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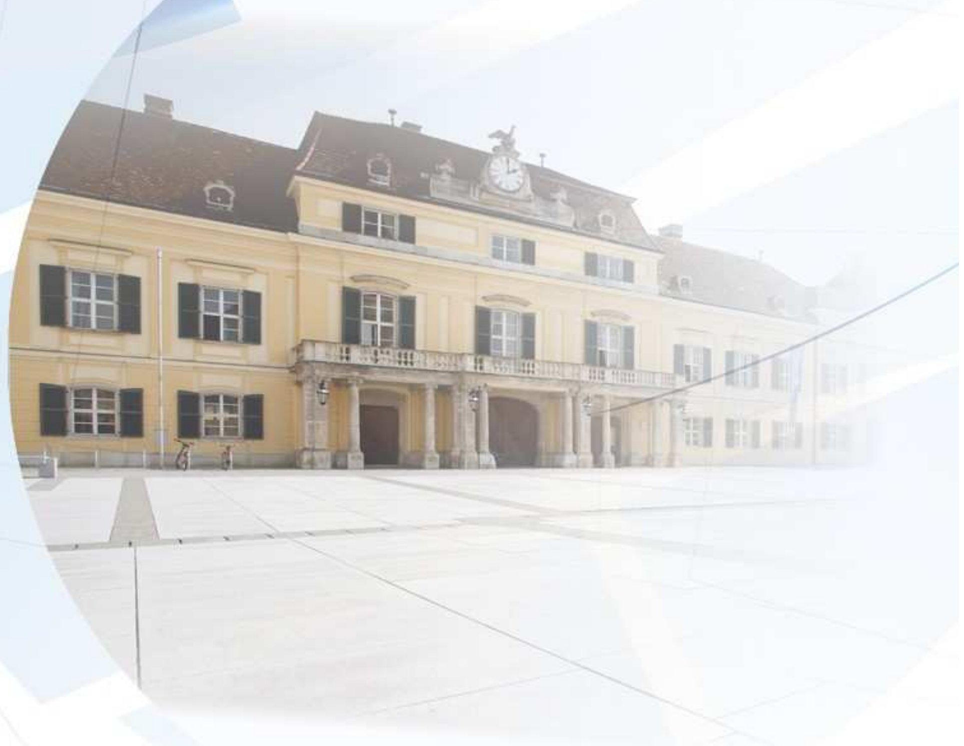

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Foreword

The aim of the paper is to present the Decision Support System which has been designed to support the management of research and development activities on the national level. The information processing capabilities of such system are discussed as well as possible methodological frameworks including implementation related issues for providing decision support are presented by the authors.

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Computer Aided Decision Support for Planning and Management of Research and Development

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1. INTRODUCTION

Research and development is planned in many countries on a national level and thus managed centrally by some (usually governmental) authority. The planning process requires supporting information and methodology background because the final R&D plan must take into account many factors like:

- structure of the national economy and its goals for the desired period
- R&D potential of the research community
- expected trends in technology and economy
- international scientific cooperation and connections between research groups and institutes
- amount of money for R&D for this period
- other possible consequences in economy, technology and society.

From this point of view the problem of planning of R&D is a multiattribute (or multicriteria) problem. More people are usually responsible for the final decision and then the problem can rise to a group decision making problem.

The aim of this paper is to describe the decision support system MDS, which is being developed to support the management of research and development on the national level. The problem is described from the point of view of necessary information support. We also introduce possible methodology for solving the problem and a brief description of computer implementation on a XT/AT compatible personal computer.

