EXPERIMENTAL EVALUATION
OF A MULTIOBJECTIVE
LINEAR PROGRAMMING SOFTWARE

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EVALUATION D'UN LOGICIEL INTERACTIF DE PROGRAMMATION LINEAIRE MULTICRITERÉE PAR EXPERIMENTATION EN LABORATOIRE

RESUME

Le niveau de la recherche empirique en matière de logiciels d’aide à la décision multicritère est relativement faible comparativement au taux de développement de nouvelles méthodes d’analyse multicritère.

Ce cahier présente la méthodologie et les résultats d’une étude empirique ayant pour but l’évaluation de la capacité d’un certain logiciel interactif (il s’agit du logiciel ADELAIS pour microordinateur) de fonctionner comme un instrument efficace d’aide à la décision pour des problèmes de programmation linéaire multicritère.

Le cadre méthodologique de l’étude comprenait une expérimentation systématique du logiciel sur un problème tricritère de gestion agricole. Le rôle des décideurs a été joué par une population d’étudiants qui ont utilisé le système ADELAIS de façon individuelle pour soutenir leur propre processus de décision.

Les résultats de l’étude ont été obtenus par: (1) évaluation de quelques indices de performance de ADELAIS, comme la capacité de converger, le volume d’information, la possibilité de modéliser les préférences du décideur et le temps de calcul; (2) recensement des avantages et des faiblesses des diverses composantes du système au cours du processus de décision pour chaque élève; (3) démonstration des utilisateurs auprès des décideurs de l’utilisateur
1. INTRODUCTION

Empirical research in decision support systems (DSSs) and in decision-aiding software in general mainly concerns the investigation of the degree to which the use of such decision tools improves the effectiveness of the decision making processes. One major class of empirical DSS studies is based on the experimental approach, according to which the performance of a DSS is tested in laboratories over simulated decision environments and controlled populations of decision makers (DMs). Representative works on this field have been recently reviewed by Sharda, Barr and McDonnell [15].

Empirical research in multicriteria decision support systems and multicriteria decision-aiding software in general is relatively sparse with respect to the rate of development of new multicriteria decision making (MCDM) methods. This is unfortunate as such research could provide strong inferences and help users in choosing among methods and software for handling real-world problems. Empirical studies in this area follow two different approaches:
- Comparative evaluation of methods/software on a set of predefined criteria;
- Tests on the performance of a certain method/software in order to distinguish and to evaluate its characteristic properties.

Some representative works of the first approach are the studies conducted by Tell [17], Kok [9] and Wallenius [18]. Tell applied four different methods, which used the notion of utility, on a budget formation problem and compared their effectiveness according to the numerical precision of the results, the time spent with each method until the final decision was reached, the ease of use and a global estimation of the aid offered by each method to the DMs. Kok compared different interactive multiobjective programming methods by applying them on a long-term energy planning problem. The effectiveness of each method was evaluated according to the computational effort, the information load, its learning effects and their applicability in group decision making. Relative, although in a different context, is the comparative study conducted by Wallenius.

According to the second approach, Hammond, Cook and Adelman [5], Lamby [10] and Yannacopoulos [19] experimented with the software packages POLICY, PREFCALC and MINORA respectively by applying them on test decision problems with a finite number of alternatives. The main purpose of these studies was to examine the effectiveness of the software when used, as tools for decision making, by individuals not initiated into multiple criteria analysis.
The work presented in this paper can be listed in the latter category of empirical studies. Its purpose is twofold. First, to evaluate the performance of the ADELAIS multiobjective linear programming (MOLP) software as a decision-aid tool. Second, to outline a general framework for relative experimental tests. A comparative study of ADELAIS with other relative MOLP softwares was avoided for two main reasons: First, a software permitting the use of different MOLP methods, including the ADELAIS underlying methodology, in a homogenous computer environment was not available. Existing MOLP softwares differ in their design philosophy and show many particularities in operation. These factors were expected to influence undesirably the results of a comparative study. Second, many interesting, from the methodological aspect, MOLP algorithms have not been as yet integrated into interactive computer programs.

