A MULTI-CRITERIA APPROACH TO APPLIED R AND D PLANNING: THE CASE OF QUALITATIVE CRITERIA

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The paper considers development of a method for planning applied scientific research and development (R and D) allowing for both qualitative and quantitative estimates of R and D projects. Major stages of an heuristic algorithm are described that was developed for R and D plan generation.

1. Portfolio optimization problem

There is a familiar formulation of applied research and development planning: N, R and D projects are given, the ith project ($i = 1,2,3, \ldots N$) being characterized by a certain value v_i (income, usefulness, cost effectiveness, etc.). Projects require appropriate resources. Constraints $R^v(t)$ are imposed on resources of the vth type (manpower, money, material) necessary for implementation of R and D projects. Several versions of an R and D project are possible differing in volume and type of required resources, and in project duration (all versions of one project are assumed to lead to the same final result). It is required to select such a set of R and D projects (with due allowance for the resource constraints and the project versions) that would have the maximal effectiveness index. It should be noted here that, most commonly, the sum of values of R and D projects included into the plan is regarded as such an index.

This problem was termed "portfolio optimization" problem [1, 2, 3]. There is a bulky literature dealing with various approaches to the problem in terms of mathematical programming.

All the known "portfolio optimization" methods estimate each project through the totality of its characteristics (quality estimation criteria).

These criteria may be grouped into two categories. The first one involves criteria characterizing the expected resource expenditures and economical effectiveness of a project. Various criteria of this group are used within the framework of mathematical models of cost and economical effectiveness. For applied R and D, these models are rather beyond question. The very existence of approved techniques for calculation of project cost and economical

1*

effectiveness makes it possible to regard the criteria of this group as objective in that both their composition and methods for estimate determination are independent of the governing body of some planning organ.

Along with these purely economical criteria, in the actual environment planning organs are using in increasing frequency other criteria reflecting the scientific and technical policy, and the specific features of a particular organization. Among such criteria there are, for example, estimates of the working quality of potential personnel, chances of success, correspondence of the expected results to the world level.

The necessity to involve into planning noneconomical criteria is due to the complexity of the environment, the impossibility of quantitative estimation of the effects of some R and D projects, and to directions of the superior levels. As a rule, the criteria have qualitative estimate scales, with each estimate being coached into words. Correspondence of the expected results to the world standards may be estimated, for instance, by the following scale:

a) expected R and D results are superior to the world standard;
b) expected R and D results correspond to the world standard; and
c) expected R and D results are inferior to the world standard.

Criteria of the second group are subjective in that both their composition and estimate scales are established by a particular planning body and cannot be accepted universally. Therefore, a model integrating criteria of both groups into a single project quality estimate cannot be universal.

The known methods of portfolio optimization may be grouped with respect to criteria used for project estimation and to models used for general evaluation of projects.

Methods evaluating project profitability [4, 5] use, as a rule, criteria of the first group only. A monetary index characterizing economical effect of project implementation is assigned to each project. Criteria of the second group cannot be integrated into the project profitability evaluation methods because of the impossibility of establishing their monetary equivalents. This is an evident demerit of this group of methods. Practically, when making decisions, the planning organs allow for many of the second-group criteria, although not systematically. Results obtained through project economical effectiveness models are corrected, not always consistently. Project profitability models cannot make the planning body sure that its orientation in science and technology was sufficiently taken into consideration during project selection.

Another popular method is that of scoring models of project profitability [6, 7]. This approach involves criteria of both groups using scales of scores; continuous scales being substituted by discrete ones for the first-group criteria. The major problem arising with application of scoring models is that of generating a model relating estimates with respect to various criteria and the general value of a project. How to establish proportion between criteria? How to compare the importance of the criteria of both groups? As it was demonstrated by critical surveys of existing methods of R and D planning [8, 9, 10], these questions have not yet found a satisfactory answer. Larichev [8] points to this fact as to one of the causes of the poor mathematical practicability of the R and D planning models. In our opinion, the very approach to the development of scoring models without representatives of the planning body is unsatisfactory.

Planning practice today requires methods for selection and evaluation of R and D projects that allow for the criteria of both (objective and subjective) groups, integration of the criterion estimates being done on the basis of the planning body (decision makers) policy. The present paper suggests a method [11] for the solution of "portfolio optimization" problems of some classes characterized below.

