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IIASA Research Report
August 1982

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RR-82-26
August 1982

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
Laxenburg, Austria

International Standard Book Number 3-7045-0042-9

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FOREWORD

One of the major categories of problems that the International Institute for Applied Systems Analysis (IIASA) considers is that of universal problems, i.e., those that lie within national boundaries, that are shared by many nations, and that can benefit from exchanges of experience and analysis. Since many universal problems arise in the context of regional development, IIASA's research program includes a substantial effort in this field.

An integrated view of regional development must include an understanding of many factors – resources, population, the environment, industry, agriculture, water, etc. – and this understanding of each factor must be based on models that incorporate both the essential behavior of the factor and its ties to the behavior of other factors.

This report presents a model for regional agriculture and applies it to a region in Poland. It is one of a set of related models that IIASA is using in its integrated regional development work. For a useful overview that places this model in its larger setting, see Murat Albegov (1981) Regional development: From cases to generalization, *IIASA Reports* 3:103–16.

C.S. HOLLING
Director

CONTENTS

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SUMMARY

The General Regional Agricultural Model (GRAM) described in this report is the product of a case study of regional development in the Upper Notec region of Poland carried out collaboratively by IIASA and the Systems Research Institute in Warsaw, Poland. The purpose of this work was twofold: to assist Polish authorities in planning the development of agriculture in the region, and to create a universal methodology in the form of a model applicable to similar problems and settings in other countries. Thus, the methodological characteristics presented in this report are based on testing and implementing the model in the concrete situation of the Upper Notec region of Poland.

GRAM was developed using the so-called "bottom-up" approach, which consists of orienting the model toward technological interdependencies at the level of the agricultural areas in the region, and including a set of variables and parameters that enable this "bottom" model to be linked with those for other aspects of the regional economy.

The model deals with the following elements: a set of crops subject to rotation constraints; types of agricultural animals, types of livestock products, and feed components in forage; three types of market and three types of land ownership; different crop growing and livestock breeding technologies; and different soil qualities and types of fertilizer, according to the contents of the elements. The model incorporates space and can give solutions for a number of regions. Technically GRAM is a large linear programming model with static relations.

The purpose of the model is to derive a detailed specification for a production structure combined with a direct utilization of its products that is optimal for a predefined objective. The model can also be used to indicate essential bottlenecks, resource distribution inconsistencies, and so on. It allows the formulations of multiobjective optimization problems to consider conflicts between different groups of producers. It is solved under constraints on labor, machinery, fertilizers, and water availability at annual and two peak levels.

Two types of objective function are used: monetary (linked with cost–benefit analysis) and physical. Among specific objective functions for which the model has been solved there are: total net return or net production value from agricultural activities within the region; balance of regional agricultural production in monetary terms; regional agricultural production in terms of nutrition units; regional trade balances in livestock products in monetary terms and in nutrition units; and export production in monetary terms. In cooperation with other elements of the regional model system, two types of information are exchanged: dual prices and volume of output.

The model was implemented on an IBM 370/168 computer using the SESAME/DATAMAT LP system designed by William Orchard-Hays, which is operative in Pisa (Italy).

1 INTRODUCTION

The subject of regional development planning and management, taken up by IIASA as a universal issue, was first approached through a series of retrospective case studies of regional development undertakings, such as the Tennessee Valley Authority in the United States, the Bratsk–Ust'–Ilimsk territorial production complex in the Soviet Union, or the Shinkansen high-speed railway system in Japan (see Knop 1976, Knop and Straszak 1978, Straszak 1980). Having gathered experiences and identified the essential general features of these regional development activities, IIASA has turned to the analysis and design work that will be of use in the planning of ongoing regional programs. Three such joint ventures of IIASA and appropriate National Member Organizations (NMOs) were completed at the end of 1981, namely, the modeling projects for the Upper Notec watershed region in Poland (see Albegov and Kulikowski 1978a, b), for the Silistra region in Bulgaria (Andersson and Philipov 1979), and for the Southern Skåne region in Sweden (Andersson 1980). A fourth project for the Tuscany region in Italy is still under way.

The main input of IIASA to such studies is a methodological one. Owing to the generally analogous nature of problems encountered in various regional circumstances, IIASA is capable, through the work of its scholars, to develop formal systemic methods, mainly connected with modeling, which are applicable to a specific region, and which can also be applied to other regional development problems. These models are practically implemented; i.e., data are gathered, results are assessed, etc., by specialists from the appropriate NMOs.

Since the emphasis in the work on regional development planning is placed upon integration, care is taken that the models developed constitute segments of a system of models that will also be partly or totally transferable. The model whose formal description and implementation are presented in this report was proposed by Albegov (1979); this was then developed as a generalizable element of a model system, and its applicability was tested for a practical regional project planning case.

The main problem is to define the model in such a way that two requirements are simultaneously fulfilled:

(i) Representation of a real system with sufficient detail, so that specific features of a particular case can be made explicit, and that communication with other models in the system is meaningful; and, on the other hand,

(ii) representation of an adequate variety of possible system configurations, so that the model can be applied to various other circumstances.

Thus, the model should fulfill the conditions of representation, inter-model communication within a system, and generality. In the presence of another (technical) condition of flexibility and operativeness, however, the above requirements may conflict.

The present report shows to what extent the basic prerequisites generally formulated can be met by a regional agricultural model that encompasses technical, economic, and partly social aspects of a regional agricultural system.

2 NEED AND PURPOSE: BASIC PREREQUISITES

2.1 Regional Development Planning and Modeling Activities

When speaking of regional development planning, one has to make a clear distinction between this activity and a routine management practice, which is focused on the structural status quo. In stable situations it is justified to decouple subsystems and manage them separately via routine mechanisms. When essential structural changes are envisaged, however, the regional system should necessarily be regarded as a whole, since such changes in one subsystem can be transmitted and cause important repercussions in all subsystems.

In consideration of regional development plans, integration therefore plays a very important role. First, the considerations of development should be comprehensive, i.e., they should comprise all the essential elements of the regional socio-economic system. However, in order for the cognitive mapping of a regional development problem to be complete (i.e., ro reflect as well the intrinsic systemic features), there should follow an integration phase, in which all the elements are interlinked. This integration has two facets: material linkages (flows, common resources, productive activities, etc.), and value interrelations (various objectives and interests represented in the regional system and the relations between them), which are defined over physical activities and interrelations.

The necessity of regarding a regional system as a whole for development planning purposes led us to coin the term integrated regional development (IRD); this approach is justified by experience gained from case studies done and under way at IIASA (Knop 1976, Albegov 1978, Straszak 1980). In particular, comprehensiveness and integration with regard to the various regional sectors involved, both resources and activities, are required. Another essential comprehensiveness and integration cross section is operations management organization; both of these are taken into account in the cases studied. The value and interest cross section, however, was considered to a much smaller extent.

In the consideration of large, multidimensional complex systems such as the regional socio-economic ones it is necessary to utilize formalized methods based upon computer models of reality and of its possible changes. This necessity of model building and application results both from the need for precision and speed in handling large amounts of data, and from the need to test the mostly intuitive assumptions concerning causal relations in real socio-economic systems.

2.2 The System of Models

It is impossible to construct a single model that will serve all regional development needs, fulfilling the comprehensiveness and integration requirement. There do exist such frameworks, e.g., Input/Output, which are meant in principle to comprise all possible components of a (regional) socio-economic system in terms of commodities and production activities, with the exception of substitution, functional, and value interrelations. There is in practice, however, no experience of or capacity for implementing any all-embracing, comprehensive, and integrating model. It is therefore necessary to elaborate systems of partial models, where each model in the system highlights with adequate precision a portion of the real regional system. Simultaneously, interconnections between the models would ensure adequate reflection of the systemic behavior of the whole. Thus, the models entering the system should not only sufficiently describe/optimize their subsystems well, but should also provide for easy and meaningful connections with other models.

Positive experience in the construction of systems of models for regional purposes have already been gained during IIASA's work in the field in both retrospective (analysis) and prospective (design) case studies: Kinki in Japan (Ikeda *et al.* 1979); Silistra in Bulgaria (Andersson and Philipov 1979); Notec in Poland (Albegov and Kulikowski 1978a, b); and Bratsk–Ilimsk in the USSR (Knop and Straszak 1978).

There is a wide range of methodological possibilities in constructing a model for the model system. Models with regional connotations are being constructed according to such methodologically differing theories as, for example, control theory or factor analysis, but it should be remembered that each type of theoretical basis for modeling ought to be placed firmly against a broad spectrum of regional socio-economic issues, so as to ensure the most appropriate utilization of these theories in solving development problems. A possible "assignment" of model types to issues is shown in Table 1 (taken from Straszak and Owsinski 1980). This table assumes a number of issues, i.e., problem areas, that appear in regional analysis and planning, such as: regionalization, regional specialization, coordination, or regional structure. On the other hand, the classification presented refers to stages in decision-making (planning) processes, in which models can take on various roles. In such a two-way breakdown the model methodologies are chosen according to their purpose.

The structure of the model system should reflect the structure of the regional system on an aggregate level, while the internal structure of each model should reflect micro-level relations. This can be illustrated by a structure for the model system, proposed by Albegov (1978), presented in Figure 1. This particular structure is oriented towards normative planning applications related to regional development. When commenting on this diagram, a number of reservations should be made. First, this is only one of several possible structures; it results from the author's experiences in development plan modeling of territorial breakdown in the Soviet Union. The assumption behind this diagram is that a certain more general planning scheme – involving modeling – exists. In particular, aggregate marginal costs, related to resource uses, are given, obtained for various regions and for the main resource groups.