2. PROBLEM DESCRIPTION

Research and development (R&D) on national level is usually managed in longer time periods (i.e. - five year plans). Assume, the aim of R&D is described in global goals $G(1),...,G(k)$, which may be thought of as expected levels of science and technology in selected areas of national economy. The description of goals is usually verbal, the goals may be subdivided into particular goals with possible quantification of expected results. The goals may be reached by possible projects $P(1),...,P(n)$, where one project may reach more particular goals or even a global goal. The aim of R&D planning is to propose those projects for the plan, which in common reach the most complex collection of goals and do not exceed the money limit M. This procedure is usually provided by managers, experts and analysts from several areas of science, technology and economy. This group is usually supported by several groups of supporting staff which is responsible mainly for information support for committee members. The duty of management committee is to:

1. set up the goals of R&D for the next planning period
2. define and evaluate criteria for project selection
3. collect proposals for research projects from research community and/or from government
4. make the decision about the R&D plan - choose the appropriate set of projects according to criteria, fulfilling the constraints of money and reaching the expected goals
5. check running projects periodically - stop non effective projects and add new ones from a permanent stock of new proposals

To fulfill these duties management committee must be provided by an immense information support covering the questions of reached levels of technology and their prognosis for the planned period as soon as the questions of economy and policy. Each of these five phases can be solved separately being in its nature a part of a multicriteria decision procedure. We shall formalize these phases and provide mathematical description of each of them.

2.1. Setting up the goals

The goals of R&D must be set up long enough before the start of the planning period, so that there is enough time to provide phases 2., 3. and 4., which require much more information support and a more complicated procedure. The description of global goals usually cannot be formalized. Assume the global goal $G(j)$ consists of particular goals

$G(j,1),...,G(j,p)$. We say that the proposed project $P(i)$ is **partially acceptable** by the committee, if there exists at least one particular goal $G(q,m), q=1,...,k, m=1,...,n$ so that the aim of $P(i)$ is to reach $G(q,m),(P(i) \rightarrow G(q,m))$. The collection of projects supporting one global goal can be thought of as a research program. A proposed project can be included in the decision agenda if, and only if, it is partially acceptable. If the partial goals require a certain level of technology which is measurable by any physical units as parameters, then these parameters should be included into the set of criteria for the appropriate procedure in the phase 2.

2.2. Defining the criteria

Criteria for selection of projects may be of different nature - quantitative or qualitative, focusing on the aspects of technology economy, ecology, sociology, level of international cooperation, level of cooperation between projects in the same research program and in different programs, expected profits, etc. As the global goals may differ essentially (i.e. high technology in machinery should have different approach from, say, biotechnology), the defining of criteria must be done in the following three steps.

2.2.1. In the first step criteria which enable comparing the technology and scientific levels of particular goals $G(i,j)$ with the expected results of proposed projects $P(k)$ are set up. These criteria must enable excluding those projects, which do not reach the expected level of science and technology at the end of the planning period. Several IF-THEN rules and limits for technology parameters can be set up as criteria. All criteria with binary evaluation (YES/NO) with principal importance for the whole decision process should be set up here.

2.2.2. In the second step criteria must be set up to enable composing the separate global goals - research programs so that all particular goals are covered by projects. The connections between projects, the research capacity of the proposed research group and possible consequences must be stressed here.

2.2.3. The third step requires defining a common set of criteria for the whole R&D plan, taking into account the point of view of structure of the national economy, effectiveness of the whole plan and the given money restriction M as the upper limit.

In all steps the group of decision makers has to come to a unique set of criteria for the procedure. The criteria are first defined verbally, then the bounds, measuring units, importance and/or aspiration levels must be set up. This phase (and all subsequent phases too) should not be performed without a computer aided decision support system. The possible methodology and software implementation is described in later parts of this paper.

2.3. Collecting of projects

This phase could be thought of as only an administrative procedure. The main goal of this step is rejecting of those project proposals, which are not partially acceptable. The project proposals should also be checked according to criteria with binary evaluation (YES/NO) and principal importance which are defined in the first step (2.2.1). Such a procedure speeds up the whole decision process although it can be fully performed by the supporting staff. As the result of this phase the Management Committee is provided by a set of partially acceptable projects Spr which moreover fulfills all principal restrictions.