2. Peculiarities of the problem under consideration

The particular version of the portfolio optimization problem discussed below has the following features. The R and D projects presented for consideration to the planning organ are oriented to a particular product, many of them being closer to developments rather then to researches. Each R and D project is independent of other projects. There is an approved technique for calculation of economical effectiveness of R and D projects that involves evaluation of both consumption of various resources, and incomes which would be obtained with the attainment of the aims.

Along with economical effectiveness, the planning body uses for decision making noneconomical criteria as well. Such criteria, for example, may involve social effects of R and D, extent of application of the expected R and D results, correspondence of the results to the world level, etc.

Projects presented to the planning body may be in one or more versions. Such versions may include: a) in-house implementation of the R and D projects; b) technological cooperation; c) purchase and use of some results (patents, technology).

Resource consumption for each R and D project is small as compared with the resources at the planning organ's disposal. Moneys in national,

COMECON or hard currencies disposed by the planning organ are regarded as resources. It is assumed that with money one can buy any other resources, delivery time may be allowed for in the total duration of a given project version. The total allowable implementation time is limited also by decisions of the planning organ.

Resources of the planning organ are insufficient for implementation of all R and D projects. The management of the planning organ, i.e. decision maker(s) (DM), poses the problem of selecting from many projects presented to consideration the most preferable ones which are to be included into the financial plan. Those projects are regarded as the most preferable which comply with the DM sceintific and technical policy and result in the greatest possible total economical effect. The State Institute-Factory Combines of the People's Republic of Bulgaria feature the above peculiarities of R and D planning. The method presented below was developed with this end in view.

3. The class of projects of special importance

The noneconomical criteria manifest themselves most prominently when DM includes R and D projects into the plan on the basis of these criteria only. In this case, such projects, naturally, have the best estimates for all or some of the second-group criteria.

The idea of the proposed approach is to separate primarily those R and D projects where the second-group criteria are stronger than those of the economical nature.

In many practical cases it is important to establish those combinations of noneconomical criterion estimates which dictate that the R and D project be included into the plan. Such estimate combinations enable classification of all projects into two groups: especially important projects (K_1) which are necessarily included into the plan (one of the possible implementation versions), and ordinary projects (K_2) whose implementation depends on the expected economical effectiveness.

By condition, R and D projects having the highest estimates for all the qualitative criteria belong to K_1, and those having the lowest estimates belong to K_2.

The boundary between the two classes may be established by finding out preferences of the planning organ DM because they reflect DM's experience and scientific and technical policy.

Thus, the first stage of the solution is to separate the class of the most important projects. Researchers working in collaboration with employees of the planning organ work out, on the basis of the former decisions and the

environment, a list of noneconomical criteria involving both criteria which were actually taken into consideration in the previous decisions, and those which should be taken into consideration from the viewpoint of the DM scientific and technical policy. For each criterion a discrete scale with several qualitative verbal estimates is generated.

Formulation of the verbal estimates for criterion scales reflects the scientific and technical policy of DM, their desire to have certain qualities in R and D projects. In addition, the qualitative estimates play another very important role. The point is that the diversity, complexity and heterogeneity of R and D projects make their estimation very difficult for DM. This leads inevitably to inviting experts making a qualified and unbiased study and estimation of the R and D projects, and suggesting possible implementation versions. In this connection, the qualitative scales are a communication language enabling DM to tell the experts which degrees of quality should be discerned in the projects under consideration.

Now one meets with a problem from the decision making theory. It should be noted that the general problems of multi-criteria decision making were treated in monographs [20, 15, 21].

Let there be n criteria having a corresponding discrete scale with a_i estimates ($i = 1, 2, \ldots, n$) each. The total number of all possible combinations of criterion estimates is

$$A = \prod_{i=1}^{n} a_i. \tag{3.1}$$

It is required to break down these combinations into two classes of ordinary and especially important projects on the basis of information given by DM.

Solution of this problem may result in a decision rule representable as a set of two-criteria estimate combination tables, the number of the tables being equal to the number of combinations of other $(n-2)$ criteria. Figure 1 illustrates such tables for three criteria.

Now pass to an algorithm for solving the above problem.

Any procedure for getting information from DM should be based upon psychological and psychometric data about possibility of getting transitive and repeatable information. Moreover, these procedures should envision the possibility of verifying the information given by DM.

Presently, one may regard the hypothesis sufficiently confirmed that the major cause of the preference DM intransitivity in the selection problem is due to numerous attributes of the objects being compared and to their multi-criteria estimates [14, 15]. Using this hypothesis, one can formulate two auxiliary hypotheses:

1. With only minor violations of transitivity, DM may compare objects differing in estimates with respect to two criteria, all other estimates being fixed.