For a more general case, when the marginal opportunity costs for resources and commodities have not been determined beforehand via a nationwide procedure, one can

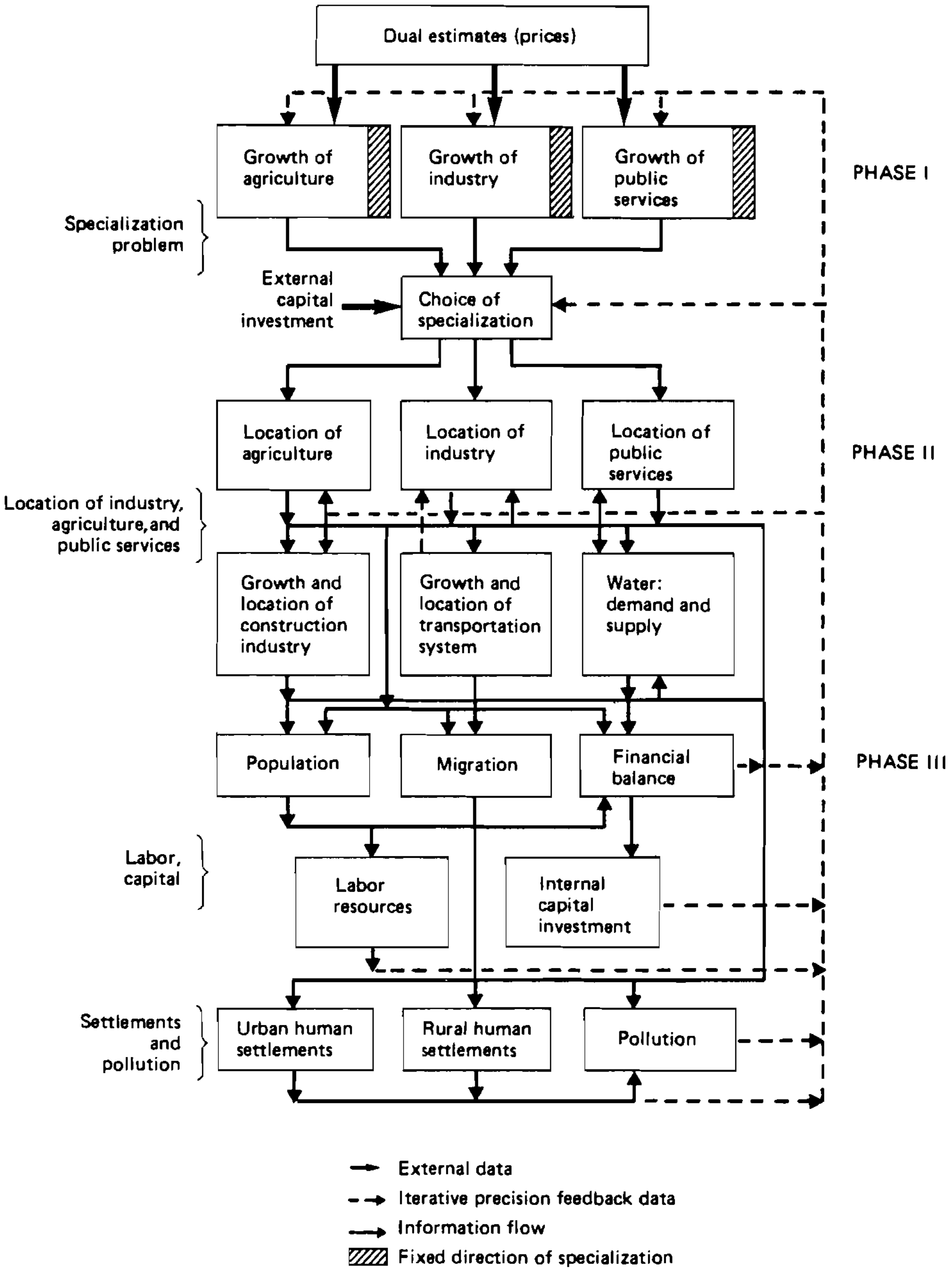

FIGURE 1 General scheme of the regional development model system structure. From Albegov (1978).

TABLE 1 Utilization of various model types and techniques according to their roles in the decision-making process, and issues considered. From Straszak and Owsinski (1980).

Issue	Role: Recognition	Debate	Pre-planning	Planning	Operational	Monitoring and control
Regionalization	Factor analysis Cluster analysis Connectivity analysis	Factor analysis Cluster analysis Connectivity analysis Structural anal.	Structural anal. Decomposition Multi-level optimization	Multi-level optimization Decomposition Tearing		Trending
Choice	Structural anal. Gaming	Gaming Decision anal.	Decision anal. Game theory	Decision anal. Game theory Multi-criteria assessment	Multi-criteria assessment Multi-objective programming	Polling
Specialization	Identification Structural modeling	Econometric Input/output Programming Structural models	Econometric Input/output Programming dual, nonlinear	Input/output Programming dual, nonlinear, dynamic	Dynamic programming Critical path Financial	Regulation Critical path Financial
Resource efficiency	Identification Input/output Structural models	Input/output Structural models Programming	Input/output Programming dual, nonlinear	Programming nonlinear, dual, dynamic Input/output Accounting	Dynamic programming Accounting	Accounting
Coordination	Gaming Structural models	Gaming Game theory	Game theory Decomposition Multi-level optimization	Decomposition Multi-level optimization Control theory	Dynamic programming Regulation	Interactive gaming Regulation Critical path

TABLE 1 *Continued.*

Issue	Role: Recognition	Debate	Pre-planning	Planning	Operational	Monitoring and control
Control	Identification Structural models Gaming Stochastic approximation	Structural models Control theory Game theory Econometric	Control theory Programming Econometric	Control theory Dynamic programming	Dynamic programming Regulation Critical path	Regulation
Stability	Identification Structural models Stochastic approximation	Structural models Control theory Catastrophe theory	Structural models Control theory Catastrophe theory	Control theory Structural models	Regulation Dynamic programming	Regulation
Structure	Structural analysis Structural models Identification	Structural analysis Structural models Catastrophe theory	Structural models Markov processes Catastrophe theory	Structural models Stochastic control theory		Trending
Characteristics	Survey Screening	Relational data base	Relational data base	Relational data base		Data acquisition

start the iterative working of the proposed system of models from the population, migration, and financial balance blocks (phase III), which determine the regional–exogenous trends. These trends can then be rectified for normative purposes, if needed, when the same blocks are "activated" again in a second iterative run of the system. Thus, the same system structure (same in the sense of intra-model structures and inter-model connections) can be used to work in various configurations. The alternative configuration proposed here, i.e., starting from population and consumption trends (phase III) and going to sectoral growth (phase I), is in fact one of the more popular ones, e.g., in the regional forecasting model elaborated by the TVA (Knop 1976).

On the other hand, the blocks of Figure 1 by no means have to be treated as separate models. In practice, the specialization and location problems (phases I and II) are quite often solved for a given sector (e.g., industry or agriculture) within one model. Similarly, the population and migration questions are usually contained within one model.

Evidently, for the working of such a model system it is necessary that some core models are operational, to provide sufficient data for other models and to make use of the information provided by them. Such core models should certainly account for the most important and dynamic sectors of the regional economy.

2.3 The Agricultural Core Model

The first two regions taken as the prospective regional case studies into which IIASA would have a positive modeling input were largely agricultural in character. Although agriculture plays an important role in almost any regional development venture – whether in connection with land-use problems, the environment, or for purely economic reasons – it unquestionably takes a leading role in the regions of Notec in Poland and Silistra in Bulgaria. Thus the model systems devised for these two cases necessarily included agricultural models. These systems and the models therein were developed on the basis of differing methodologies, but the contents of the systems on the level of blocks (modeling objectives) were similar.

According to the above, a regional agricultural model included in such a system would describe adequately the agricultural socio-economic regional subsystem and provide sufficient data for other models in the system. This places definite requirements on agricultural model representations of such resource subsystems as labor force, land, infrastructure, water, fertilizers, etc.

The model should therefore be limited to solving agricultural problems, but must also be able to include all significant feedbacks and results from other subsystems. It is generally assumed that a regional development problem should be separated according to its sectoral components, so that each component can be solved by the corresponding model within the framework of the set of regional models. Such an approach would allow each subproblem to be described in as much detail as is necessary, and would avoid the use of complicated "hybrid" models ("hybrid" in the sense that they include elements of several sectors, such as water, industry, and agriculture). During the interaction between the agricultural and the other regional models, it should be possible to change some coefficients in accordance with the results of the other models. Communication with other parts of the model system on various resources can be carried out by transmitting information on their absolute volumes and/or costs, values, and efficiencies, absolute or marginal.

In this way, information on specialization capacities is gathered. The model should account for both material and financial flows, since both these methods of measurement are perceived explicitly in the system. This also has a bearing on different values being sought in the region and with regard to the region to be operationalized in the model via quantitative objective functions. In particular, the interests of various groups (producers, administrators) within the regional agricultural system should be accounted for, as well as various types of values in general.

The principal purpose of the model is to achieve results that can be used in the formulation of policies regarding future regional agricultural production, structure, and specialization. These may depend on issues such as land use, present production structure, soils, farm types, animal feeding methods, technology choices, labor skills and their use, availability of resources, etc., all of which are examined in more detail below.

A model fulfilling the above requirements would constitute an effective core for a model system. In the work of IIASA as an international institution, however, there is still another essential requirement – generality. The construction of the model should therefore ensure that it can be used under changing conditions, i.e., that various aspects of the system be accounted for, even though they may not necessarily be present in all cases. The contents of these aspects should therefore not be overdefined, so as to allow a flexible fill-in procedure in particular implementations.

Such a model has been formulated and implemented at IIASA, and is called the generalized regional agriculture model (GRAM).

When looking at the experiences that could serve as a starting point in our work we found that quite a limited number of models had been developed that fulfilled to a reasonable degree the conditions set out here. Outstanding work in the field has been done by E.O. Heady and associates (see Nicol and Heady 1975, Heady and Srivastava 1975), for the United States. References to similar models in other countries can be found in Heady and Srivastava (1975). Relevant models for our purposes were also reported by von Sauer (1970) for Lower Saxony, by Egbert and Estacio (1975) for Portugal, and also by Semionova (1976) for the Soviet Union. Of earlier works one should mention here the Swedish model, as presented by Birowo and Renborg (1965), the Norwegian one by Langvath (1962), and the French method by Klatzmann (1965). It was mainly the question of transferability and adequate representation that made our search for an appropriate structure difficult.