The paper is organized as follows. In section 2 the operational principles of ADELAIS are outlined. Section 3 presents the criteria which were used for the evaluation of the performance of the system. The experimental procedure is presented in section 4. In section 5 the results of the study are presented and discussed in some detail. Finally, some suggestions for improvement, which was deduced from the study, are given in the conclusion.

2. OPERATIONAL PRINCIPLES OF ADELAIS

ADELAIS is a fully interactive and menu driven computer program which is designed to support decisions in MOLP problems of the general form:

\[
\begin{align*}
\text{[max]} & \quad g_1 (x) = c^T_1 x \\
\text{subject to} & \quad x \in A = \{ x \in \mathbb{R}^m : \ A x \leq b, \ x \geq 0 \}
\end{align*}
\]

(1)

where \( x = (x_1, ..., x_m) \) is the vector of the decision variables, \( A \) is the matrix of the technological coefficients, \( b \) is the right-hand side of the constraints and \( c_j = (c_{j1}, ..., c_{jm}) \) are the coefficients of the objective \( g_j \).

ADELAIS consists of twelve independent modules, which as a whole support extensive data management and realize a coherent MOLP methodology. Detailed information about the underlying methodology of ADELAIS, which is also presented briefly in the rest of this section, as well as its software structure and the user interface are given in two papers, respectively Siskos and Despotis [16] and Despotis and Siskos [3].
The MOLP method incorporated in ADELAIS operates in four stages. (An interesting three-stage method has been proposed by Jacquet-Lagrèze, Meziani and Slowinski [7]).

**Preliminary stage**

In this stage upper and lower bounds for the objectives (say $g_1^*$ and $g_{1*}$ respectively) are obtained by maximizing and minimizing respectively each objective on the feasible set $\mathcal{A}$. Particularly, if all or some of the minimization problems are unbounded, and this may happen even though the original MOLP problem has been well formulated in order to have a finite maximum, the lower bounds are computed with a heuristic (cf. [16]). Afterwards, an initial efficient solution (i.e., a solution which is not inferior to any other feasible solution) is estimated in a way similar to that in Step Method (STEM) of Benayoun et al. [1]. This technique guarantees that the objective values which correspond to the estimated solution will be as close as possible to the upper bounds with respect to the weighted Tchebycheff norm.

The iterative part of the method can be resolved in three successive stages.

**Stage I**

At each iteration the system provides the DM with a new efficient solution and
Stage II

Stage II implies a learning process of the DM's preferences. At first, a simple technique is set up to build a reference set of decision profiles (i.e., a set of n vectors that might be assumed by the n objective functions). These reference alternatives are presented in pairs to the DM, who is asked to rank order them according to his/her preferences. Then a concave additive utility function, which is as consistent as possible with the DM's ranking, is assessed by a modified version of the LPA ordinal regression algorithm (cf. Loomes, Larrage, and Sugeno).
Convergence

An iterative procedure is said to have good convergence properties if it is able to approach some final solution in a finite number of iterations. This means that the investigation of convergence is directly related to the definition of the final solution. However, in decision problems involving multiple objectives, there is no solution which could be objectively judged as the final one. Particularly, in MOLP problems the final solution (i.e., the "most satisfactory" solution) is exclusively defined by the DM's individual preference system and not by mathematical conditions. Thus, mathematical convergence is not easy to investigate in MOLP methods. Moreover, requiring "absolute" convergence from interactive methods seems to be against the principle of the "learning mechanism" on which these methods are based.

In multiple objective interactive methods it is more convenient to investigate "requisite" convergence (Phillips [12]). This property reflects the capability of an interactive method to model progressively the preference system of an individual in such a way that he himself be able to reach a satisfactory solution. However,
Information load

The information load is a considerable factor that influences the general performance of an interactive method and more precisely its applicability. As the interactive MCDM methods differ in the way they assess the DM's preferences, the information processing operations performed by the DM vary from one method to another.