2.4. Selection of projects

This is the final and most important phase of the whole decision procedure. It is to be performed again in three steps according to the structure of the problem and defined sets of criteria in the second phase (steps 2.2.1 to 2.2.3). Relevant steps in this phase require decision in

- comparing the proposed projects with the expected particular goals and their parameters
- composing projects to research programs each for reaching one global goal
- getting together the whole R&D plan

The result of any of these steps is a ranking of projects according to all criteria defined for that step. This is in general a problem of multicriteria evaluation of finite set of alternatives, although there are differences between the methodology which can be used in particular cases. There is one essential limit for the whole planning process:

the sum of all money requirements cannot exceed M

2.4.1. The procedure of comparing the expected results of proposed projects with the particular goals of the plan evokes problems of methodology. The final ranking of projects for a particular program has to provide an evaluation of each project in such a way that the values of projects in different programs (i.e. projects reaching different global goals) might be compared in later steps. On the other hand, the nature of the decision situation in different areas of science and technology requires various methods of evaluation (i.e. interval scale methods, pairwise comparison methods, Saaty methods, aspiration level methods, etc.), which must be modified to give as a result a comparable relative evaluation. Thus if $Rs(P(i))$ is the evaluation of project $P(i)$ as a result of the method $M(s)$ from the set $ME=\{M(1),...M(t)\}$ of available methods then $Rs(P(i))$ must express the relative quality of the project in a predefined scale, say, in the interval <0,1>. As a result the Management Committee becomes a ranking list of all projects $P(i),i=1,...,n$ and separate ranking list for each program. The values of $Rs(P(i))$ must be of high importance for the next step. This resulting value may be considered as a criterium with appropriate high weight in the next step.

2.4.2. The main goal of the second step is the reordering of the ranking lists according to the criteria set up in the step 2.2.2. As the problem of composition of programs should have similar attributes a common methodology is to be used for all programs - global goals. The result of this step is a reordered list of projects which takes into account mainly the connections and relations between projects and the complexity of possible research programs. Each project gets a new evaluation $E(P(i))$ and a research program, represented by its global goal $G(j)$, is to be evaluated by a value E'(G(j)). Programs with better covered particular goals should be preferred.

2.4.3. The final step of the decision process may be provided with two basic policies from the point of view of management committee. The first one is to reorder again all projects according to weights E' of corresponding programs and criteria set up for this step. The projects are then selected according to this final ranking. The second possible policy is to distribute the given amount of money M into programs proportionally with respect to their values E' and provide the selection according the criteria inside the programs. These two policies are completely different from the procedural point of view and they may have a different impact on the final solution. Further combinations of these two ways are possible, but the decision support system must enable at least these two possibilities.

2.5. Checking of running projects

Running projects are to be checked according the effectiveness during the planning period. Each project is to be checked separately. The result of these procedure can be stopping of non effective projects and thus providing an additional amount of money for new projects, which can be added during the planning period. The procedure of 2.2.1 and 2.4.1 can be used for this purpose, but it requires a huge information support to enable the comparison of running projects with the latest trends in the "other" world. Such a policy requires a permanent dialogue between the management committee and the research community and submitting of new suitable project proposals.

3. INFORMATION SUPPORT

The management committee must be provided by an adequate information support concerning all running and prepared projects. The information support should be the duty of the supporting staff and it may be done in a computerized form as a database on the same computer as the decision support system itself. The main problem of information support for management activities described above is an efficient information transfer between a database used for the standard information support in other management activities and the decision support system. There are several ways how to solve this problem. A DSS system may use its own data management system with no import or export data facilities to other data structures. The latest version of SCDAS, see Lewandowski, Johnson, Wierzbicki (1986), is an example of such an stand alone system. From the point of view of a decision maker it may be important to have the same interface to both - information in a database and the decision support system or to have the possibility to access data in the database from the DSS environment. Another problem connected with steps 2.2.1 and 2.4.1 is the access to information databases with some factographic data on mainframes. The online connection to such facilities is an important and necessary need for the management committee and its supporting staff. In the decision support system described later we used a standard database environment to maintain the data.