3 MODEL STRUCTURE, CONTENTS, AND USE

In accordance with the previous remarks on the purposes that the model was intended to serve within the model system, and on its characteristics allowing for its generality, the prerequisites of the formulation of the model will now be presented in more detail.

3.1 The Structure of the Model

The structure of the system studied, i.e., regional agriculture, is schematically presented in Figure 2(a). The figure follows in outline the actual form of the model described below, but it contains certain elements that are as yet absent from the model, such as seed or livestock reproduction feedbacks.

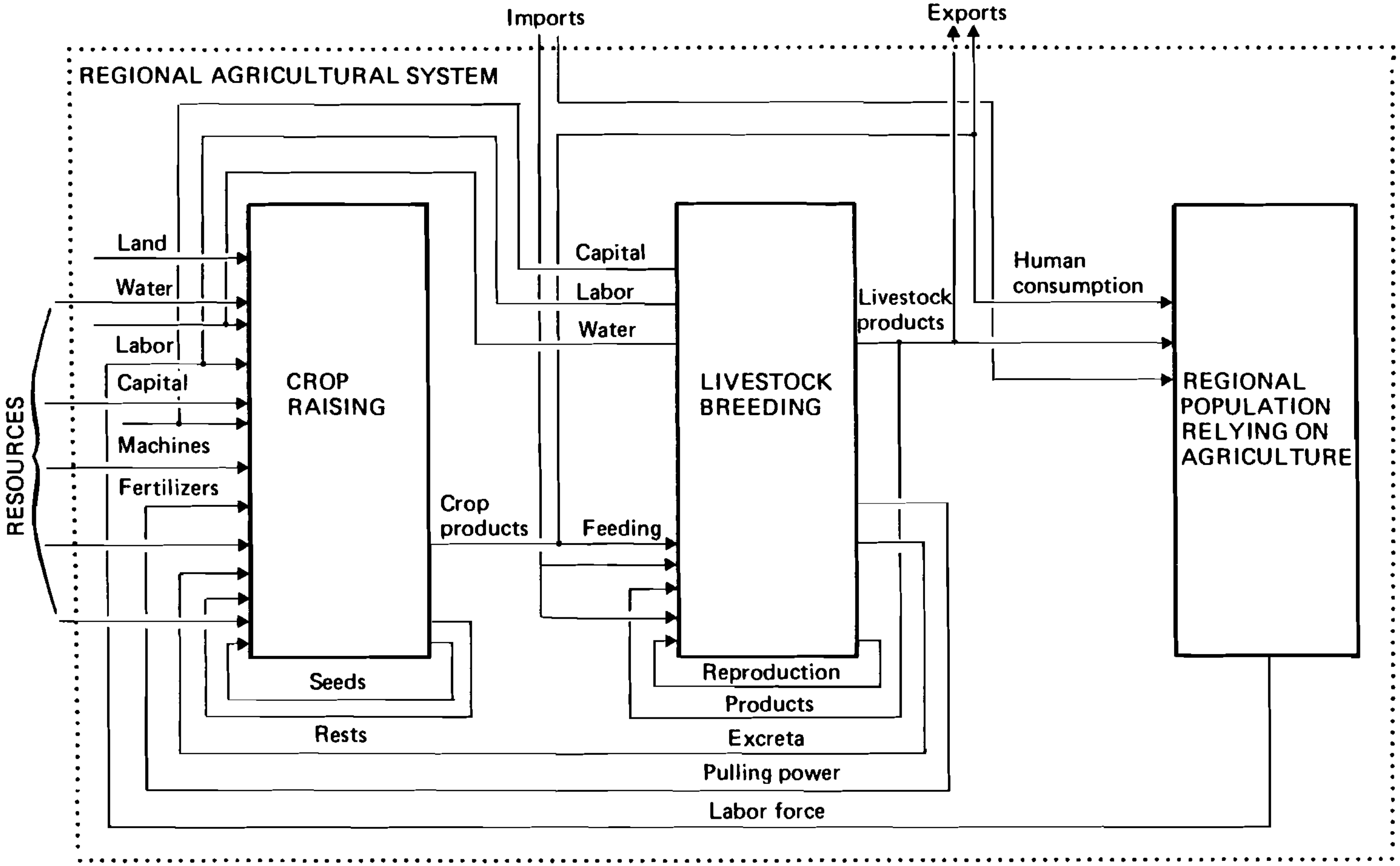

FIGURE 2(a) Structure of product and physical resource flows in the system under study.

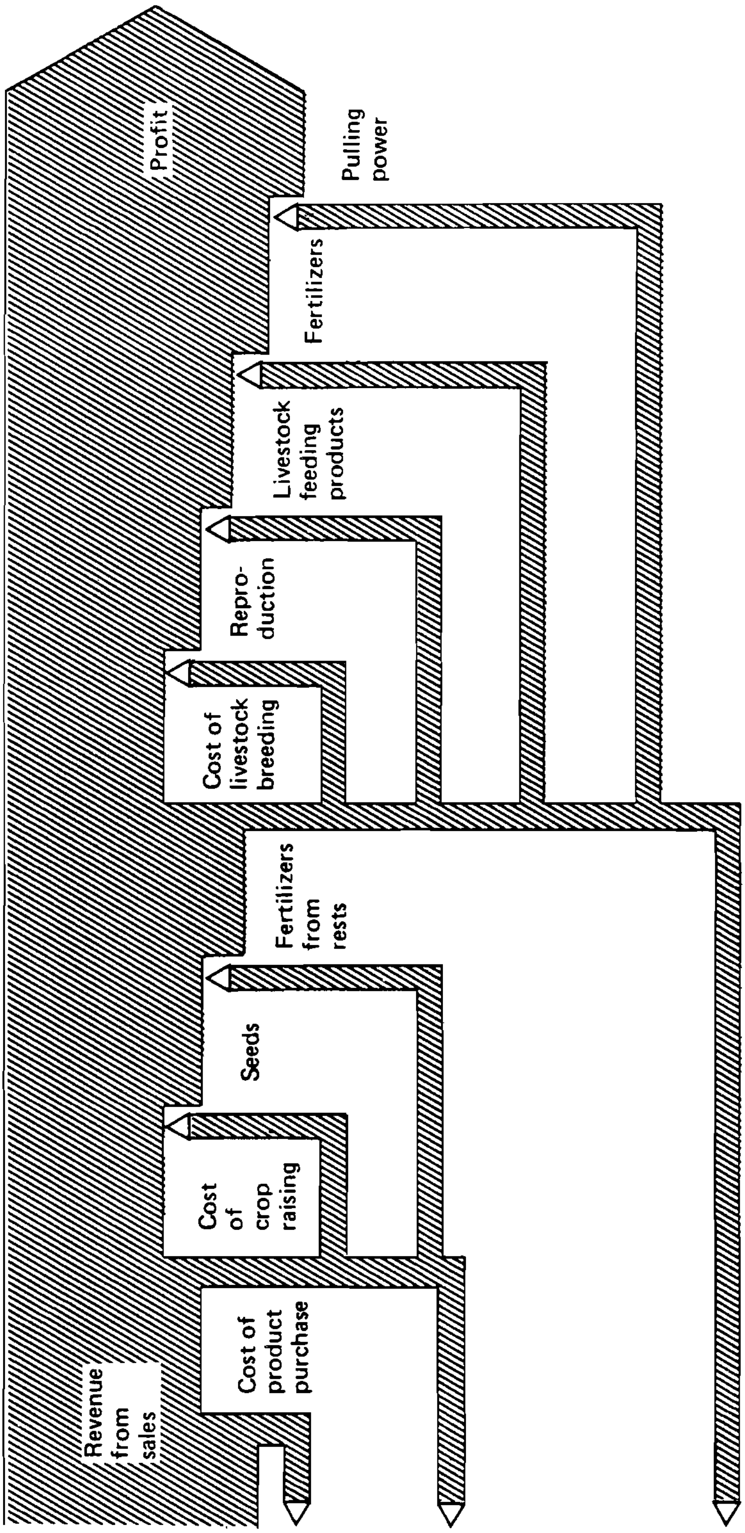

FIGURE 2(b) Structure of the financial accounting scheme for a farm in the system under study.

