable by all resources*	6	8	8	10	10	6
c_{19}	*Realign resources to handle surge*	4	2	6	10	10	4

Table 4. Decision makers' evaluations for 3 alternatives

Criteria	Alternative 1 evaluations						Alternative 2 evaluations						Alternative 3 evaluations					
	DM1	DM2	DM3	DM4	DM5	DM6	DM1	DM2	DM3	DM4	DM5	DM6	DM1	DM2	DM3	DM4	DM5	DM6
c_1	2	4	6	1	1	1	10	5	8	9	9	9	8	4	6	8	9	2
c_2	9	8	7	7	6	7	9	8	7	1	2	10	3	1	5	1	2	10
c_3	9	2	8	7	6	7	10	4	7	10	9	10	6	5	7	8	8	10
c_4	10	6	4	4	4	3	10	2	8	7	8	8	8	8	8	6	7	2
c_5	3	1	9	1	2	1	5	10	7	3	2	7	3	7	2	8	9	9
c_6	4	5	3	1	2	1	10	5	7	8	7	7	5	9	2	7	7	3
c_7	8	9	4	2	2	8	9	6	10	7	5	10	7	4	6	7	8	8
c_8	6	4	6	2	2	2	8	7	8	7	5	10	5	10	6	7	8	3
c_9	5	6	8	2	2	8	6	10	6	2	1	5	6	5	6	5	7	9
c_{10}	2	10	8	1	1	1	4	8	8	7	6	9	10	10	6	9	9	9
c_{11}	6	5	6	1	1	1	8	9	8	8	9	7	7	4	2	7	8	2
c_{12}	2	8	2	1	1	1	10	1	7	6	6	8	6	6	5	6	6	5
c_{13}	1	1	2	1	1	1	8	2	8	7	6	9	5	10	5	7	6	5
c_{14}	3	6	2	1	1	1	9	5	8	7	8	10	4	4	2	6	6	7
c_{15}	5	4	2	1	1	1	8	10	6	8	8	10	4	8	2	8	7	8
c_{16}	7	8	1	1	1	1	7	9	9	8	7	9	7	10	1	7	8	7
c_{17}	10	9	10	7	5	10	3	8	4	5	4	5	5	9	2	8	8	7
c_{18}	4	4	1	1	1	1	2	6	1	1	1	1	1	10	1	1	2	1
c_{19}	4	2	1	1	2	1	8	8	6	7	6	8	3	8	2	6	5	6

The proposed combinatorial optimization model (1) – (3) leads to the following optimization task formulation:

$$\max \begin{pmatrix} w_1^1 A_1^1 + w_2^1 A_2^1 + ... + w_{19}^1 A_{19}^1 + \\ + w_1^2 A_1^2 + w_2^2 A_2^2 + ... + w_{19}^2 A_{19}^2 + \\ .... \\ + w_1^6 A_1^6 + w_2^6 A_2^6 + ... + w_{19}^6 A_{19}^6 \end{pmatrix} \tag{4}$$

subject to

$$A_1^1 = (a_{1,1}^1 x_1 + a_{1,2}^1 x_2 + a_{1,3}^1 x_3) \tag{5}$$

$$A_2^1 = (a_{2,1}^1 x_1 + a_{2,2}^1 x_2 + a_{2,3}^1 x_3) \tag{6}$$

$$\text{.....} \qquad \text{...}$$

$$A_{19}^1 = (a_{19,1}^1 x_1 + a_{19,2}^1 x_2 + a_{19,3}^1 x_3) \tag{23}$$

$$A_1^2 = (a_{1,1}^2 x_1 + a_{1,2}^2 x_2 + a_{1,3}^2 x_3) \tag{24}$$

$$A_2^2 = (a_{2,1}^2 x_1 + a_{2,2}^2 x_2 + a_{2,3}^2 x_3) \tag{25}$$

$$\text{.....} \qquad (\text{...})$$

$$A_{19}^2 = (a_{19,1}^2 x_1 + a_{19,2}^2 x_2 + a_{19,3}^2 x_3) \tag{42}$$

$$\text{.....} \qquad (\text{...})$$

$$A_1^6 = (a_{1,1}^6 x_1 + a_{1,2}^6 x_2 + a_{1,3}^6 x_3) \tag{90}$$

$$A_2^6 = (a_{2,1}^6 x_1 + a_{2,2}^6 x_2 + a_{2,3}^6 x_3) \tag{91}$$

$$\text{....} \qquad (\text{...})$$

$$A_{19}^6 = (a_{19,1}^6 x_1 + a_{19,2}^6 x_2 + a_{19,3}^6 x_3) \tag{108}$$

$$x_1 + x_2 + x_3 = 1,\ x_i \in \{0, 1\} \tag{109}$$

The formulated in such way optimization task (5) – (109) can be solved by any linear programming solver. In the paper it was solved by means of LINGO solver [22] API implemented as a module in Web-based application for group decision support.

