OPERATIONAL MULTIPLE GOAL MODELS FOR LARGE ECONOMIC ENVIRONMENTAL MODELS

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1. Introduction

Already a few decades ago, a number of scholars (Tinbergen [1952, 1965], van Eijk and Sandee [1957], Theil [1964], have brought macro economic policy making into a mathematical programming framework. More recently, it has been emphasized that this problem can be handled in a much more flexible way by means of multiple criteria decision methods (Spivey and Tamura [1970], Despontin and Vincke [1977] and Wallenius et al. [1978]).

In this paper we give an illustration of the use of a new multiple criteria decision method applied to an existing input-output model. The multiple criteria decision method used, Interactive Multiple Goal Programming (cf. Nijkamp and Spronk [1978a, b, c]), is described in section 2. In the third section we describe the structure of the input-output model, which has been used to demonstrate this method. For this purpose we defined six different and mutually conflicting goal variables, which are described in section 4. The decision-maker - using a terminal display - repeatedly proposes combinations of the goal variables for which the consequences are calculated by a set of computer programs (section 5). An example of a session with a decision-maker solving his decision problem in the indicated fashion, is presented in the sixth section.

2. Interactive Multiple Goal Programming

Recently, interactive methods have become rather popular in decision analyses. They are based on a mutual and successive interplay between a decision-maker and an analyst. These methods do neither require an explicit representation or specification of the decision-maker's preference function nor an explicit quantitative representation of trade-offs among conflicting objectives. Obviously, the solution of a decision problem requires that the decision-maker provides information about his priorities regarding alternative feasible states, but in normal interactive procedures only a set of achievement levels for the various objectives have to be specified in a stepwise manner. The task of the analyst is to provide all relevant information especially concerning permissible values of the criteria and about reasonable compromise solutions.

Interactive Multiple Goal Programming (IMGP) was developed to combine some of the advantages of multiple goal programming (as devised and further developed by Charnes and Cooper) with some of the advantages of interactive procedures. Because of its use of aspiration levels and preemptive priorities, multiple goal programming is in close agreement with decision-making in practice. Although it is one of the stronger methods available, an important drawback should be mentioned: multiple goal programming requires a considerable amount of a priori information on the decision-maker's preferences. That is why we are proposing an interactive variant of multiple goal programming (IMGP).

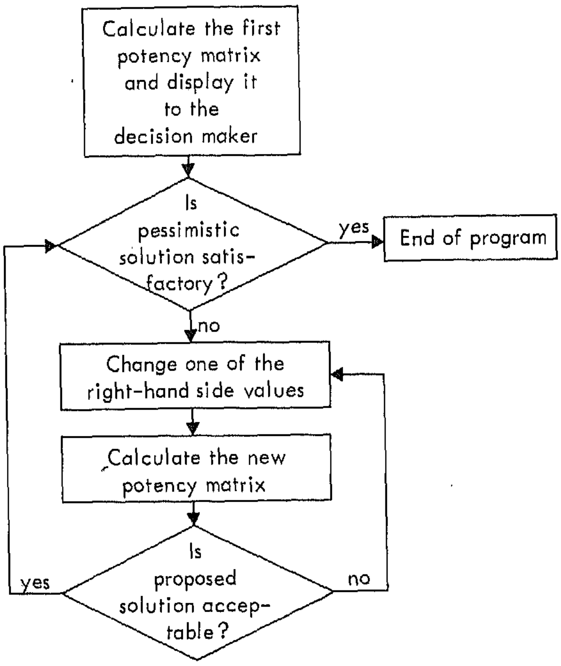
In IMGP the decision-maker has to provide information about his preferences on basis of a solution and a potency matrix presented to him. A solution is a vector of optimum values for the respective goal variables. The potency matrix consists of two vectors, representing the ideal and the pessimistic solution, respectively. The ideal solution shows for each of the goal variables separately the maximum value, given the solution concerned. The pessimistic solution lists for each of the goal variables separately the worst value obtained during the successive maximizations needed to obtain the ideal solution. The decision-maker only has to indicate whether a solution is satisfactory or not, and if not, which of the minimum goal values should be improved, and by what amount. Then a new solution is presented to him together with a new potency matrix. He then has to indicate whether the shifts in the solution are outweighed by the shifts in the potency matrix. If not, a new solution is calculated and so on. IMGP may be characterized as a systematic procedure (guided by the decision-maker) of imposing constraints on the set of feasible actions. A flow chart of the procedure is given in Figure 1.