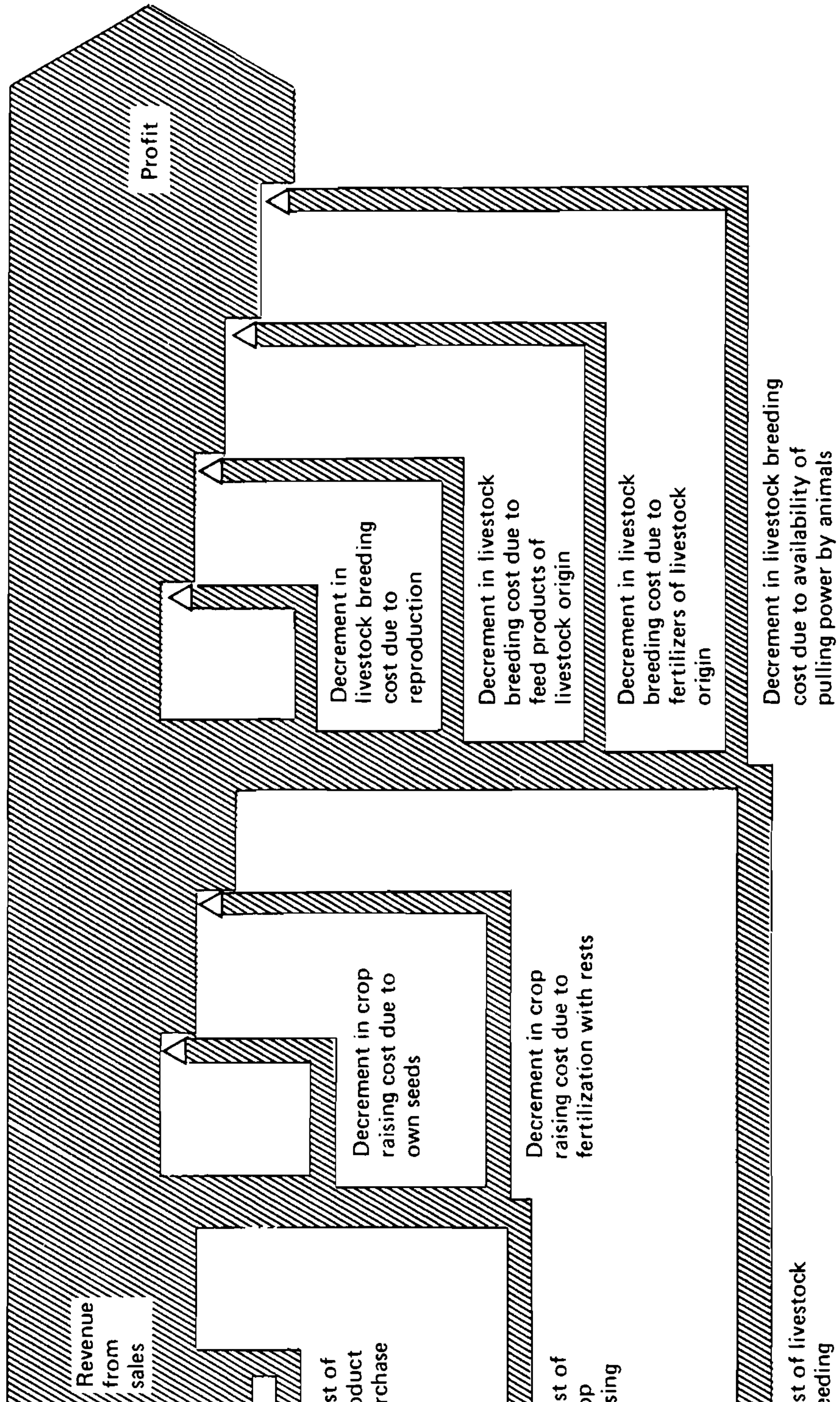

FIGURE 2(c) Structure of costs for crop raising and livestock breeding for the system under study.

As can be clearly seen from the figure, the main subject matter of the model is the description of various aspects of crop raising and livestock breeding activities. The more important items appearing in these activities will be commented upon in this section.

3.2 The Form of the Model

The individual elements and aspects of the agricultural system outlined in Figure 2, and the way they ought to be represented in the model, are discussed in the following section. Prior to these considerations, however, some general comments are necessary to justify the major choices made in model elaboration.

The model was intended to be a tool in development planning, whereby essential changes in the activity structure, etc. are implied. It was assumed that additional outlays and resource supplies would occur, and that conscious policies would be exerted to direct the use of additional resources and possibly ensure an effective course of development. Thus it was decided that the model would be normative and would provide a broad overview of potential controls, which could be operated by development centers (local administration, authority, corporation, etc.), depending upon the specific legal, administrative, and organizational conditions of a development undertaking. For each control instrument (such as prices, interest rates, subsidies, infrastructural investments, land-use regulations, supplies), there should be a way of assessing its efficiency in terms of its influence on producers' behavior. Furthermore, for each optimal structure and specialization obtained, the opportunity costs related to it for each producer group should be established. In this way the feasibility of an optimum can easily be assessed. As can be seen, these policy indication requirements necessitate from the model great facility of dual and marginal cost and price calculations. (Further details of the decision-making applications are given in Section 3.4.)

Since the model was intended for planning purposes in a changing environment it was deemed inappropriate to use aggregated magnitudes and relations, which are often quite abstract and rely on conditions that might totally change due to the development program itself. These include various production functions for agriculture as a whole, regardless of specific conditions, possibilities of activity reallocation, etc. Instead, it was decided to start with explicit consideration of various soils, producer types, climatic and hydrological areas, technologies, etc. Furthermore, an explicit solution to the diet problem was to be included in the model insofar as dramatic changes in crop production patterns may make the predefined diets not just suboptimal, but even obsolete. This variety, coupled with crop and animal types as well as product and monetary flows, results in a very complex picture.

Bearing in mind the requirements of normativeness and of facility in producing dual and marginal values for policy indication purposes, and also the assumed complexity of the model, it was decided to implement it as a linear programming (LP) model. This would also ensure that the model would be able to communicate with others in the system, and the simplicity of potential transfers.

Such a choice necessitated essential simplifications to some relations that were known to be highly nonlinear (e.g., discrete technological options rather than continuous production functions), and we did not find satisfactory the justification for actual forms of nonlinear relations accounting for bigger aggregates. On the other hand, empirically based production functions, which are defined for individual crops and resources in particular subregions (see Hexem and Heady 1978), would limit the model dimensions.

Some of the feedback effects shown in Figure 2, if appropriately accounted for, might ultimately lead to a dynamic model. It was anticipated, however, that the dimensions of the resulting LP model, in which spatial and productive aspects were assumed to be of major importance, could inhibit dynamic formulations; that is why at the present stage of work, a static LP model form was adopted. With a model size constraint resulting from the requirement of operativeness this aspect was chosen to be covered in more detail. Secondly, dynamics would not be a major problem for most of the elements accounted for in the model. Dynamics, in fact, enters mainly into the herd structure programming and into financial and investment considerations. For the aggregate, "comparative statics" type of analysis, the omission of these dynamic aspects does not introduce essential errors, provided the time horizon is not too long and a stable situation is envisaged.

For an LP model its communication with other elements of the system can be easily organized through the exchange of information concerning right-hand side (RHS) values in the constraints (Albegov 1978, Gutenbaum *et al.* 1980). Other models may specify resource availabilities, for example, which enter the agricultural model (GRAM) as RHS values, while the agricultural model, on the basis of either appropriate dual variables or absolute increments in the objective function, would specify relative or absolute sectoral costs/values of the resources in the region. In cases of more flexible software implementations it is feasible to exchange some information on coefficients of the objective functions or even of the constraint coefficient matrix. The organization of the appropriate iterative procedure then becomes more complicated.

3.3 The Content of the Model

In accordance with Figure 2(a), our comments start with the resource side of the system. Resource conditions are generally treated through appropriate requirement and availability balances.

3.3.1 Constraints

Land use. To obtain a comprehensive description of regional land use, the following points need to be examined when setting up land-use balances and availability constraints (care should also be taken of the areal changes due to urbanization, etc.):

(1) the possibility of implementing major land-improvement techniques such as irrigation, drainage, terracing, chemical applications;

(2) variations in the quality of land;

(3) the possibility of cultivating a second crop in some areas;

(4) the conditions for crop rotation.

The effectiveness of implementing land-improvement technologies depends on the quality of the land. Thus, the economic efficiency of capital investment and current expenditure in such undertakings is variable. The overall efficiency is also influenced by the situation of the land: for example, the closer an area requiring irrigation is to a river, the more economically effective an irrigation scheme will be. This aspect can, of course, be dealt with through appropriate cost coefficients. In general, GRAM should account for the land-improvement factor by including several different types of "technology" in the model description. These technologies should, in principle, represent vectors defined in a set of multifactor production functions. Since it is not feasible to use all these production functions, even in a linear form (there would have to be production functions, such as for crops, depending on labor, water, fertilizers, and machine energy, for each soil type, subregion, and producer type), only a limited number of such vectors should be used.

It should therefore be remembered when defining technologies and related coefficients describing resource use, costs, etc., what sort of (explicit) assumptions are made with respect to yields, capital, and running costs, their dependence on soils, technologies, and farm types, etc.

Crop production conditions cannot be considered uniform for all subregions because of the differences in soil quality and/or in cultivation traditions, and consequently in the results of land improvement. These differences can be described adequately by accounting for an appropriate number of subregions. In GRAM, the regions might be divided according to soil quality, farm type, and administrative divisions, and the model should be capable of handling up to 40–50 such subregions. In general, the division of space, and therefore also of agricultural land, must meet the modeling requirements not only of the agricultural sector but also of other sectors, such as industry, water supply, and settlement patterns. It is impossible to achieve a division of the land area of the region that is "ideal" for all sectors. Thus, the boundaries of the subregions should be defined by some factor of importance for the leading sector of the regional economy and should ensure feasibility of policy-making with regard to these entities.

It is essential – and of direct relevance to land use – that various types of farm economy be taken into account in consideration of technological and financial coefficients. Thus, land-use balances should also be made over farm types, since their shares must be considered relatively stable within the time horizon of the model. In some regions the distinction might be based upon farm size, while in others, on farm organization or specialization. Such distinctions are envisaged in GRAM. Because of the conditions of the first implementation, the types corresponded to land ownership (private, cooperative, or state), but this is by no means binding for other implementations. Having introduced the farm economy types these will now be referred to as "producer types". A further distinction could be a "producer group", which is a producer type spatially or otherwise located.

In some regions it may be possible to harvest a distinct second crop and this should also be represented in the model description. Similarly, crop rotation should also be accounted for. In the case of crop rotation schemes used as activities there is no need for appropriate land-use conditions. However, since the present model assumes consideration of real entities in all their potential configurations, crops are regarded as activities.

An important problem connected with land use is the question of how to define the ratio of perennial to annual crop production. It is possible to find the exact proportions for a particular year by using a longer-term model that describes an average annual harvest. Perennial production may change from year to year, but the way in which these changes occur (that is, the dynamics of production) can be assumed to be constant for any given five-year period. Thus, balances of land use (note being made of possible soil losses due to other activities) should take into account the following details:

(i) the availability of land of given soil type for a given producer group (subregion and producer type);

(ii) the feasibility of introducing given technologies on individual portions of land as defined above;

(iii) balance conditions for the second crop areas;

(iv) the land-use constraints for various crops resulting from crop rotation conditions and from the proportions of perennial and annual crops.

Use and supply of labor. The tendency for migration from rural to urban areas during certain stages of socio-economic evolution is a worldwide phenomenon, so that restrictions on the availability of labor merit some discussion. At this point, however, it is unnecessary to consider the coordination of labor distribution between the main economic sectors (industry, agriculture, and services). The inclusion of labor force constraints will enable information on marginal and total costs to be exchanged with other sectoral models.

