Multiobjective and Goal Programming Techniques for Solving Agricultural Planning Problems

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Abstract: This paper presents the results of research undertaken to assess the suitability of multiple criteria decision techniques to agricultural planning problems. The conventional mathematical programming paradigm as used in the form of linear programming is inadequate to deal with real agricultural planning problems when multiple goals and objectives are important elements of the situation. Goal programming and multiple objective programming techniques offer the most promising prospects of application to these problems; therefore, these programming structures are examined from that point of view, and the advantages over conventional approaches are examined.

Introduction

The traditional agricultural planning models used by agricultural economists are developed within a paradigm that assumes the following axioms:

- the decision maker has a single objective to optimize;
- that objective is a mathematical function (usually linear) of decision variables;
- limited supplies of resources and other constraints define the feasible region within which optimization can be pursued; and
- the purpose of the model is to search for the optimal set of values of decision variables.

Despite the usefulness of this paradigm, some of its axioms seriously limit its application to real life problems. In reality, the decision making may not be optimizing a single objective but seeking a compromise among a set of conflicting objectives. For instance, one may be interested in maximizing gross margin, producing enough food to feed the family, maximizing leisure, or minimizing casual labour. Hence, an adequate representation of the reality of decision making requires frameworks different from the conventional paradigm, such as multiple criteria decision-making techniques.

Agricultural economists have been rather slow in exploiting the potential of such techniques, which is particularly striking when one looks at the work in water resources research and forest planning, where considerable time and effort have been devoted to multiple criteria decision-making techniques. This paper attempts to summarize the recent research undertaken by the authors to assess the suitability of multiple criteria decision-making techniques to agricultural planning problems. In this context, two approaches—goal programming and multiobjective programming—are most promising. The basic features of these two techniques are reviewed in order to offer observations on their theoretical limitations and on the difficulties associated with their practical use.

Goal Programming Approach

To understand the key features of goal programming, the concept of a goal must be clearly stated. First, one must define a target: a target is an acceptable level of achievement for one of the decision maker's objectives. On combining an objective and a target we have a goal. For instance, if the decision maker wants a particular farm plan to yield a gross margin of at least $20,000, we have a goal (Romero and Rehman, 1983). Therefore, a target can be violated without necessarily producing an infeasible solution.

Goal programming has two main variants: weighted goal programming and lexicographic goal programming. Weighted goal programming, introduced by Charnes and Cooper (1961), minimizes the deviations among the desired levels of goals (targets) and the actual achievements, which is accomplished by converting inequalities into equalities by including positive and negative deviation variables that permit under- or overachievement of each goal. Weighted goal programming considers all goals simultaneously in a composite objective function that minimizes the sum of all the deviations among goals and their targets. The deviations are weighted according to the relative importance of each goal for the decision maker. The first application of weighted goal programming in farm planning was by Wheeler and Russell (1977).

Lexicographic goal programming was also first introduced by Charnes and Cooper (1961) and later developed by Ijiri (1965), Lee (1972), and Ignizio (1976). It assumes that dividing goals into priorities is possible. Further preemptive weights can be attached to sets of goals situated in different priorities. In other words, the fulfilment of the goals in a given set Q_i is immeasurably preferable to the achievement of any other set situated in a lower priority Q_j. In lexicographic goal programming, high priority goals are satisfied first, and only then are lower priorities considered. The deviational variables to be minimized are placed in an ordered vector called an achievement function. Each component of this vector represents the deviation variables that must be minimized in order to make sure that the goals ranked in this priority come closest to the established targets. Several algorithmic approaches (such as sequential linear method, modified simplex method, and partitioning algorithm) can be used to solve lexicographic goal programming problems. For a nontechnical exposition of both weighted goal programming and lexicographic goal programming, see Romero and Rehman (1984).

The first application of lexicographic goal programming in farm planning was by Flinn *et al.* (1980), for subsistence farming in Philippines. Six goals were established in a decreasing order of importance:

- to produce enough rice for family subsistence;
- to generate sufficient cash for household expenses;
- to minimize borrowing from relatives and friends;
- to minimize borrowing from the landlord;
- not to become increasingly more indebted; and
- to generate as large a surplus as possible.

Each goal is placed in one priority except the two goals to minimize borrowing, which are combined into one priority. So Flinn *et al.* proposed a model with six goals placed in five preemptive priorities. They set the targets of the goals placed in the first four priorities pessimistically, being easy for them to be satisfied, while the target of the goal situated in the last priority is a lower bound that cannot be achieved (i.e., the cash surplus is maximized). Under such circumstances, the lexicographic goal programming model solution coincides with an ordinary linear programming solution, which optimizes the goal considered in the last priority as the objective function and sets the goals in the first priorities as constraints (Romero and Rehman, 1983). That can also happen with weighted goal programming models as in the case of Barnett *et al.* (1982), who analyzed the problems of Senegalese subsistence farmers. To conclude, as Barnett *et al.* do, that for these reasons goal programming is a technique of dubious usefulness, is quite erroneous because the equivalence of solutions has to do with the formulation of the problem rather than with the potential usefulness of goal programming.