This hypothesis was checked in [18, 19], their results indicate to its plausibility.

2. For a small (2—3) number of estimates along the generalized criterion scale (in this case, K_1 and K_2), DM may make stable (good repeatibility for repeated inquiries) and consistent (rare violations of transitivity)

	B_1	B_2	B_3
Б$_1$	K_1	K_1	K_1
Б$_2$	K_1	K_1	K_2
Б$_3$	K_1	K_1	K_2

A_1

	B_1	B_2	B_3
Б$_1$	K_1	K_1	K_1
Б$_2$	K_1	K_2	K_2
Б$_3$	K_2	K_2	K_2

A_2

	B_1	B_2	B_3
Б$_1$	K_1	K_2	K_2
Б$_2$	K_2	K_2	K_2
Б$_3$	K_2	K_2	K_2

A_3

Fig. 1

Criterion A

Importance of expected results for the R and D contractor's standing in the environment

A_1 — very great, A_2 — great, A_3 — insignificant

Criterion Б

Work done by the contractor in anticipation.

Б$_1$ — the contractor has already done a major part of the work required by the given R and D. The rest does not involve principal difficulties.

Б$_2$ — R and D involve a number of difficult problems. There are ideas for their solution, and areas of studies have been defined.

Б$_3$ — R and D require study of new and insufficiently explored problems. There are no ideas for their solution.

Criterion B

Correspondence of the anticipated result to the world standard

B_1 — anticipated R and D results are superior to the world standard;

B_2 — anticipated results of R and D correspond to the world standard;

B_3 — anticipated results of R and D are inferior to the world standard.

estimates with respect to the generalized criterion scale for any combination of estimates of two criteria under the assumption that with respect to other $(n-2)$ criteria estimates are the best.

This hypothesis was studied in [13] and also may be regarded plausible.

According to these hypotheses, information required for the solution of the problem above may be obtained from DM by means of Table T for all combinations of two criteria under the supposition that other $(n-2)$ criteria have the best estimates (see, for example, Fig. 2). For all pairs of criteria, DM puts K_1 or K_2 into each entry of the tables. Redundant information may be used for DM consistency checking.

	A_1	A_2	A_3
B_1	K_1	K_1	K_1
B_2	K_1	K_2	K_2
B_3	K_2	K_2	K_2

Fig. 2

Criterion A

Anticipated level of R and D
The anticipated results are
A_1 — superior to the world standard;
A_2 — corresponding to the today's world standard;
A_3 — inferior to the world standard.

Criterion B

Social effect of R and D implementation
B_1 — the R and D project has a direct and very great bearing upon the improvement of the life standards of wide sections of the population;
B_2 — the R and D project contributes directly to the improvement of life standards of wide sections of the population;
B_3 — implementation of the R and D project has no direct bearing upon the living conditions of wide sections of the population.

DM should meticulously analyse contradictions in the two-riteria estimate combination tables in order to correct its scientific and technical policy.

It may be readily seen that in the particular case where all estimates have binary estimate scales and where reduction of estimates for any criterion pair results in the class K_2, the information obtained from DM through tables T is sufficient for generation of the decision rule. Sometimes one can reduce the situation to this particular case by uniting similar rows and columns in tables T (for instance, one can pass to binary estimates of criteria A and B in Fig. 2).

In the general case, the information in tables T is insufficient for decision rule generation. These tables are coordinate planes in the n-dimensional criterion space, and the boundary between the classes K_1 and K_2 may be restored through its projections on these planes.

Note, first of all, that some entires of the decision rule table are filled according to the evident rule: reduction of estimates with respect to some criterion does not result in increase of the class of quality.

To fill the balance of the decision rule tables, DM compares pairwise objects differing in estimates with respect to two criteria, quality class (K_1 or K_2) of one of the objects being known. Denote by $\rightarrow$ qualitative superiority of one object over another. Let O_1 and O_2 be compared objects. It is easy to see that the following relations hold:

$$\begin{array}{ll} \text{if } O_1 \in K_2 \quad \text{and} \quad O_1 \rightarrow O_2, \quad O_2 \in K_2 \\ \text{if } O_1 \in K_1 \quad \text{and} \quad O_2 \rightarrow O_1, \quad O_2 \in K_1. \end{array} \tag{3.2}$$

The entries left undetermined after application of (3.2) may be classified by putting the following question to DM: "Does reduction of quality with respect to one/two criteria move the object from K_1 to K_2?"