If regional limits to the labor supply are accounted for in GRAM in a changeable way, it should be possible to determine the regional agricultural structure and output when employees change their field of work, or if the distribution of skills changes. Additional balances of labor supply between various types of farming, such as in the case of providing staff when required, should also be considered. This may be done by introducing variably tight constraints representing labor supply restrictions on various organizational and economic forms of farming for the region.

Water resources. The interdependence of agriculture and water supply is obvious, but the scale on which an irrigation scheme is introduced significantly affects the marginal costs of the water supply. Therefore, an optimal solution to the water supply problem in an agricultural region must be found. Our approach has been to separate water demand (described in the agriculture model) from supply (described in the water supply model), although in many agricultural regions conditions of water supply and demand are in fact determined internally. Information about the price of water and/or the limits of supply is obtained from the water supply model and included in the agriculture model.

However, the water shadow-pricing system could be complicated as a result of the irregularity of agricultural water demand, which is much higher in spring and summer than in autumn and winter. To avoid complications it can be assumed that for a given water resource system structure there is a constant cost of water entering the agricultural system. However, for a more precise calculation, several values for the cost of water might be introduced.

The same applies to water resource shadow prices, which can be defined for the all-year availability constraint, and/or for some shorter-period constraints. The exchange of information on water volumes, costs, shadow prices, etc., between supply and demand models should lead to a rationally balanced regional solution.

The supply of technological and technical resources. The general approach used in GRAM to solve the problem of the supply of technological and technical resources was to establish coefficients reflecting the requirements of the basic and additional supply of technological and technical resources, such as machinery and fertilizers. If supply restrictions on certain items exist, the corresponding constraints should be introduced into the model. These can also serve as accounting devices. The various unit volumes of additional supply and the corresponding costs are incorporated in the coefficients for appropriate technological variants.

It should be kept in mind, for fertilizers in particular, but also, as shown above, for water, and in fact for most of the physical resources, that the supply–demand approach has definite limits. Thus, as well as appropriate costs and prices, physical balances should also be taken into account. In a simplified model, this might also be a way around the essential nonlinearities of shadow prices. In the case of fertilizers, the physical balances are indispensable in view of environmental limitations.

Capital investment and incomes. The total capital investment required for regional agriculture has to be assessed. The investment needed by the various producer types for different activities carried out using various technologies should be estimated on an individual basis. Let us comment on the financial aspect for the distinction of three producer types on the basis of land ownership in a mixed economy: state, cooperative, and private. Capital investment conditions for collective and private farms may be assessed similarly, but a different approach should be used for state farms. The differences in farm organization are reflected in these two approaches. On state farms all income goes to the state, which pays the farmworkers a wage. The workers are thus not dependent on the results of production for their income, as are those on collective or private farms. The state also supplies the farms with all requirements such as seed, fertilizers, and the capital investment necessary to achieve the desired level of growth in output and expansion of activities. In the case of collective farms, it is the members who decide what proportion of the farm income should be spent on capital investment and what on consumption through disposable income. However, they are able to obtain some external funds for the expansion of activities, usually in the form of credits, loans, or subsidies from the local or central authorities. In the case of private farms, the owner is responsible for providing most of the capital investment necessary to increase his output or to expand his activities, which is thus closely connected with his current expenditure and revenue. In GRAM the capital investment constraints are therefore allowed to vary according to producer types, as are also constraints specifying minimum income levels per capita.

The availability of external capital investment funds is one of the main factors in determining the rate of regional agricultural growth. In this respect, constraints resulting from the addition of internal and external funds exist at the subregional as well as the regional level. It is possible to ascertain the degree of dependence of the region's agricultural structure, output, and income on the allocation of external finance by varying the level of external investment in agriculture. Furthermore, the efficiency of this investment can be measured and compared with the efficiencies achieved in other sectors of the economy.

Animal feeds. To achieve regional livestock growth, it is essential that livestock be provided with adequate and well balanced feeds. Thus, the following main issues should be examined.

(1) Is the region able to supply its livestock with a complete range of animal feedstuffs (a balance of feed types and elements, such as green or rough, and succulent or protein content, should be included in the model)?

(2) What possibilities exist to export excess feedstuffs produced?

(3) What influences do internal and external animal feed supplies have on regional livestock specialization and on the scale of future levels of feed production?

Some models (e.g., Gouevsky and Maidment 1977) treat animal feed supply alternatives as fixed; this has both advantages and disadvantages. Although it may simplify the model description, it can lead to errors in cases where the real situation is more complex (and changeable), so that even a great number of fixed "diets" would not suffice to define the effectively optimal diet and the related production structure. It can never be assumed a priori that an adequate precision of optimization can be achieved via the fixed diet approach in conditions of changing crop production structure, particularly insofar as it is impossible to know in advance what the dependence of the objective function will be upon the location of the program in the vertices in the vicinity of the optimal one. Therefore, the approach chosen for GRAM is free formation of animal feeding schemes, through (implicit) solutions of the optimal diet problem embedded in the whole LP problem. The diet problem is expressed through a set of constraints on minimal and maximal consumption of feed elements. This enables a choice to be made about optimal animal feed production according to regional specialization of crop cultivation and available external supplies. In most cases, such an analysis appears to be very important. It has been shown that in the USSR an economy of several million tons of crop could be achieved using optimal free balances of forage crops (Albegov 1975).

Because a significant part of crop production is required for feeding livestock, it is important that an optimal balance between crop and livestock production can be explicitly obtained. The problem of organizing the animal feed processing industry should be solved separately, analogously to food processing in general, and this is discussed below.

Product balance constraints. First, there are product balances in the form of equations that sum up all the products obtained on the one hand, and all the ways in which they are used on the other. In addition, there are internal production balances that express, for example, import quotas or capacities of storage and transportation facilities. These sales and purchases constraints, because of their simplicity, can also be used just for accounting purposes, even in cases when some or all of them are insignificant. Their importance is obviously greater in strictly controlled economies or in economies under stress.

3.3.2 Activities

As mentioned above, it was decided that in GRAM the activity variables should refer to crops and not to crop rotation schemes. Although this choice in fact determines only a small portion of the model (such as constraints defining crop rotation conditions), it has an important influence on data preparation and interpretation of results, and thus determines to a high degree the philosophy of the model. The justification for such a choice is analogous to that for the explicit diet problem solution for livestock feeding. First, a much greater number of crop rotation schemes than crops would usually be required. Furthermore, even for quite a large number of crop rotation schemes it is quite possible that the economically optimal one will not be among them. Another problem arises when there is a need to change the rotation scheme in the middle of the sequence.

Production structure. To obtain practical results, a detailed model is required in which all major agricultural products (about 20–30, including livestock and annual and perennial crops) are described. For instance, for the USSR (Albegov 1975) it has been shown that at the national level no fewer than 15 crop products should be described in the model (spring wheat, winter wheat, rye, oats, barley, maize, beans, potatoes, forage and sugar beets, annual and perennial grass, different types of animal feed products), and there should also be a place for fruit and vegetable production. At the regional level a similar number of crops is usually specified, although the types differ slightly from the aggregated ones specified at the national level.

The production structure in general should be defined, as indicated before, according to crops, subregions, producer types, soil quality, and technologies. Such a structure is shaped by all the resource availability and balance constraints mentioned above.

In principle, agricultural processes directly involve dynamics. However, when considering problems of a general nature, such as regional agricultural specialization, it is not necessary to specify details of the dynamics such as year-to-year changes in the area of land used for cultivation of a particular crop and in the livestock production structure. A detailed time-span analysis, however, is more important when a significant variation in the volume of production of some important crop or livestock product occurs, or when the amount of a resource increases or decreases dramatically over time.

The dynamics of regional livestock production is reflected directly in the herd structure, which in turn influences the structure and volume of livestock products. Thus, not only should these products be included in GRAM in an aggregate form, but also livestock specialization might be represented, e.g., cattle rearing for meat, milk, or both; sheep rearing for meat or wool; poultry breeding for meat or eggs. The model (if compared with that of Gouevsky and Maidment 1977) could therefore describe the structure of future regional livestock production, taking into account all available alternatives. The above points are included in GRAM by the use of indices representing appropriate technology and specialization in the variables concerning livestock production. The herd structure, however, is not described directly, but has to be determined exogenously or through appropriate cost-and-price coefficients, reflecting average reproduction parameters and animal prices.

Since the tendency to organize agriculture on the basis of agro-industrial integration is becoming more widespread, the agricultural product processing industry needs to be briefly discussed. Once the optimal volumes and locations of crops and livestock are defined the problem of where the processing plants should be located and at what capacities can be solved. Location depends to a large extent on the transport infrastructure, since for many products rapid transportation of the products to users and consumers within and outside the region is essential. The separation of the procedure into two stages, as proposed above, could introduce errors, although these can be diminished through use of production and sale limits, whose values are based upon certain predefined feasible configurations and capacities of processing plants, transportation facilities, etc., for which aggregate shadow prices could thereafter be obtained. Thus, an iterative procedure leading to a globally optimal location and capacity program can be established.

Errors resulting from separation would therefore not be as significant as in the case when a detailed description of the processing industry is included in the model. For this latter case, the description of crop and livestock production would have to be simplified because the size of the model is restricted and decisions would have to be made about the geographical extent of processing, storage, and transport facilities to be taken into account.

Another way around this question could be to introduce just a few additional aggregate activity variables for processed food, making it possible to assess the efficiency of processing in a crude fashion.

Choice of technology. When developing a regional agriculture model, it is essential to examine the various types of agricultural technology that can appear in the system. These should be evaluated in relation to the particular conditions of the subregion, such as the availability of capital investment, the cost of water and fertilizers, and the labor supply. Thus the determination of an optimal set of technologies to be considered in the model requires some preliminary calculations, which should be carried out during the establishment of the data base. The results should be combined with a variety of possible technology options and then included in the appropriate version of GRAM.

When preparing the resource use and cost coefficients for various technologies, extensive use should be made of the data specifying explicit production-function-type relations. (Implicit marginal substitution relations can be obtained through optimal characteristics for a given regional setting.)