We conclude this section by mentioning some key properties and possibilities of IMGP. In IMGP the goal variables are assumed to be known and concave in the instrumental variables. The preference function of the decision-maker is not assumed to be known. However, it is assumed to be concave, both in the goal variables and in the instrumental variables. Given these assumptions, both optimizing and satisficing behaviour can be incorporated.

The decision-maker has to give only information on his local preferences. However, all available a priori information can be incorporated within the procedure. The decision-maker has the opportunity to reconsider this a priori information during the interactive process. In order to include more of such learning effects, it is wise to repeat the procedure several times.

As shown in Nijkamp and Spronk [1979b], IMGP converges within a finite number of interactions to a final solution, which does exist and is feasible. Apart from an ε-neighbourhood, this solution is optimal. Whether this solution is unique or not, depends on the decision-maker's preferences (for instance, if the decision-maker is a satisficer having formulated targets which are attainable within the feasible region, a unique final solution does not exist in general).

Figure 1. A simpliflied flow chart of interactive multiple goal programming.



Given a new (proposal) solution, the optima of the goal variables must be (re)-calculated during each iteration of IMGP. This can be done with the help of any optimization method which meets the fairly unrestrictive requirements imposed by IMGP. If the problem is stated in linear terms, IMGP can make a straightforward use of goal programming routines.(see Nijkamp and Spronk [1979c]).

3. Structure of the model

The restrictions that define the boundaries of the feasibility region of the goal variables are dynamic Leontief-type inequalities:

$$(3.1)\qquad x_t \geqq (A + D)x_t + K(w_{t+1} - w_t) + v_t$$

$$x_t \leqq w_t$$

All variables are expressed in constant prices. The vector w is the vector of production capacity in every year, and x is the vector of actual production. The vector v is defined as the sum of final consumption and export surplus.

The matrix A of technical coefficients is derived from the input-output tables published by the Statistical Office of the European Communities. The matrix of capital coefficients K was computed using the vintage model method, from which the depreciation coefficients D result as a byproduct. A more detailed description of the construction of the matrices A, K and D, can be found in van Driel et al. [1979, sections I.2. and I.5.].

The full model contains the 17-sectors of the NACE-CLIO classification of the Statistical Office of the European Communities, to which five pollution sectors have been added. The pollution problem was treated by means of the emission-approach. In this approach the nuisance, i.e. the unabated pollution, can be evaluated at its abatement costs. Five columns are added to the matrix of technical coefficients. The elements in the upper part of each of these columns are the technical coefficients that represent the relative expenses on conventional goods needed to abate one unit of the pollution concerned. The abatement sectors themselves pollute too. These abatement costs form the lower part of the columns in exactly the same fashion as is done for the conventional sectors. Five rows were added to the technology matrix to represent the amounts paid per unit of activity to each of the abatement sectors. The data were taken from a study of the Central Planning Bureau of the Netherlands [1975].

To start the experiments with IMGP we used an aggregated version, which consists of three conventional sectors and one pollution sector. The main components of these aggregates are:

sector 1: building and commerce
sector 2: chemical products, metal products and means of transport
sector 3: agriculture, foods, textiles and the services sectors (exclusive of commerce)
sector 4: all abatement sectors

A further discussion on the choice of these aggregates can be found in van Driel et al. [1979, section III.2.]. The numerical data of this aggregated version of the model were computed in such a fashion that in each sector the export surplus equals zero. The model describes the industrial region lying within a radius of 300 km around Rotterdam, consisting of the Netherlands, Belgium, Nordrhein-Westfalen and France Nord. As a consequence of the extreme extent of the aggregation, the assumption of no export surplus is not far beyond the truth.