Note, that in practice the problem of the boundary between the classes K_1 and K_2 is essentially simplified by the fact that the number of estimate combinations classified as K_1 is small.

If several DM groups participate in the development of the planning body policy, filling and discussion of such tables is a convenient means of establishing a joint scientific and technical policy.

4. Formalized model

Separation of two classes of R and D projects allows to pass to another stage in the solution of our problem. A special difficulty involved in generation of a plan is due to the fact that no project implementation version can be selected independently of the whole package of proposals. Each project version requires at each stage certain resources of each kind. Consequently, under limited resources, inclusion of some versions of a project into the plan cannot but say upon the possibility of including other projects into the plan if they require resources of the same kind. Therefore, versions of each project should be considered jointly when forming a plan.

Let q_{ij} be the jth version of implementation of the ith project belonging to class K_1, and let p_{ij} be the jth implementation version of the ith project belonging to class K_2.

Impose the following constraint on the duration of projects:

$$T_{ij} \leq T_0 \qquad (4.1)$$

where T_{ij} is implementation term for the jth version of the ith project, and

T_0 is a constraint imposed by DM.

The problem under consideration may be formulated as follows:

$$\operatorname*{Max}_{x_{ij},y_{ij}} \left(\sum_{i,j} D_i x_{ij} + \sum_{i,j} D_i y_{ij} \right) = \sum_i D_i + \operatorname*{Max}_{x_{i,j},y_{i,j}} \sum_{i,j} y_{i,j} \qquad (4.2)$$

$$\sum_j x_{i,j} = 1 \qquad (4.3)$$

$$\sum_j y_{ij} \leq 1 \qquad (4.4)$$

$$\sum_{i,j} x_{ij} R_{ij}^{(vt_k)} + \sum_{i,j} y_{ij} R_{ij}^{(vt_k)} \leq R^{(vt_k)} \qquad (4.5)$$

where D_i is the economical effectiveness of the ith project ("income" of the planning body);

$R_{ij}^{(vt_k)}$ is consumption of the v-th resource at t_kth planning period necessary to implement the jth version of the ith project;

$R^{(vt_k)}$ are constraints on the value of v-th resource at tth planning stage.

$$x_{ij} = \begin{cases} 1 \text{ if the project } q_{ij} \text{ is included into the plan} \\ 0 \text{ if the project } q_{ij} \text{ is not included into the plan} \end{cases}$$

$$y_{ij} = \begin{cases} 1 \text{ if the project } p_{ij} \text{ is included into the plan} \\ 0 \text{ if the project } p_{ij} \text{ is not included into the plan.} \end{cases}$$

Note that Condition (4.3) necessarily requires that some versions of the R and D projects of class K_1 be included into the plan.

5. Solution method

The above problem (4.2)–(4.5) may be regarded as a version of the "multi-dimensional knapsack problem" [17] well known from the literature. Hence, the methods of integer programming [17] may be applied to this problem. It should be noted that significant computational difficulties may arise with application of precise methods for finding extremum owing to the great number of variables and constraints in (4.2)–(4.5).

Allowance for the particular features of the problem under consideration enables development of a special heuristic algorithm giving, as it has been verified in many cases, quite satisfactory results.

Introduce some notations.

Let W_{ij} be the economical effect index for implementation of the jth version of the ith project:

$$W_{ij} = \frac{D_i}{R_{ij}} \tag{5.1}$$

where R_{ij} is the total consumption of resources required for the jth version of the ith project.

R_{ij} may be computed as follows: denote by α_ν deficiency index of the ν-th resource. These indices may be found through the following conditions

$$\alpha_\nu = \frac{R_{\text{req}}^\nu}{R_{\text{pl}}^\nu}; \qquad \sum_\nu \alpha_\nu = 1 \tag{5.2}$$

where R_{pl}^ν is the value of the ν-th resource at the disposal of the planning organ;

R_{req}^ν is the value of the ν-th resource required for implementation of all versions of all R and D projects.

R_{ij} is computed as

$$R_{ij} = \sum_\nu \alpha_\nu \sum_{t_k} R_{ij}^{(\nu t_k)} \frac{1}{(1 + k)^{t_k}} \tag{5.3}$$

where $R_{ij}^{(\nu t_k)}$ is the consumption of the ν-th resource at the t_kth financing stage required for implementation of the jth version of the ith project; and

k is the discount coefficient assigned by the planning organ.