The choice and parameters of a technology depend on many features of the farms in the area, such as size, which in turn depend on the type of property ownership. As a preliminary calculation, it is therefore necessary to assume the future size of each type of farm (by, for example, determining the optimal farm size if analyzed in a normative framework). The optimization method presented by Kulikowski (1978) could for instance be used for this purpose. For such a forecast, one should have some idea of possible technologies that depend on machinery, fertilizers, water, use of manual labor, and so on, although these dependences could be presented in a more explicit production function form.

The farmer's real response to modern technology is an important factor governing the success of the implementation of the model. The farmer must be convinced that new technology will significantly improve his output in the long term before he replaces his old machinery and methods, and so the model should determine conditions for such a situation. Thus, for example, in order for the farmer to use water the price of water (for a certain volume meant for irrigation) coupled with unit cost of irrigation structures on the farm should be less than the marginal value of water. In this case it would be necessary to investigate the water pricing system since the inducing price may be below the supply cost level. GRAM should then be constructed in such a way that it is possible to account for the influences of water cost as an element of technology on the structure and volume of regional agricultural output.

Product flows. Since the model will explicitly establish the balance between crop and livestock production, and will account for financial relations within the system, it is necessary to introduce activity variables connected with the origins and destinations of product flows. Flows of produce meant for livestock, for local human consumption, and for export, as well as the appropriate flows of imported products, should all be distinguished.

Additionally, it was assumed necessary, because of the variety of prices and of differing sale and purchase conditions, to distinguish markets on which appropriate transactions are made. Thus, the markets might be export/import and internal, wholesale and retail, etc. Such distinctions make it easy to account for sales and purchases with appropriate prices in financial constraints and in objective functions.

3.3.3 Objective Functions

The type of objective function used is primarily dependent on the policy defining the agricultural development of the particular region. Thus objective functions should in principle be custom-made, although a small number of general objective functions could be formulated to fit most regional development cases.

Hence, the major types of objective function that should be included in the model are: monetary net output and monetary (or physical) gross output. For the former, a direct cost–benefit comparison is made, while for the latter, some policy-oriented objectives are sought, such as maximization of a certain predefined product or product contents. Usually an equivalence coefficient vector has to be introduced in physical objective functions for purposes of aggregating various commodities. Such coefficients may be based on the protein content, for example, on the protein content weighted with some other elements, or just upon a previously defined "optimal" element mix ("diet"). These coefficients play the role of prices used in monetary objective functions. Non-monetary objective functions are not often used, so the monetary type will be described in more detail. The prices applied change according to the destination and origin of the products, or to variations in the structure of the model, i.e., the interpretation of flows in the objective function. The various product uses, and the potential sales and purchasing of products via various markets should be explicitly considered.

Actual expressions of monetary objective functions first have to include income from agriculture, i.e., full accounting of revenues and expenses on primary agricultural products, with alternative treatment of capital and current expenditures and wages in various producer groups. Another objective function of the accounting type is the balance of regional trade. There may also be monetary objective functions of gross output type, which may account for the whole productive output or for portions of it.

It should be emphasized that for each case considered the specification of objective functions and their interpretation should be given over to appropriate decision-makers, interest groups, and other participants in regional development. As already mentioned, the duty of the modeler in this respect is to determine the feasibility and scope of control, and also to coordinate achievements that will satisfy all interested parties.

3.4 Uses of the Model

The main output of the model is a detailed specification of the production structure, together with the pattern of direct utilization of production. The structure obtained is optimal with respect to a predefined objective. By parametrizing the main resource constraints, the model can be used to indicate essential bottlenecks, distribution inconsistencies, etc. When appropriately wide ranges of dual variables are obtained, they can be used for intersectoral efficiency studies within the region, and for interregional assessments of agricultural efficiency. Simultaneously, the information thus acquired is sufficient for communication with other models in a regional development model system.

The model is intended to be used in decision- or policy-making, and that is what the information gained with it should be used for. As far as real policy-making is concerned, the situations theoretically range from a strict government taking into account the interests of direct producers merely through appropriate constraints, to an "invisible hand" directing the rational behavior of seemingly uncontrolled producers. In practice, there is always an "intelligence" and decision center whose capacities may vary; and there are always interest groups that can more or less effectively influence the policies and their outcomes by shaping the policy instruments themselves, and then by behaving more or less according to a "central decision-maker's" anticipations. Let us begin by looking at the possibilities of policy-making with the help of GRAM that the decision center has.

Policies can be determined by optimizing the model for objectives of all involved groups of producers, and comparing the shadow prices for the distribution-prone resources (capital investment funds, water projects, etc.) thus obtained with those for global objective functions. When this information has been obtained, one can optimize the efficiency of the resources used as control devices. (The use of resources can be optimized based uniquely on values of their shadow prices for one global objective function, but only where the agricultural system is assumed to be wholly under one management.) Such a procedure should not be confused with the standard price coordination technique since in this case the full model is solved explicitly and no regularizing assumptions are made.

Another multi-criteria approach, which also refers to producer groups or types as seen from the regional decision center, has been proposed by Seo and Sakawa (1979). This approach postulates the construction of a utility function based on resource shadow prices for different producers, and then proceeds to their aggregation for the whole system.

Thus, if the initial problem is

$$\max_{x_i \in X} \{f_1(x_1), \ldots, f_m(x_m)\}$$

where x_i is an n-dimensional decision vector of the ith producer group ($i = 1, \ldots, m$), then this problem is transformed into another:

$$\max_{x_i \in X} U\{f_1(x_1), \ldots, f_m(x_m)\}$$

where U is a multi-attribute utility function. In fact, U is not directly defined over f_i, as will be seen below. The procedure starts with the producer group problems

$$\max_{x_i \in X_i} f_i(x_i)$$

for which dual solutions λ_i are obtained. Values of λ_{ij} for individual resources j are used to construct the subsystem's utility functions. Since, provided certain standardization assumptions hold true, the numerical values of the shadow prices λ_{ij} correspond to a local decision-maker's preference ordering, the utility is determined by a linear transformation. The subsystem utility functions are then nested into a global, multi-attribute utility function, which can be optimized while keeping track of the satisfaction of the producer types. The method outlined is fully feasible with a well programmed LP model.

Either of these two methods can handle a compromise between a global objective and the objectives of producers. On the one hand, this compromise can be observed via dual values, and on the other simply via income levels (in the minimal income constraints) for producer groups. Such a mechanism enables an explicit compromise to be made between all the elements involved over the values represented in the model.

In addition to this question of inter-actor coordination with respect to a given objective there is also the problem of goal structure stemming from the fact that usually a number of goals are pursued at each level. In many cases special studies are required in order to establish the goal structure within a development program. In this situation coordination or compromise should be performed among goals or goal achievement measures.

For an explicit solution of the essentially multi-objective problem (i.e., not a coordination with respect to a higher-level objective or an aggregation) the interactive technique proposed by Wierzbicki (1979) can be used. Suppose we have an initial multi-criteria problem

$$\max(C_i^T x = q_i) \qquad i \in \{1, \ldots, p\}$$

subject to $\Omega x = \gamma$ and $x \geqslant 0$, where x is an n-dimensional decision variable vector, C_i are vectors of the criterion coefficients, Ω is the matrix of technical coefficients, γ is the vector of the right-hand sides, and p is the number of criteria.

The method proceeds by specifying the aspiration levels, referred to as "reference points": $\bar{q}_i$, $\bar{q} = (\bar{q}_1, \ldots, \bar{q}_p)$. For the vector reference point $\bar{q}$ and the vector of actual values q, a scaling function $s(q - \bar{q})$ has to be defined. A proposed function is

$$s(q - \bar{q}) = s(w) = -\min\left(\min_i g w_i, \sum_i w_i\right) - ew$$

where $g \geqslant p$, $e \geqslant 0$, $w = q - \bar{q}$. With this "distance" function one can formulate a unicriterion LP program, which is solved instead of the initial problem. The reformulated LP problem yields a Paretian solution $\hat{q}$ with regard to $\bar{q}$ (see Kallio *et al.* 1980), which is a very strong and important property.

An interactive procedure can be organized for obtaining successive $\hat{q}_k$ that correspond to $\bar{q}_k$ given by the decision-maker on the basis of previous results. From the conceptual point of view, the method makes it possible to reflect the very nature of the situation considered. Namely, there exist definite requirements of the aspiration level (reference point) type, e.g., to produce a certain amount of grain, sugar beet, etc. or to attain a certain income level per capita, etc. The use of explicit reference points is much more adequate than weighting or trade-off coefficients, which in any case may be obtained with this method a posteriori. The interactive mode of operation is helpful in the solution search.

The software for the technique outlined, i.e., for the transformation of the LP problem, has been developed and is available at IIASA.

It should be remembered, however, that the reference point technique provides Paretian solutions with regard to $\bar{q}$, and not to initial $C_i^T x$. In fact, the distance function $s(q - \bar{q})$ refers to $w = q - \bar{q}$, and not explicitly to q. To obtain Paretian solutions for the initial problem one would have to utilize a sort of goal-programming approach, which is much less numerically acceptable. Hence, by combining these two types of multi-criteria assessment techniques one can obtain balanced policy proposals. According to previous indications these may address various types of decision-making situations.

As indicated above, the model is meant to cooperate with other elements of the regional model system. Two predominant types of information will be exchanged in the coordination process: shadow prices (dual variables) used hereafter as cost coefficients, and output volumes used hereafter as constraints. It is certainly much easier to deal with the latter since they do not require intervention in the coefficient matrix. Such changes are, however, in general unavoidable, and they should be provided for via appropriate software procedures. Some resource distribution models may require knowledge of the whole optimal characteristic function for a number of resources being distributed, in order to dispose of an efficiency indicator hypersurface of use of a resource, whether on a subregional, regional, or interregional level (see Kulikowski and Krus 1980 for the application of a net production efficiency indicator function in a regional distribution problem). This would necessitate a number of model runs for each function through parametrization of the right-hand sides, but should not represent a serious difficulty.