5 Web-based Application for Group Decision Support

Decision making relies heavily on the availability of relevant information in the right format and at the right time. A framework of a Web-based application for group decision support is proposed that is intended to aid the decision making process by providing easier information management and the application of integrated intelligence (mathematical model and optimization). This tool is designed to enable the easier and faster generation of weighted decision matrix and solution of corresponding optimization task. Solving of the optimization task by this tool does not need knowledge of solution method – a specific solver module is integrated and activated by a single button. Thus, the defined optimal alternative can help to make reasonable decision in complex situations when a group of decision makers have different evaluations of criteria and alternatives. In the context of decision support tools, different techniques and methods are aggregated to fulfill the function of decision making support. Web-based application format was chosen because Web applications offer some essential advantages – instant access, automatic upgrades, and opportunities for collaboration on a massive scale. Web applications use Web documents in a standard format which are supported by all Web browsers. These applications can be considered as a specific variant of client-server software where the client software is downloaded to the client machine when visiting the relevant Web page. Client Web software update may happen each time the Web page is visited. During the session, the Web browser interprets and displays the pages, and acts as the universal client for any Web application. Web applications provide cross-platform compatibility in most cases (i.e., Windows, Mac, Linux, etc.) because they operate within a Web browser window. Creating Web applications requires different approaches than traditional applications and involves the integration of numerous technologies as HTML, Java, JavaScript, and AJAX. Today AJAX (Asynchronous JavaScript and XML) is one of the most popular Internet application technologies [21]. The integration of AJAX engine on the client-side allows simplification of the implementation of the code, which is needed for a specific function on the client. This is a new way to use existing standards allowing to exchange data with server and to update parts of a Web page without reloading the whole page.

The proposed framework of group decision support application has modular architecture. If it is needed, the additional modules could be easily integrated. The described combinatorial optimization approach is coded as a mixed integer programming (MIP) module. The generalized framework of the proposed of group decision support application is shown on Fig. 3.

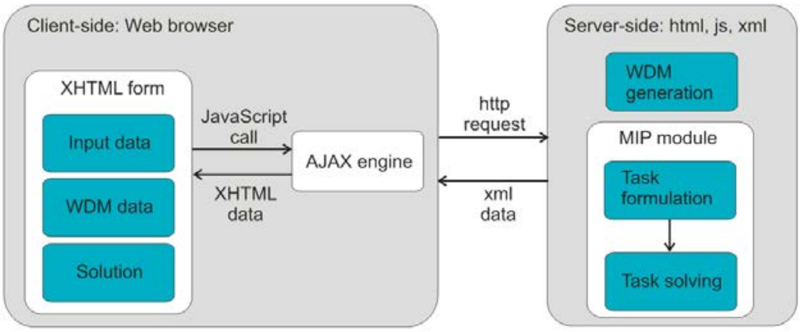

Fig. 3. The generalized framework of group decision support application

This software tool should provide an intuitive interface without the need of knowledge about used OR method. For the goal a Web based application was developed with main screen as shown in Fig. 4.

Fig. 4. Main screen of group decision support application

The structure of WDM matrix is generated automatically after entering input data about the numbers of decision makers, criteria and alternatives. Then the corresponding data about criteria weights and DMs' evaluations of alternatives are to be entered. Pressing of the single button ("Optimal solution") will apply the described approach and the optimal alternative is defined and shown.

6 Results and Discussions

In the developed prototype of group decision support application the LINGO solver [22] is implemented by its API as a module in a Web-based application. The decision of the numerical example (5) – (109) defines as optimal solution *Alternative 2* that coincides with the decision described in [10].

The experimental results with the developed prototype demonstrated that the implementation of the proposed approach is quite helpful and facilitate the group decision making. The simple and intuitive GUI was very well accepted by the practitioners during the prototype testing.

It is known, that there exists a distance between managers and operations researchers. Managers fails to understand the mathematical insides of OR methods and on the other side, OR specialists might not be aware of the business problems. This contradiction leads to use of WDM for group decision making through simple enumerative methods. These methods are based on multiplying the weight of each criterion with the evaluation of each alternative decision and summing the results in columns of each alternative. Then the alternative (column) with highest score result is chosen as best decision of the problem. In practice, the application of these methods is based on using of electronic spreadsheets. It cannot be said that this is the best approach because on the one hand, it requires a thorough knowledge of spreadsheets capabilities and on the other hand, the process of calculations is relatively slow and does not use the computational power of modern computers and algorithms. The other direction of group decision making is based on using of MAUT methods. These methods exploit the potential of computers and algorithms much better, and such flexible approach based on combinatorial optimization is developed in the paper.

The existing gap between the managers and operations researchers can be overcome by an easy-to-use software tools. These tools can be based on complex OR methods and calculations but their usage should be realized without need of specialized knowledge about the insights of methods. This means that developing of tools for business decision support should have in mind business managers' background and corresponding simple and intuitive graphical user interface (GUI) should be used. The testing of the developed prototype of group decision support application confirms that.

7 Conclusion

In the current paper a Web-based framework of group decision support application is described. The essence of the proposed tool is using of combinatorial optimization approach. As opposed to traditional multi-attributes approaches the explicit consideration of all of the criteria weightings of different DMs is modeled. The proposed modeling approach allows formulation of a single criterion mixed integer optimization task whose solution defines an optimal alternative. For the goal of using the proposed approach by managers without specific mathematical background, the corresponding optimization module is integrated in a group decision support application. A framework for the development of such a tool as a Web-based application is described. Easy-to-use and intuitive graphical interface was tested through the specially developed prototype using a real life numerical example. The testing shows the applicability of the proposed combinatorial optimization approach and approval of the developed framework for group decision support application. It can assist managers to make decisions by easiness of information presenting and interpretation of various alternatives by mathematically reasoned methods. As a future development this application can be extended to simulate different decision making scenario by simulating choice of particular alternative and its estimation by calculating the corresponding objective function value.

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