The heuristic algorithm below [11] is based upon the idea of successive filling of "many knapsacks". Owing to the peculiarities of the problem under consideration, all the obligatory items, i.e. class K_1 project versions, are first packed. Further, projects from the class K_2 are added in accordance to their index. When constraints are reached, some project versions are excluded in a prescribed order. The algorithm does not require selection of solution versions and is, therefore, very simple. Now we shall give its detailed description.

The algorithm [11] for the solution of problems (4.2)–(4.5) has some stages.

1. All the implementation versions of all class K_1 projects are ordered with respect to W_{ij}. The same is done separately with the class K_2 projects.

2. A hypothetical plan

$$P_h = \{q_{ij}\} \tag{5.4}$$

is formed involving all the versions of the class K_1 projects ordered with respect to W_{ij}.

Plan P_h is verified in terms of constraints (4.1) and (4.5). If temporal constraints are violated for all the versions of some q_{ij}, DM is informed in order that they assign another T_0 or revise the boundary between projects of classes K_1 and K_2.

If at some planning stage resource constraints (4.5) are violated, those projects q_{ij} are excluded from P_h that require this resource at this stage. (Condition (4.3) should be necessarily observed requiring that, at least, one version of each q_i is left in P_h.) If such an exclusion does not satisfy constraints (4.5), DM is informed in order that they move the boundary between classes K_1 and K_2.

3. Let plan P_h be formed without violations of the constraints (4.1) and (4.5). All the versions which do not satisfy (3) are excluded from the sequence of versions p_{ij} ordered with respect to W_{ij}. Versions p_{ij} are introduced into the plan successively beginning from those with greatest W_{ij} down until some of the constraints from (4.5) are violated.

4. Let introduction of the next version p_{ij} violate the financial constraint (4.5) for some kind v of resources at the t_kth planning stage. Then, beginning from the versions of q_{ij} with lowest W_{ij}, those are successively excluded from P_h that require resource v at the given planning stage. In doing so, one checks each time whether condition (4.3) is observed, i.e. whether some versions of each q_{ij} are left. After each exclusion of version q_{ij}, the next-by-value version p_{ij} is introduced into the plan.

5. Let only one implementation of each q_i be left and let addition of the next version p_{ij} violate the financial constraint (4.5) for some resource at the planning stage t_k. Those p_{ij} are separated from the previously included ones that were included into the plan in several versions. Those versions p_{ij} are successively eliminated that require at planning stage t_k greater resource v as compared with other versions of the same project (elimination begins with versions with lower W_{ij}). In doing so, the following condition is observed: some versions of projects p_i previously included into the plan should be left there. As versions p_{ij} are excluded, new ones are added into the plan from a sequence ordered with respect to W_{ij}.

6. Let all p_{ij} and q_{ij} be included into the plan in one of their implementation versions, and let addition of the next p_{ij} violate the constraint (4.5) for the v-th resource at the planning stage t_k. Then, from a list of ordered with respect to W_{ij} versions of p_{ij} which were not previously included into the plan, those versions are excluded which require resource v at the planning stage t_k. The balance of versions is included into the plan according to the procedure above.

7. The plan is regarded as formed if addition of new versions p_{ij} becomes impossible because resources are required at those planning stages where financial constraints have been reached.

For one planning interval and one kind of resource, this algorithm resembles the well-known method for approximate solution of the classical knapsack problem [12]. This method involves successive packing of objects according to the importance-to-weight ratio. The algorithm presented in [12] gives the optimal solution for objects of the same weight. Under a similar condition and for one planning interval, the above algorithm gives the optimal solution as well.

Indeed, let there be one planning period, and let expenses on all the projects coincide ($R_{ij} = R^*$). Let the above algorithm result in plan P_c, constraint (4.5) on resource v preventing introduction of new p_{ij}'s into the plan. Then plan P_c is optimal with respect to the criterion (4.2), provided the constraints (4.5) and (4.3) are observed.

By condition, all the projects require the same amount of resource. According to the above algorithm, resource v is required only by those q_{ij} which cannot be otherwise realized. Hence, changes in the plan P_c may be done by substituting p_{ij} which are not included in the plan for those which are included.

According to the above algorithm, this results in decrease of the functional (4.2).

The practical problems for which this algorithm is intended feature comparable project expenses that are small as compared with the total resource. In this connection, one can assume that the heuristic algorithm would enable fairly satisfactory solutions.