It should be kept in mind when devising model coordination schemes that shadow prices can be treated merely as indices for iterative procedures and that their economic significance, though sometimes important, is quite limited. Sounder conclusions can only be drawn from the full shadow price optimal characteristics, from which real costs could also be inferred.

There may be a number of other particular problems connected with model coordination, such as consistency of regional breakdown or correspondence of constraints to limits and limits to costs, but these should be solved separately for each case.

4 MODEL FORMULATION

The model has the standard LP form:

$$\Omega \widetilde{X} \left\{ \begin{matrix} \leqslant \\ = \\ \geqslant \end{matrix} \right\} \Gamma$$

$$\omega_\eta \widetilde{X} \rightarrow \max,$$

where Ω represents the matrix of coefficients, $\widetilde{X}$ is the vector of all decision variables (activity values), Γ is the vector of constraining values (mostly resource limitations, requirements, or balance conditions), and ω_η are the objective function cost-and-income coefficients for the activity variables. It has multiple objective functions $\eta = 1, 2, \ldots$, and is complemented with some additional procedures, described below. The model, as described here, represents the implementation valid as of January 1980. Further improvements have been made since then.

An overview of the constraints Ω, $\widetilde{X}$, and Γ is given in Table 2, where all coefficient subtables and their correspondence to appropriate portions of $\widetilde{X}$ are indicated. The table also gives the nature of the constraints and bounds, i.e., constraining values. The details and complexity of the model are, however, not fully revealed by the table, since summations

TABLE 2 Schematic GRAM model constraints. GRAM-Gen mnemonics refer to the software implementation explained in Section 5.

GRAM No.	GRAM-Gen mnemonic	Lower limit^a	GRAM variable classes X	Y	Z	U	V	W	O	P	Q	R	S	T	Con. type	Right side	Index subsets
(1)	EL.PR.		U												$=$	L^{pr}	$w = m^b$
(2)	BL.PRA	$L^{min}_{pr\alpha}$	U												$\leqslant$	$L^{max}_{pr\alpha}$	
(3)	BL.PR.	L^{min}_{wpr}	U												$\leqslant$	L^{max}_{wpr}	$w = m^b$
(4)	BLSPRA	$L^{min}_{prs\alpha}$	U												$\leqslant$	$L^{m}_{prs\alpha}$	particular s
(5)	AM.PR.		U												$\leqslant$	L^{m}_{pr}	$w = m^b$
(6)	CIYPR.		$-U$	U^1											$\leqslant$	$\emptyset$	
(7)	LIIPR.		1	1	-1		-1						-1		$=$	$\emptyset$	
(8)	LJMPR.					0		-1	-1					-1	$=$	$\emptyset$	
(9L)	CNNPR.N				$-M$	R			$-N$	$-M$					$\leqslant$	$\emptyset$	according to pr
(9R)	CNNPR.M				M	$-T$			N	M					$\leqslant$	$\emptyset$	according to pr
(10L)	CNNP. .N				$-M$	R			$-N$	$-M$					$\leqslant$	$\emptyset$	according to p
(10R)	CNNP. .M				M	T			N	$-M$					$\leqslant$	$\emptyset$	according to p
(11)	BII. . .	F^{min}_{i}					1				1				$\leqslant$	F^{max}_{i}	
(12)	BJM. . .	F^{min}_{m}						1				1			$\leqslant$	F^{max}_{m}	
(13)	AB.PR.		B	B		G									$\leqslant$	B_{pr}	
(14)	AB. . . .		B	B		G									$\leqslant$	B	
(15)	AD.PR.		D	D		I									$\leqslant$	D_{pr}	
(16)	AD. . . .		D	D		I									$\leqslant$	D	
(17)	AK.PR.		J	J		K									$\leqslant$	$\hat{D}^1_{pr}$	
(18)	AK. . . .		J	J		K									$\leqslant$	$\hat{D}^1$	
(19)	AY.PR.		S	S		Y									$\leqslant$	$\hat{D}^2_{pr}$	
(20)	AY. . . .		S	S		Y									$\leqslant$	D^2	
(21)	AE.PR.		E	E		$-W$									$\leqslant$	E_{pr}	

TABLE 2 *Continued.*

GRAM No.	GRAM-Gen mnemonic	Lower limit[a]	GRAM variable classes												Con. type	Right side	Index subsets
			X	Y	Z	U	V	W	O	P	Q	R	S	T			
(22)	AE. . . .		E	E		$-W$									⩽	E	
(23)	BFF. . .	M_f	A	A		$-F$									⩽	G_f	
(24)	BFFPR.	M_{fpr}	A	A		$-F$									⩽	G_{fpr}	
(25)	KPI. .L									1					⩽	H_{il}	
(26)	KQI. .L										1				⩽	I_{il}	
(27)	KRM. .L											1			⩽	I_{ml}	
(28)	KSI. .L												1		⩽	$\bar{I}_{il}$	
(29)	KTM. .L													1	⩽	$\bar{I}_{ml}$	
(30)	AC.PR.		H	H'		L									⩽	C_{pr}	
(31)	AC. . . .		H	H'		L									⩽	C	
(32)	DW.PR.		$-SX$	$-SU$		$-SU$				$-\$P$	$-\$Q$	$-\$R$	$\$S$	$\$T$	⩾	$W_p B_{pr}$	

[a]Omitted when all zero.
[b]$w = m$ means pasture land.

over various subsets of indices in coefficient tables and in decision variables may occur. It is therefore necessary to present the model explicitly. The following items will be specified: indices used; coefficients (hence coefficient tables); bounds (i.e., constraining values); and decision variables. Also, formulae for constraints and objective functions are presented.

Indices. The indices used in the model are as follows:

i = type of crop, e.g., wheat, sugar beet;
$I = \{i\}$, set of all crop indices;
ω = index of crop rotation group I^{ω}, where $\cup_{\omega} I^{\omega} = I$, $I^{\omega'} \cap I^{\omega''} = \emptyset$, $\omega' \neq \omega''$, e.g., grains or starchy root crops;
j = type of livestock, e.g., milk cows, sows;
k = specialization of livestock production, e.g., meat, dairy products;
m = type of livestock product, e.g., meat, milk;
r = number of subregion corresponding, for example, to an administrative division;
n = feed component for livestock, e.g., nutrition units, dry mass;
l = type of market for purchasing/selling commodities, such as internal state market;
p = type of farm (producer), e.g., private, state-owned;
s = technology of crop raising, e.g., presently used, intensive with sprinkling;
α = land quality, e.g., weak and light, or weak and heavy soils;
s' = breeding technology, related for example to size of herd or stable;
f = type of fertilizer, e.g., containing nitrogen or phosphorus, or mixed artificial, natural;
β_i = second crop, the best or only successor to the first crop i.

Coefficients. The following coefficients are included, forming appropriate tables (the letters in parentheses indicate notations from Table 2):

(A) $a_{fiprs\alpha}$ = demand of fertilizer f to produce unit of crop i on land α in subregion r by producers p with technology s;
(F) $\hat{a}_{fjks'}$ = production of manure fertilizers per unit of livestock raised;
(B) $b_{iprs\alpha}$ = labor requirement in crop production;
(G) $b_{jkprs'}$ = labor requirement in livestock breeding;
(H) $c_{iprs\alpha}$ = capital (investment) demands in crop raising without technology transformation;
(H′) $\bar{c}_{iprs\alpha}$ = as above, with technology transformation;
$c_{jkprs'}$ = capital (investment) demand in livestock breeding without technology transformation;
(L) $\bar{c}_{jkprs'}$ = as above, with technology improvement;
(D) $d_{iprs\alpha}$ = water demand for crop raising (annual total);
(J) $\hat{d}^1_{iprs\alpha}$ = as above, for the first peak period;
(S) $\hat{d}^2_{iprs\alpha}$ = as above, for the second peak period;
(I) $d_{jkprs'}$ = water demand for livestock breeding (annual total);

(K) $\hat{d}^1_{jkprs'}$ = as above, for the first peak period;

(F) $\hat{d}^2_{jkprs'}$ = as above, for the second peak period;

(E) $e_{iprs\alpha}$ = machinery demand for crop production;

(W) e_{jkp} = equivalent pulling power of animals jk in farm p;

(R, T) $f^{\min,\max}_{njk}$ = minimum and maximum demand for feed components for livestock;

(M) g_{in} = contents of feed components in crops;

(N) g_{mn} = contents of feed components in livestock products;

(O) $h_{mjkps'}$ = livestock product yields per unit of livestock bred;

n_i = contents of nutrition units in crops;

n_m = contents of nutrition units in livestock products;

($S) P_{il} = unit price of home-produced crops on market l;

($T) P_{ml} = unit price of home-produced livestock products on market l;

($P) P^{imp}_{il} = unit price of crops purchased for livestock feeding on market l;

($Q) $\bar{P}^{imp}_{il}$ = as above, for human consumption;

($R) P^{imp}_{ml} = unit price of livestock products purchased for human consumption on market l;

($X) $s_{iprs\alpha}$ = cost of crop production with seeds and fertilizers;

($U) $s_{jkprs'}$ = cost of livestock production, without forage;

(U) $u_{iprs\alpha}$ = yield of crops;

(U^1) $u^1_{iprs\alpha}$ = yield of crops raised as secondary crops.

Bounds. The following lower and upper bounds are used:

B = labor force, total in the region;
B_{pr} = as above, for producer types and subregions;
C = maximum external and internal capital (investment) funds available in the region;
C_{pr} = as above, for producer types and subregions;
D = total annual water volume available;
$\hat{D}^1$ = as above, for the first peak period;
$\hat{D}^2$ = as above, for the second peak period;
D_{pr} = annual water volume available, for producer types and subregions;
$\hat{D}^1_{pr}$ = as above, for the first peak period;
$\hat{D}^2_{pr}$ = as above, for the second peak period;
E = total available machinery;
E_{pr} = machines available for producer types and subregions;

$F_i^{\min,\max}$ = minimum and maximum human consumption of crops i;

G_f = maximum available amount of fertilizer f;

G_{fpr} = as above, for producer types and subregions;

H_{il} = maximum crop purchases for livestock feeding from market l;

I_{il} = maximum crop purchases for human consumption from market l;

I_{ml} = maximum purchases of livestock products from market l;

$L_{wpr}^{\min,\max}$ = minimum and maximum area for crop group w (due to crop rotation conditions);

$L_{pr\alpha}^{\min,\max}$ = minimum and maximum area of given soil quality;

$L_{prs\alpha}^{\min,\max}$ = minimum and maximum area of land transformable with technology s;

L_{pr} = area of arable land;

L_{pr} = area of meadows and pastures;

M_{fpr} = environmental bounds on fertilizers and manure;

W_{pr} = minimal income per capita.