The simulations cover a period of ten years, together with the relations that define the goal variables, we end up with a model consisting of 160 relations in 130 structural variables. The computations involved in manipulating this model are not too expensive. One iteration consisting of solving 6 of these LP-problems takes some 30 seconds of central processing unit time. On the other hand, the system is not that aggregated that its behaviour becomes obvious. Experience indicates that the outcome of each iteration shows unexpected traits. The interrelations even in so small a system cause the prediction of its behaviour to be a hazardous task. Nevertheless, experiments with the full model will remain necessary. Because of its greater scope the lessons to be learned from the larger model will be much richer. Furthermore, the description of reality by means of 22 sectors is optimum in the sense that an equilibrium is attained between the advantages and disadvantages of more detail (Ibid., section IV.1.), while the four sectors of the aggregated model are statistical constructs, combining essentially dissimilar sectors into one aggregate.

4. Selection of goal variables

In our experiment we chose six goal variables, thus not exceeding Miller's magical number seven (cf. Miller [1956]). Our choice was to some extent arbitrary, because at this stage of the experiments we could not consult 'real-life' decision-makers. At the same time, we wondered whether these decision-makers, while using our procedure, would propose changes in the set of goal variables (see section 6). It should be stressed that, when our procedure is being used in less experimental situations, the decision-maker must have the opportunity to formulate this set at the start of the procedure and to change it whenever he likes. In this experiment we have chosen the following goal variables.

(1) Wages - Defined as the sum of all wages over all ten years of the planning period. Because the model is formulated in real terms, this goal variable can be considered to be a proxy for employment. This goal variable was indexed in terms of the wages of the year just before the planning period. If the annual wages would not change during the planning period, this goal variable would have a value of 1000. This goal variable is to be maximized.

(2) Consumption - Defined as the sum of the consumption of products from sectors 1, 2 and 3 (see section 3) over all ten years of the planning horizon. This goal variable was indexed in terms of the consumption in the year before the planning horizon. This goal variable is to be maximized too.

(3) Minimum Growth of Consumption - This goal variable was defined as the minimum over the planning period of the annual rise of the sum of consumption of products from sectors 1, 2 and 3. The goal variable was indexed in the same fashion as goal variable two. Also this goal variable is to be maximized. Implicitly, we restricted the value of this goal variable to be non-negative. If the decision-maker would not like such a restriction, it can easily be removed.

(4) The goal variable "Nuisance" - Nuisance is defined as the amount of unabated pollution. Amounts of pollution are defined by means of the production costs

of the abatement industries (see section 3) over all ten years of the planning horizon. This goal variable was indexed in terms of the nuisance in the year before the planning horizon. This goal variable is to be minimized.

(5) Maximum Growth of Capacity - This goal variable, which is to be minimized in order to eliminate too large jumps in the series, has been included as a means to 'stabilize' the growth path of the economy. This goal variable was indexed by reference to the total production capacity in the year before the planning horizon.

(6) Production of the Anti-Pollution Industry - This goal variable was not indexed. It is measured in millions of 1965 Eurodollars production worth (like originally all variables in the input-output model). Although this goal variable is not the object of economic endeavour, we included it deliberately to obtain information about the learning aspects of our procedure.

In section six, discussing the results of the experiment, we shall show that the experiences with the interactive procedure include learning effects concerning the relevance of the goal variables.