Results of practical applications of the heuristic algorithm were analysed as follows:

Each version of each project was represented by a point in the space of the following dimensions: execution time, expenses, various resources required for implementation, and income. Further, a dimensionality reduction method of major components [16] was used to represent projects on a plane where they were grouped by closeness of their characteristics. A similar representation was obtained for projects included into the plan through the above algorithm. The visual representation enabled DM to analyse both proposals and projects. Detailed study of the characteristics of the groups of excluded projects has demonstrated that the scientific and technical policy of DM was not violated. Analysis, carried out for several practical applications, allows to estimate the proposed algorithm as fairly satisfactory.

6. Plan sensitivity analysis

Constraints on various resources are prescribed to DM by the superior authority. The values of constraints, however, are not rigidly fixed. It is reasonable to expect that the superior organ would agree with a comparably small increase of some resources if it may result in significant increase of the criterion (4.2) value.
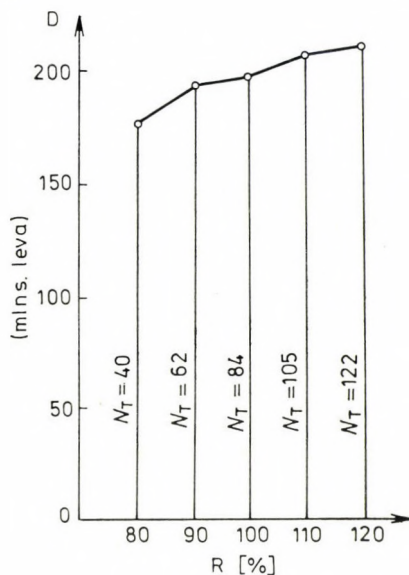

Fig. 3

The final verification of the chosen plan is done by the analysis of sensitivity of the extremum reached with respect to the criterion (4.2) to variations of constraints on each resource. Analysis is done by DM by means of the graphical relations between the total expenditures on a given kind of resource and the total income.

The method above was used for planning applied R and D for the State Institute-Factory Combines of the People's Republic of Bulgaria. Figure 3 illustrates analysis of R and D plan sensitivity to constraint variations (consideration was given to the constraints on national, COMECON and hard currencies, and also on the project implementation time). Variation of the total economic effect D with the total expenditures ($T_0 = 3$ years, N_T is the number of themes in the plan) is shown in Fig. 3.

It follows from Fig. 3 that 10% increase of expenditures results in appreciable increase of income, while reduction of grants by the same 10% does not practically effect the income.

Thus, expenditures should be either reduced or increased by 10% with respect to this characteristic value.

As Fig. 3 demonstrates, further increase of expenditures would be less effective.

7. Conclusions

The governing bodies of R and D organizations come across the following problems:

1. determination of the total R and D budget;

2. selection of particular R and D projects within the budget framework.

In our opinion, these two problems are inseparable, and possible expenditures on R and D projects should be largely dictated by their characteristics. The method presented here enables selection of R and D projects (one or another implementation version) and comparison of economical effects attained with various expenditures on R and D.

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Многокритериальный подход к проблеме планирования прикладных научных исследований и разработок при качественных критериях

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В статье рассматривается проблема выбора из совокупности проектов научных исследований и разработок (НИР) наилучших проектов при ограничениях, наложенных на различные виды ресурсов. Каждый из проектов может быть выполнен в одном из нескольких вариантов, отличающихся количеством и видом потребляемых ресурсов и длительностью выполнения проекта. Предполагается, что проекты независимы. Качество каждого из проектов оценивается по совокупности критериев, часть которых имеет экономический характер (расходы различных ресурсов, ожидаемый экономический эффект), а другая часть отражает научно-техническую политику планового органа (например, соответствие директивным указаниям, социальный эффект от выполнения проекта и т. д.). Критерии второй группы имеют качественный характер. Основная проблема состоит в разработке метода планирования, позволяющего учесть как качественные, так и количественные критерии. В качестве критерия оптимальности плана НИР рассматривается максимум суммарного экономического эффекта от выполнения проектов при соблюдении научно-технической политики планового органа.

Основные идеи предлагаемого подхода заключаются в следующем.

На основе предпочтений планового органа определяются такие сочетания оценок критериев неэкономического характера, при которых проект относится к классу особо важных проектов, которые обязательно должны быть включены в план. Разработан эвристический алгоритм для ЭВМ формирования субоптимального плана НИР, обеспечивающий выбор совокупности проектов НИР в определенных вариантах их выполнения, причем в план входят все особо важные проекты. Дан пример анализа чувствительности выбранного плана к изменению ряда параметров.

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2