4. METHODOLOGY

From the point of view of methodology the planning problem is (according Lewandowski, Wierzbicki (1987)) a so called alternative based group decision problem. The steps 2.2.1 and 2.4.1 need several methods for multicriteria evaluation of alternatives for ranking of project proposals. Methods for multicriteria evaluation of alternatives are well known and described in several books and papers(i.e. Keeney, Raiffa, (1976), Fotr, Pišek, (1986) or Lewandowski, Wierzbicki, (1987)). From the point of view of experts, who take part in this activity, the methodology for evaluation should be mostly understandable for them. This is because most of them are unexperienced computer users and know very few suitable methodologies for evaluation. The decision maker needs help either from an expert who advises him on the best possible method for the particular evaluation, or from the decision support system itself which must have some attributes of an expert system for identifying the decision situation and proposing the appropriate way of solution. The experimental version of the MDS system described in section 5 does not contain any expert system facilities yet. An expert system is being developed for this purpose, using only the kernel of a standard inference mechanism. All other parts of the expert system are developed to support the decision process with MDS.

The whole agenda is directed by a committee chairman who is treated by the system as a privileged user with full access rights. He is responsible for setting up the problem and management of the whole decision process. In cases when methodology is to be chosen he treats the final decision. Each committee member has a voting factor $v(k)$ expressing his competence and position in the committee.

Most of the methods for setting up attribute weights assume, that all attributes are mutually independent. This assumption is usually invalid with real life problems. That is why the MDS system modifies the procedure of setting up of criteria weights by introducing rules, which enable to set up dependences between criteria and alternative scores. The rules are expressed either in IF - THEN form or as conditions or limits for alternative evaluation. Each rule is weighted or evaluated in the same way as criteria. This approach is similar to LIGHTYEAR, see LIGHTYEAR, (1984).

The principal question of the methodology used in all steps of phase 2 is the disagreement analysis in case of group decision making. One of the possible ways of how to solve this problem is the principle used in SCDAS, see Lewandowski, Wierzbicki, (1987), for aspiration levels. This algorithm can be used also for other methods in the following way:

Denote K the number of experts in the committee and J the number of criteria defined for the particular problem, $p(j,k)$ the evaluation of criterium j by the committee member k. The value $p(j,k)$ is a result of any method used for evaluation of criteria weights or aspiration levels. It is obvious, that all the committee members must use the same method for solving the particular problem. Now the algorithm for computing the disagreement indicator DI(j) of SCDAS can be used to indicate the differences in opinions of committee members (see the same paper for details of algorithm).

Denote $q(j,k)$ the evaluation of attribute j by committee member k. The mean value

$$q(j) = \sum_{k=1}^{K} g(j,k)/K$$

is then used for alternative - attribute assignment in phase 4.

Assignment of alternative - attribute scores in particular steps of phase 4 result in evaluation $E(P(i),k)$ of each project $P(i)$ by all committee members k=1,...,K. The value E is a result of evaluation and ranking over all attributes with mean attribute weights transformed into the $<0,1>$ interval.

The group evaluation $EG(P(i))$ of each project $P(i)$ is computed as the sum of individual evaluations over all committee members with respect to voting factors:

$$EG(P(i)) = \sum_{k=1}^{K} v(k)E(P(i),k) \; / \; \sum_{k=1}^{K} v(k)$$

where $v(k),k=1,...,K$ are voting factors of committee members.

The step 2.4.2 requires additional evaluation of research programs. Most of the criteria should be qualitative in this case. The aspiration level methodology seems to be very useful for this type of problem.

The last step of the decision procedure - 2.4.3 requires two different policies of final ranking. The selection of the policy is to be treated before the evaluation and is due to the decision maker (in individual decisions) or to the committee chairman. Both policies can be executed and compared. The alternative - attribute assignment and final ranking can be performed in the same way for both with no special methodology.

5. COMPUTER IMPLEMENTATION

The decision support system MDS for the planning agenda is in this experimental version implemented on a PC XT/AT compatible microcomputer running under MS DOS 3.20 operating system.