Weighted goal programming and lexicographic goal programming are the oldest and the most widely used multiple criteria decision-making techniques. Since the early 1970s, interesting methodological extensions, such as fractional goal programming, fuzzy goal programming, and chance constrained goal programming have been made and now come under the heading of generalized goal programming (Ignizio, 1983). This general framework actually involves any multiple criteria decision-making technique where targets have been assigned to all the objectives following the Simonian "satisficing" concept. For an extensive survey, see Romero (1986).

Multiobjective Programming Approach

Multiobjective programming (or vector optimization techniques) tackles the problem of simultaneous optimization of several objectives subject to a set of constraints (usually linear). As an optimum solution cannot be defined when several objectives are present, multiobjective programming seeks the set of efficient (nondominated or Pareto optimal) solutions.

The elements of an efficient set are feasible solutions; and, for each solution outside the efficient set (but within the feasible domain), an efficient solution exists for which all objective functions can achieve the same or better performance, being strictly better for at least one objective. The purpose of multiobjective programming is thus to generate the efficient set; hence, the problem can be formulated as:

$$\mathit{eff}\ Z(x) = [Z_1(x), Z_2(x), \ldots, Z_q(x)],$$

subject to $x \in F$, where *eff* means the search for the efficient solutions in the optimizing set and F represents the feasible set.

Basically, three methods exist to generate or at least to approximate the efficient set. First, the *weighting method* is where all the objectives are combined into a single objective function. A weight is attached to each objective function, and then all the objectives are added. Through parametric variations of the values of the weights, the efficient set is generated, as first suggested by Zadeh (1963). Second, the *constraint method* is where one of the objectives is optimized while others act as restraints. Through parametric variations of the right-hand side of the objectives expressed as constraints, the efficient set is generated as introduced by Marglin (1967). Third is the *multicriteria simplex method*, where the basic idea for generating the efficient set is to move from one extreme (efficient) point to another adjacent extreme (efficient) point. This method was first proposed by Philip (1972) and Zeleny (1973).

Multiobjective programming techniques have scarcely been applied to agricultural planning problems, perhaps with the exception of Hitchens *et al.* (1978), where a land allocation problem in Australia is studied involving two conflicting objectives: net money income and net environmental benefits. For an explanation of multiobjective programming techniques in the context of farm planning, see Romero and Rehman (1985).

Multiobjective and Goal Programming: Pros and Cons

Multiobjective and goal programming provide an alternative paradigm to single objective optimization via linear programming. The concept of optimum is thus replaced by the notion of nondominance in multiobjective programming, while goal programming attempts to combine the logic of optimization in linear programming and a decision maker's desire to satisfy several goals.

Despite their suitability for dealing with multiple criteria decision making in farm planning, both goal programming and multiobjective programming are not without weaknesses. A practical use of goal programming would demand substantial information from decision makers on their objectives. They must provide the analyst with information on the targets of their goals, the weights attached to each goal, and the preemptive ordering of preferences (in lexicographic problems). In practice, most decision makers are not likely to be able to provide this information in precise detail or with confidence. Therefore, sensitivity analyses for parameters such as weights attached to goals and the ordering of priorities may become inevitable. Admittedly, the need for such analyses will increase the computational burden for the analyst.

An inherent drawback with the lexicographic goal programming approach is that it does not optimize the utility function of the decision maker (Romero and Rehman, 1984). But this may only have a theoretical significance rather than practical meaning, as a farmer's behaviour could conceivably be better represented by a lexicographic ordering than by maximizing a utility function.

Fixing the targets for various goals in a goal programming model can be a problem, as setting them at too pessimistic a level can generate dominated solutions (Zeleny and Cochrane, 1973). This possibility is highly likely when the optimal solution of a goal programming model includes zero values for a relatively large number of deviational variables. A remedy is to conduct a parametric analysis of the aspiration levels assumed in the model to see if increasing the satisfaction of some goals without reducing the achievement of others is possible, or else one could use a test of nondominance such as the one suggested by Hannan (1980).

The lexicographic goal programming approach assumes that trade-offs among goals are possible only when they are in the same priority. Trade-offs are not allowed across different priorities. The priorities are independent of each other in a preemptive way. This appears to make the lexicographic goal programming model rather restricted but is in fact not different from a conventional linear programming model where no trade-off is assumed to exist between the objective function and the restraint set (Ignizio, 1976).