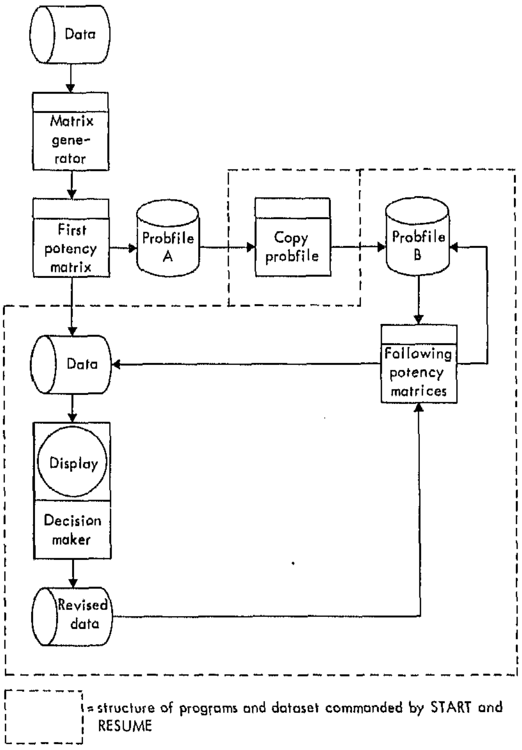
5. A brief description of the computer programs

The computer programs for IMGP have been designed in a way, such that the decision-maker - sitting at a computer terminal - is in conversational contact with the computer system (in the case of our experiments the IBM 370/158 of the University of Technology in Delft, the Netherlands). Structured programming was used, having the advantage that parts of the program can be tested (and changed) independently of other parts. The programs were solved by means of calls to the IBM's MPSX/370-package, imbedded in PL/I computer programs. These modules were coordinated by means of command procedures.

We give a sketch of the system of programs in figure 2. Given a new problem, the following programs have to be carried out once. The data have to be transformed into the required MPSX input format by means of the matrix generator. Then a PL/I computer program using MPSX, calculates the first potency matrices. The outcomes of the linear programs, which have to be solved in order to calculate this potency matrix, are stored in the dataset PROBFILE A. The potency matrix itself is stored in a dataset which can be displayed to the decision-maker.

After these initial operations, the decision-maker can choose between two command procedures, 'START' and 'RESUME', which are essentially the same, except for one thing. START copies the data of the linear programs underlying the first potency matrix (stored in PROBFILE A) to the dataset PROBFILE B and displays the first potency matrix to the decision-maker. RESUME does not include such a copy command, thus leaving the dataset PROBFILE B as it was after the last iteration of the preceding session. Accordingly, it displays the accompanying potency matrix to the decision-maker. Clearly, START is used when a new decision-maker starts tackling the problem, or when a decision-maker wants to restart the whole interactive procedure from the beginning. RESUME is used when a decision-maker wants to continue the session after a break.

Figure 2. The system of computer programs used for the implementation of IMGP.



Thus both START and RESUME display a potency matrix together with a sequence of questions, which have to be answered by the decision-maker. The first question is whether the presented solution is satisfactory or not. If the decision-maker states it is satisfactory, he can subsequently ask for a detailed (hardcopy) description of the results. If not, he has to indicate which goal variable should be changed in value and to what amount. These data and the data of PROBFILE B are then used in a PL/I program (again using the MPSX-package) which calculates the new potency matrix. The dataset PROBFILE B is changed. It now contains the data of the linear programs underlying the last calculated potency matrix. The potency matrix itself is stored in a dataset, which again is displayed to the decision-maker. The procedure terminates when the decision-maker states that the presented solution is satisfactory.