5.1. Main characteristics of MDS

The integrating point of the whole system is the dBASE like structure of its data management. It supports both individual and group decision making in all phases of the decision procedure. It makes no restrictions on the character of attributes and alternatives. The number of attributes and alternatives is unlimited from the point of view of implementation. Of course, a large number of attributes decreases the influence of each attribute on the final ranking. The attributes may be mutually opposite, of different measuring units or uncomparable, they can be quantitative, qualitative or considered as aspiration levels. Quantitative attributes are characterized by its name, measuring unit, upper and lower bound; qualitative attributes are characterized by its name and a linguistic or numeric scale. There are no theoretical or implementation limits on the number of users - committee members and the number of problems - decision procedures. On the other hand, relation and access rules between the problems and users are exactly defined. A single user can work with more problems and one problem can be evaluated by more users -

the management committee. In this case MDS requires the definition of users' access rights according to the actualization of problem data. The committee chairman is responsible for this act.

All methods for attribute - alternative evaluation are considered to be separate software modules, including modules for statistical analysis and graphic representation of results. The number of methods in the system is not limited. It is possible to add new modules and enlarge the MDS system in this way. The only requirement for a module to be included into the system is to fulfill the interface of data structures of databases including the data of users, problems, attributes and alternatives. The structure of these databases is unified and it is the integrating element of the whole MDS system.

In order to cover all the problems of R&D planning and management the system enables following modes of setting up attribute weights and alternative - attribute assignment:

a) modes of setting up attribute weights
   - weights of attributes are set up in the initialization phase and are not due to expert evaluation
   - weights of attributes are evaluated interactively; evaluation of disagreement level in group decision is possible
   - aspiration levels for all attributes are set up interactively with disagreement analysis

b) alternative - attribute assignment
   - scores of alternatives are constant and are not subject to expert evaluation (i.e. technical parameters of production)
   - scores of alternatives are set up in the interaction between the user and the system; aggregation of individual assignments and comparing individual and group results is possible.

Different modes of attribute weights and assignments of alternative scores are independent from the methods used for evaluation, following only the needs and characteristics of the problem. The implementation of the system allows any reasonable combinations of described modes.

The character of the decision process requires a proper preparation of each decision and provides the decision maker with the opportunity of using a decision support system before taking part in a group decision. The MDS system enables to solve one problem separately by more users, analyze the results and then, in the second step include all single users into a common group of decision analysis. There is a big difference between individual and group decision making from the point of view of access rights to problem data. In case of individual decision the user has access to all data structures with possibility to add or remove attributes or alternatives. This is usually prohibited in group sessions.

5.2. The structure of the system

The MDS consists of several types of databases, where system and problem data are stored, and of software modules which enable a user-friendly interface or provide methodology support. The whole decision procedure supported by MDS consists of two phases - *initialization phase and dialogue phase.*

The initialization phase enables setting up the problem, defining committee members and mutual relations for the decision procedure. It also includes the first phase of the planning agenda (setting up the goals). The data are stored in system and problem databases.

The dialogue phase represents the decision support procedure itself (all subsequent phases).

The system databases are created during the system initialization phase and they contain data:

- user access rights to the system (the set of users recognized by MDS)
- problem definition (problem name and description of global and particular goals)
- relations between the problem and individual users (projects in one particular program - reaching the same global goal may be evaluated by a part of management committee including only specialists from the area of science and/or some additional staff, hence for the steps 2.2.1 and 2.4.1 special access rights must be defined for each program (treated by the system as a new decision problem). The committee chairman has special access rights.
- relations between particular decision problems
- methods available in system

The permanent access to all data in system databases is a necessary condition for running the system.

The problem databases contain data of attributes (name, measuring unit, type, mode) and data of alternatives (name, abbreviation, comments).

The dialogue phase is a menu driven with some comments and hints for the user. The communication module provides the dialogue with the user and calls necessary software modules. It also contains some important error messages. A fully self documented version is under development.

6. FUTURE DEVELOPMENT OF THE SYSTEM

Although the system has been developed to support R&D management on the national level, it can be used also for the same activity on a lower level (a large company, a region). The principal goal for the next development is the parallel development of the supporting expert system and other necessary modules (graphical representation of data, statistic functions, etc.). The compatibility of MDS with a standard information processing system enables connection to data structures used for another information processing. A further development in this direction should be preferred.

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