When a large number of priorities (naïve prioritization) is established, goals situated in the lower priorities are likely not considered by the model (redundant goals) (Romero and Rehman, 1985). This happens because all the algorithms devised to solve lexicographic goal programming problems are based on the underlying assumptions that the first problem of the sequence has alternate optimal solutions. If no alternate optimal solutions exist, the algorithm can be stopped, and goals belonging to lower priorities can be avoided. In general, therefore, applications of lexicographic goal programming and (especially in the field of agricultural planning) dividing the goals into more than four or five priorities can render the model naïve rather than realistic. Dividing the goals into a small number of priorities is, therefore, desirable. Ignizio (1976) suggests five as an upper bound.

Assuming that the decision maker is able to establish infinite trade-offs among goals situated in distant priorities (as is often assumed in operations research literature) is quite unrealistic.

As regards multiobjective programming, its main weaknesses are of an operational and computational nature. When multiobjective programming is applied to problems of relatively large size, the generation of an efficient set requires a large amount of computer time (Steuer, 1976). Even when the problem is of a moderate size, the number of extreme efficient points to be explored can be huge. Several authors have reported cases where few objectives and less than 50 or so variables and constraints have generated several hundred extreme efficient points. Of course, such a situation is not desirable, as the decision maker is inundated with information, making the choice of an optimum solution almost impossible.

Several approaches have been suggested to mitigate this problem. Steuer (1976) advocated the use of interval (rather than fixed) criterion weights as the weighting method. With this approach, only that part of the efficient set that is of greatest importance to the decision maker is analyzed. In this way, a substantial amount of computer time is saved, and the size of the efficient set is considerably reduced. Steuer and Harris (1980) recommend using filtering techniques to discard efficient solutions that have already been computed and retained by the filter. This pruning operation makes the efficient set manageable.

Another approach is to rely on interactive techniques. This implies a progressive definition of the decision maker's preferences through an interaction between the decision maker and the model. The interaction becomes a conversation in which decision makers transmit their preferences or trade-offs to the model. For a detailed discussion of the main multiobjective programming interactive techniques, see Hwang *et al.* (1979).

Zeleny (1973) pioneered a method called compromise programming that allows the decision maker to choose the optimum solution from the efficient set. This method starts by establishing what Zeleny calls the "ideal point." The coordinates of this point are given by the optimum values of the various objectives of the decision maker. The "ideal point" is usually infeasible; if it is feasible, then no conflict exists among objectives. When the "ideal point" is infeasible, the optimum element (compromise solution) for the decision maker is given by the efficient solution that is closest to the "ideal point." This is Zeleny's "axiom of choice." Depending on the particular measure of distance from the "ideal point" used, a set of compromise solutions can be established. For further explanation of this technique using a farm planning example, see Romero and Rehman (1985).

Notwithstanding the above weaknesses, both goal programming and multiobjective programming are superior to traditional mathematical programming models on two counts. First, the real decision-making process on farms is oriented towards the "satisfaction" of several goals (or in establishing a compromise among multiple objectives) rather than to the optimization of a single objective. Second, goal programming and multiobjective programming subsume traditional mathematical programming as their special case. In practical terms, any traditional mathematical programming model can be formulated as a goal programming or multiobjective programming model, but the converse is not possible. However, in agricultural planning involving multiple criteria decisions, the choice of goal programming or multiobjective programming as the modelling techniques will depend on several factors. As Ignizio (1983, p. 278) says: "..there is not known, and probably never shall be, one single 'best' approach to all types of multiobjective mathematical programming problems." In any case, a thorough analysis of the problem situation should clarify the most appropriate technique to be used. For a comparison of goal programming and multiobjective programming, see Willis and Perlack (1980).

Since the early 1970s, a Kuhnian scientific revolution would appear to be under way in management science and operations research. A new mathematical programming paradigm has emerged challenging the traditional single objective optimization approach. The new multiple criteria decision-making paradigm overcomes the weaknesses and anomalies within the old one, has matured in the last decade or so, and promises an impressive future. However, until now agricultural economists have not taken sufficient interest in this paradigm and its effectiveness in solving farm planning problems. The authors hope that this research is a step in the right direction and encourages others to apply these two most promising multiple criteria decision-making techniques to agricultural planning problems.

Note

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Discussion Opener – *Wilhelm Scheper*

Chambers and Lopez have tried to explain the process of cumulative circular poverty causation at the household or firm level with a neoclassical model similar to models used in macroeconomic theories of optimal economic growth. The model can be described as follows: maximal labour force and population are constant; technical progress is neglected; only one good is produced, serving alternatively as a consumption and investment good; capital input is the main determinant of production; the production function is of the continuous type and shows decreasing rates of return on capital; if the capital stock K is smaller than K^{oo}, the amount of production is not sufficient to provide enough consumption goods to meet the subsistence level; dissaving is necessary; if the capital stocks K is larger than K^{oo}, accumulation of capital is possible, and K^{oo} earmarks an equilibrium point that can be called the "Myrdal equilibrium point." Chambers and Lopez have assumed that many individuals are situated at or close to this equilibrium point, and the location of the equilibrium point varies due to shocks (e.g., changing yields, subsidies, or taxes). From both those assumptions, they conclude that a zone of stagnation or poverty trap exists. Perhaps in contradiction to this, the authors interpret the point K^{oo} as a main reason for growing inequalities in income distribution.