Larichev and Nikiforov [11] identified eleven information processing operations, which are widely employed in the interactive MCDM methods, and assigned to each of them a general estimate reflecting their complexity. Some of these operations are elementary (i.e., they cannot be broken into other operations) while others can be analyzed in a sequence of elementary operations.

The requirements of ADELAIS in information processing operations are limited. In fact, in stage I the DM must discriminate between satisfactory and not satisfactory objective values, with respect to the solution obtained at each iteration. This operation involves comparisons of the obtained objective values against the respective upper bounds and is sufficiently reliable as it can be performed by the DM without many contradictions. Following Larichev and Nikiforov's
can reproduce the DM's subjective ranking. This latter is easily obtained by Kendall's $\tau$, whose value results from the number of violations caused by the model on the input ranking ($\tau=1$ for full consistency and $\tau=-1$ for complete inconsistency).

Computational time

The time spent by an interactive system in computations is a considerable factor that influences its applicability. In fact, this time determines how long the user should wait until the system responds to his inquiries. In the case of interactive MOLP systems, in which the information-retrieval operations are limited, the computational time is the most considerable factor that influences the response time of the system. The computational time is a function of the computational load of the system but depends also on other factors such as the efficiency of the algorithms and the computational speed of the computer on which the system is implemented.

In MOLP methods the computational load is a function of the number and the dimensions of the linear programs solved at each iteration.

The computational load of ADELAIS is accumulated in stages II and III (see [16] for a detailed analysis of the dimensions of the linear programs solved).

Additional indices

Some other features of ADELAIS, such as its factionality, the ease of use and its applicability were evaluated by using the subjective judgments of the participants after the experience they had with the system. All relative data were recorded with the help of a questionnaire.

4. THE EXPERIMENT

Subjects

Participants in the study were 20 students of the Piraeus Graduate School of Industrial Studies enrolled in a game theory and business policy course. In the framework of this course students had the opportunity to become familiar with decision making in simulated business environment by working on business simu-
The decision problem

The decision problem which was used in the study concerned the planning of an annual cultivation program for a Spanish agricultural cooperative. The case study was initially presented in Romero, Amador and Barco [13] as an application of compromise programming.

The linear programming model formulated for this study had 25 decision variables and 21 constraints. Three objectives were under consideration in this problem as they were determined by the Agrarian Reform Law for Andalusia:
was assigned at random to each one. These solutions had been calculated prior to the experiment by applying the first step of the algorithm by Choo and Atkins [2] to the data of the MOLP problem under consideration. For the conduction of the experiment, each participant was invited individually to assume the role of the DM within the farm planning problem and to reach the efficient solution assigned to him/her by modeling his/her preferences to this direction with the help of ADELAIS.

5. RESULTS AND DISCUSSION

The results of the study are classified in three categories:

- results obtained from the measurement of the basic performance indices of the system (convergence, information load, consistency and computational time);
- results obtained by recording the extent to which the various components of the system were used;
- results obtained from the analysis of the questionnaires.

Basic indices

The results concerning the basic performance indices (extreme and mean values) are summarized in table 2.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>values</th>
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<tr>
<td></td>
<td>minimal</td>
</tr>
<tr>
<td>Convergence (number of iterations)</td>
<td>2</td>
</tr>
<tr>
<td>Information load (number of pairwise comparisons)</td>
<td>11</td>
</tr>
<tr>
<td>Consistency (Kendall’s τ)</td>
<td>.714</td>
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</table>

Computational times(*)

<table>
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<tr>
<th>Criteria</th>
<th>values</th>
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<tr>
<td>Comput. time for the assessment of the utility function (sec)</td>
<td>4</td>
</tr>
<tr>
<td>Comput. time for the determination of an efficient solution of maximal utility (sec)</td>
<td>3</td>
</tr>
<tr>
<td>Total time spent with the system (min)</td>
<td>59</td>
</tr>
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(*) Reported on an IBM 8580-111, 80386-20Mhz microcomputer.
Convergence