6. Some results

In this section we describe a session with a decision-maker using IMGP as described in section two, by means of the computer programs described in section five. We assumed his problem to be given by the model described in the third section and the goal variables specified in the fourth section. The session described was the third of the decision-maker in question. In our description of this session we shall also point to the learning effects obtained from the earlier sessions. The starting solutions are the following:

iteration 1	optimal (ideal) values	accepted (pessimistic) value
(1) wages (≃ employment)	3292	793
(2) consumption	2810	1000
(3) min. growth consumption	20	0
(4) nuisance	79	2751
(5) max. growth capacity	0	290
(6) anti-pollution production	28189	0

Inspecting the pessimistic values, which are lower bounds of the values the decision-maker has to accept, we see that - in this worst case - he has to accept a considerable reduction of employment, while the consumption does not necessarily grow, there may be a tremendous amount of nuisance, and there may be years in which the capacity triples. Also, in this unfavorable case, the anti-pollution industry does not produce anything. (Note - as the decision-maker did in one of the earlier experiments - that the production of this industry is not a proper goal variable because its value can be raised by switching to heavily polluting sectors). The first goal variable to be changed was chosen to be the wages, being a proxy for employment. The proposed value for this goal variable was 1500, corresponding with an average yearly growth of about 8 percent. It was estimated by the decision-maker that the existing unemployment could be removed in this way, while also a good deal of the housewifes could get a job. The consequences of this desire are shown below:

iteration 2	optimal (ideal) values	accepted (pessimistic) values
(1) wages (≃ employment)	3293	1500
(2) consumption	2810	1000
(3) min. growth consumption	20	0
(4) nuisance	79	2751
(5) max. growth capacity	12	290
(6) anti-pollution production	28189	0

It can be seen, that this alteration only influences the 'optimal' value of the capacity variable. Thus, where in the former solution it was conceivable that the capacity did not grow, there is now at least one year in which the capacity grows with 12 percent (of the capacity in year 0). Accepting this consequence, the decision-maker next wants to limit the nuisance to at most a value of 500. This implies the following characteristics:

iteration 3	optimal (ideal) values	accepted (pessimistic) values
(1) wages (≃ employment)	3091	1500
(2) consumption	2643	1000
(3) min. growth consumption	19	0
(4) nuisance	79	500
(5) max. growth capacity	12	255
(6) anti-pollution production	28189	9704

These results show that it now becomes necessary that the anti-pollution industry starts producing. Furthermore, consumption and wages can not increase as much as in the earlier iterations. Next, the decision-maker wants to limit the maximum capacity growth to a value of 30, in view of the estimated capital market conditions and to avoid too large instabilities within the economic system.
This leads to the following results:

iteration 4	optimal (ideal) values	accepted (pessimistic) values
(1) wages (≃ employment)	2024	1500
(2) consumption	2274	1000
(3) min. growth consumption	19	0
(4) nuisance	79	500
(5) max. growth capacity	12	30
(6) anti-pollution production	19977	9704

Our decision-maker continued the procedure until a solution was found which appeared satisfactory to him. The complete results of this experiment are given in Hartog et al. [1979]. The final solution is shown below.

iteration 14	optimal (ideal) values	accepted (pessimistic) values
(1) wages (≃ employment)	1600	1600
(2) consumption	1890	1890
(3) min. growth consumption	10	10
(4) nuisance	251	252
(5) max. growth capacity	15	15
(6) anti-pollution production	13556	13545

Obviously, it is not necessary for a decision-maker to continue the interactive procedure so far as the present decision-maker did, i.e. to proceed until a unique (or nearly unique) final solution occurs. One may as well stop at an earlier iteration, being left with a number of 'scenarios' all satisfying the minimum conditions specified by the decision-maker. The choice out of these scenarios can be made e.g. by a committee or otherwise.

An examination of the detailed results associated with the final result attained by this decision-maker showed that nearly all instrumental variables within the model behaved according to smooth growth paths. However, because no goal variable had been included to take care of a balanced distribution of activity over the industrial sectors, some undesired effects occured in this respect. In fact, this was one of the learning effects, which resulted in discussions and proposals for new goal variables. Other learning effects have led a.o. to the proposal to delete the sixth goal variable as being irrelevant. Furthermore, the nuisance goal variable was proposed to be changed in a per year maximum nuisance level.

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