To get a clearer picture, the model has to be extended in several ways. Assuming the existence of an implicit investment function that fulfills the conditions of optimal economic growth is not sufficient, because the properties of this function can be rather different depending on the shape of the utility function. In this context, much emphasis should be put on the case where all K located in the range $K^{oo} \leq K < K^{T}$ lead to $K^{\bullet} = 0$. In this case, we have a Myrdal equilibrium set consisting of many Myrdal equilibrium points and therefore a better explanation of Myrdal's zone of stagnation. A more detailed modelling of an individual's situation is a necessary but not sufficient condition for a meaningful discussion of policy implications. One must also make some assumption about the asset distribution between individuals. Otherwise, no substantial conclusions can be drawn about the impacts of redistribution policies on saving rates. Chambers and Lopez's far-reaching policy assessments do not have a sound basis.

Parton puts great emphasis on the differences between the lexicographic wants approach and the neoclassical utility approach. For the modelling of an individual farmer's behaviour, he favours the first approach. He is of the opinion that smooth neoclassical utility functions imply too many possibilities of substitutions and too many alternatives. I agree to a certain extent. The lexicographic wants approach is simple to handle and sufficient in many cases. However, we should not underestimate the possibilities of neoclassical models. For instance, we can use an n-level utility function of the smooth type similar to n-level production functions developed by Sato and others. Such a function can be considered as a generalization of Lancaster's consumer model, which explains the transmission of consumer goods, leisure, and other sources into satisfactions of ultimate wants. The parameters of the function can be chosen in a way that the maximization of the function under alternative constraints leads to almost the same result as the lexicographic approach; i.e., fulfilling of want packages in a lexicographic manner. Parton argues that common constraint utility maximization models neglect many variables that are main determinants for decisions in reality. This is true. Many economists take standard models from the textbooks and apply them without sufficient adjustments. Models developed for decision making on large commercial farms are not appropriate for the analysis of small farms in LDCs. For small farms in LDCs, we need models that put strong emphasis on household assets and decision making.

Rehman and Romero's paper (and also Parton's paper) show us the crucial role of definitions. Some models are described as utility maximization models and some are not. This grouping, to a large extent, depends on the definition of maximization. If we define maximization in a rather broad sense, almost all meaningful models try to identify solutions, which, in terms of utility or benefits, are better than or equivalent to other feasible solutions. Rehman and Romero show us how to reduce misunderstandings by careful definitions of terms like objectives, targets, goals, optimality, and efficiency. More attention has to be given to comprehensive and balanced schemes of objectives and means. Such schemes have to be adjusted properly to the corresponding subject of interest. Rehman and Romero give interesting examples and clearly convey the message that the choice and adjustment of farmer's decision making models can be improved by dialogues between model builders and farmers.

General Discussion – *Stephen C. Thompson*, Rapporteur

The presentations by Parton and Rehman and Romero assume sharp cleavages between various types of want fulfilment. Are the boundaries of the want pyramid defined sharply enough to employ lexicographic analyses? Also, the models may fail to explain why so many goods are consumed, if the list of wants is so short. Might it not be necessary to assign a particular utility value to each good?

Goal programming is a necessity for the realistic application of optimization procedures. How do multi-goal techniques take account of climatic variability and market uncertainty?

Does the approach proposed by Rehman and Romero of asking the decision maker to choose an optimum from a list of many efficient solutions not place us back where we were 20 years ago with linear programming? By involving the decision maker's preferences, are we not short-circuiting the model?

Parton stated that case studies conducted by economic anthropologists in developing countries indicate a depth of analysis far beyond ordinary utility analysis. A potential exists for flip-overs in demand functions if actual wants systems are of a hierarchical nature, and recognizing this when estimating demand functions econometrically is important.

Rehman stated that a most attractive feature of goal programming is the mathematical impossibility of an infeasible solution. Goal programming allows interaction with the user, who has like opportunity not only to define his objectives but also to discover them. Monte Carlo programming also tries to overcome the problem of a single optimum. Hazell's MOTAD model is also a very special case of goal programming. Including variability in a multiple criteria model such as goal programming is possible.

Participants in the discussion included G.T. Jones, B H. Kinsey, F Rosa, and G. Schiefer.