All participants reached the final solution within acceptable accuracy after a small number of iterations (mean number equal to 1.8). Participants varied.
The revisionary operations referring to the formulation of the MOLP problem were excluded from the experiment and consequently are not included in table 3 as no modification of the MOLP model was assumed during the decision process. Among the revisionary operations provided by the system the one most used was the operation related to the revision of the preference ranking during the assessment of the DM's judgment policy. This fact may be rendered to the ability of the system in persuading the user of his/her judgment errors.

The operation which is related to the revision of the satisfaction levels and which in fact permits the dilation of the decision space was first used during the third iteration by the 21% of the participants who proceeded to this iteration. This operation was exclusively used in cases where the reduction of the decision space in the first two iterations caused the omission of the efficient solution which was supposed to be reached. For the same reasons this operation was also used in the fourth iteration by 25% of the participants who proceeded to this iteration.

Finally, during the first three iterations, 15%, 20% and 5% of the participants respectively proceeded to a trade-off analysis in order to modify directly their utility model and to preserve their subjective preference ranking against the suggestions of the system.

_Users general estimations_

The users estimations with respect to the general performance characteristics of the system can be summarized in the following.

_The software interface of the system provides a robust and operational framework_

Users did not meet difficulty in controlling the system operations. They were easily oriented and navigated through the components of the system. Internal checks prevented the users from making mistakes in operation on the one hand, on the other hand prevented them from getting senseless messages or output. Besides, users seemed to comprehend and manipulate without difficulty the information provided by the system. Particularly, the graphical representation of the results during the utility assessment process helped the users to digest concepts, such as "criteria weights", "marginal and global utility" and "consistency-inconsistency".

_The response time of the system is satisfactory_

Recall here that the system was tested on a high speed microcomputer IBM 8580-111.
- *Information processing requirements are limited*

Participants did not meet difficulty in discriminating between satisfactory and not satisfactory objective values when they evaluated a new compromise solution. Indeed, such an operation does not show in general any innate difficulty but it is simplified more when facilitated, as in ADELAIS, by auxiliary elements concerning the attained solution, such as the satisfaction levels, the upper bounds of the objectives and the rates of achievement with respect to the upper bounds. Contrarily, the definition of a preference ranking on the reference alternatives is not an easy task to go through as it includes pairwise comparisons among the reference alternatives. However, 35% of the participants did not meet difficulty in performing pairwise comparisons. This fact may be rendered to the relatively small number of objectives considered in the decision problem, as well as to the way the system brings together the reference alternatives. Indeed the system, in order to facilitate the DM to exteriorize his judgment policy, does not simply puts side by side the alternatives to be compared but underlines the pros and cons of preferring one than another.

- *The system permits the DM to revise and to readjust his/her preferences*

The free readjustment of the preferences, according to their consequences in the course of the decision process, is an innate property of ADELAIS which is promoted in two levels: Globaly, by means of the revisionary operations which permit the re-examination of solutions excluded in previous iterations and locally, during the assessment of the utility function and the analysis of inconsistencies where the DM can revise his judgment policy and thus to alter the search direction.

- *The system helps the DM to improve his/her knowledge about the decision problem*

In the course of the decision process participants showed progressively greater facility in expressing their preferences as the trade-off analysis provided by the system helped them perceiving more and more the relation between the objectives and what was feasible and what was not. This fact may be correlated to some extent with the declining tendency of the mean duration of the iterations (fig. 1)
6. CONCLUSION

A framework for testing interactive MOLP softwares is outlined in this paper. The empirical study conducted within this framework showed that the ADELAIS software package succeeded satisfactorily in its role as a decision-aid tool for multih-
REFERENCES