Decision variables. The following decision variables are included in the model (the letters in parentheses denote abbreviations used in Table 2):

(X) $X_{iprs\alpha}$ = volume of primary crop i produced by producers p of subregion r, using technology s, on soil α;

(Y) $Y_{iprs\alpha}$ = as above, for secondary crops;

(V) W_{ipr} = own consumption of crop i produced by producers p of subregion r by population connected with producers p in subregion r;

(Z) Z_{ipr} = as above, consumed by own livestock;

(U) $X_{jkpr'}$ = number of livestock j bred in specialization k and technology s', by farms p in subregion r (producer groups pr);

(W) W_{mpr} = own consumption of livestock products produced in a pr by population related to that pr;

(O) Z_{mpr} = as above, for human consumption within pr;

(P) P_{iprl} = purchase of crop i for forage from market l by producers p of subregion r;

(Q) Q_{iprl} = as above, for human consumption within pr;

(R) Q_{mprl} = purchase of livestock product m for human consumption within pr from market l;

(S) R_{iprl} = sale of crop i to market l by producer group pr;

(T) R_{mprl} = as above, sale of livestock product m.

Constraints. The description of constraints is divided into the following groups concerning particular aspects:

1. *Land use*

(a) Availability of arable land:

$$\sum_{\substack{i \in I-I^m \\ s,\alpha}} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} = L_{pr} \tag{1}$$

where $m = \omega$ for meadows and pastures.

(b) Availability of land of a particular quality:

$$L_{pr\alpha}^{\min} \leqslant \sum_{i,s} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant L_{pr\alpha}^{\max} \tag{2}$$

(c) Availability of arable land for crops I^{ω} due to crop rotation:

$$L_{\omega pr}^{\min} \leqslant \sum_{\substack{i \in I^{\omega} \\ s,\alpha}} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant L_{\omega pr}^{\max} \tag{3}$$

(d) Availability of transformable land, i.e., for a particular technology s:

$$L_{prs\alpha}^{\min} \leqslant \sum_{i} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant L_{prs\alpha}^{\max} \tag{4}$$

(e) Availability of meadows and pastures:

$$\sum_{\substack{i \in I^m \\ s,\alpha}} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant L_{pr}^{m} \tag{5}$$

where $m = w$ for meadows and pastures.

(f) Availability of land for secondary crops:

$$\sum_{\substack{i^* \in \beta_i \\ s,\alpha}} \frac{Y_{i^*prs\alpha}}{u^1_{i^*prs\alpha}} - \sum_{s,\alpha} \frac{X_{iprs\alpha}}{u_{iprs\alpha}} \leqslant 0 \tag{6}$$

2. *Crop and livestock product balances*

(a) Crops:

$$\sum_{s,\alpha} (X_{iprs\alpha} + Y_{iprs\alpha}) - W_{ipr} - Z_{ipr} - \sum_{l} R_{iprl} = 0 \tag{7}$$

(b) Livestock products:

$$\sum_{j,k,s'} h_{mjkps'} X_{jkprs'} - W_{mpr} - Z_{mpr} - \sum_l R_{mprl} = 0 \tag{8}$$

3. *Forage balances*

(a) For a particular pr:

$$\sum_{j,k,s'} f_{njk}^{\min} X_{jkprs'} \leqslant \sum_i g_{in} Z_{ipr} + \sum_{i,l} g_{in} P_{iprl} + \sum_m g_{mn} Z_{mpr}$$

$$\leqslant \sum_{j,k,s'} f_{njk}^{\max} X_{jkprs'} \tag{9}$$

(b) For the whole region but possibly also according to p:

$$\sum_{j,k,r,s'} f_{njk}^{\min} X_{jkprs'} \leqslant \sum_{i,r} g_{in} Z_{ipr} + \sum_{i,r,l} g_{in} P_{iprl} + \sum_{m,r} g_{mn} Z_{mpr}$$

$$\leqslant \sum_{j,k,r,s'} f_{njk}^{\max} X_{jkprs'} \tag{10}$$

4. *Limits of agricultural product consumption by local population*

(a) Crops:

$$F_i^{\min} \leqslant \sum_{p,r} W_{ipr} + \sum_{p,r,l} Q_{iprl} \leqslant F_i^{\max} \tag{11}$$

(b) Livestock products:

$$F_m^{\min} \leqslant \sum_{p,r} W_{mpr} + \sum_{p,r,l} Q_{mprl} \leqslant F_m^{\max} \tag{12}$$

5. *Resource constraints*

(a) Labor:

For a particular pr,

$$\sum_{i,s,\alpha} b_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,s'} b_{jkprs'} X_{jkprs'} \leqslant B_{pr} \tag{13}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} b_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} b_{jkprs'} X_{jkprs'} \leqslant B \tag{14}$$

(b) Annual water availability:

For a particular pr,

$$\sum_{i,s,\alpha} d_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,s'} d_{jkprs'}X_{jkprs'} \leqslant D_{pr} \tag{15}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} d_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} d_{jkprs'}X_{jkprs'} \leqslant D \tag{16}$$

(c) Water availability in the first peak period:

For a particular pr,

$$\sum_{i,s,\alpha} \hat{d}^1_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,s'} d^1_{jkprs'}X_{jkprs'} \leqslant \hat{D}^1_{pr} \tag{17}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} \hat{d}^1_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} d^1_{jkprs'} \leqslant \hat{D}^1 \tag{18}$$

(d) Water availability in the second peak period:

For a particular pr,

$$\sum_{i,s,\alpha} \hat{d}^2_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,s'} \hat{d}^2_{jkprs'}X_{jkprs'} \leqslant \hat{D}^2_{pr} \tag{19}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} \hat{d}^2_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} \hat{d}^2_{jkprs'}X_{jkprs'} \leqslant \hat{D}^2 \tag{20}$$

(e) Pulling power:

For a particular pr,

$$\sum_{i,s,\alpha} e_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) - \sum_{j,k,s'} e_{jkp}X_{jkprs'} \leqslant E_{pr} \tag{21}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} e_{iprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) - \sum_{j,k,p,r,s'} e_{jkp}X_{jkprs'} \leqslant E \tag{22}$$

(f) Fertilizers:

For a particular pr,

$$M_{fpr} \leqslant \sum_{i,s,\alpha} a_{fiprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) - \sum_{j,k,s'} \hat{a}_{fjks'} X_{jkprs'} \leqslant G_{fpr} \tag{23}$$

For the whole region,

$$M_f \leqslant \sum_{i,p,r,s,\alpha} a_{fiprs\alpha}(X_{iprs\alpha} + Y_{iprs\alpha}) - \sum_{j,k,p,r,s'} \hat{a}_{fjks'} X_{jkprs'} \leqslant G_f \tag{24}$$

6. *Purchase limits*

(a) Crops for livestock (may not concern all i):

$$\sum_{p,r} P_{iprl} \leqslant H_{il} \tag{25}$$

(b) Crops for human population (will concern a limited number of i):

$$\sum_{p,r} Q_{iprl} \leqslant I_{il} \tag{26}$$

(c) Livestock products for human population:

$$\sum_{p,r} Q_{mprl} \leqslant I_{ml} \tag{27}$$

7. *Sale limits*

(a) Crops (may not concern all i):

$$\sum_{p,r} R_{iprl} \leqslant \bar{I}_{il} \tag{28}$$

(b) Livestock products:

$$\sum_{p,r} R_{mprl} \leqslant \bar{I}_{ml} \tag{29}$$

8. *Financial limits*

(a) Capital investments:

For a particular pr,

$$\sum_{i,s,\alpha} (c_{iprs\alpha} + \bar{c}_{iprs\alpha})(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{j,k,p,r,s'} (c_{jkprs'} + \bar{c}_{jkprs'}) X_{jprs'} \leqslant C \tag{30}$$

For the whole region,

$$\sum_{i,p,r,s,\alpha} (c_{iprs\alpha} + \bar{c}_{iprs\alpha})(X_{iprs\alpha} + Y_{iprs\alpha}) + \sum_{i,j,s'} (c_{jkprs'} + \bar{c}_{jkprs'})X_{jkprs'} \leqslant C_{pr} \tag{31}$$

(b) Minimal income for particular types of farms:

$$\sum_{i,l} P_{il}R_{iprl} + \sum_{m,l} P_{ml}R_{mprl} - \sum_{i,s,\alpha} s_{iprs\alpha}X_{iprs\alpha} - \sum_{j,k,s'} s_{jkprs'}X_{jkprs'} - \sum_{i,l} P_{il}^{\text{imp}}P_{iprl} - \sum_{i,l} \bar{P}_{il}^{\text{imp}}Q_{iprl} - \sum_{m,l} P_{ml}^{\text{imp}}Q_{mprl} \geqslant W_p B_{pr} \tag{32}$$

Objective functions. The objective functions specified below represent some aggregate activity indicators, related either to financial flows or to production volumes.

(a) Total net return or net production value resulting from agricultural activities within the region:

$$\sum_{i,p,r,l} P_{il}R_{iprl} + \sum_{m,p,r,l} P_{ml}R_{mprl} - \sum_{i,p,r,s,\alpha} s_{iprs\alpha}X_{iprs\alpha} - \sum_{j,k,p,r,s'} s_{jkprs'}X_{jkprs'} - \sum_{i,p,r,l} P_{il}^{\text{imp}}P_{iprl} - \sum_{i,p,r,l} \bar{P}_{il}^{\text{imp}}Q_{iprl} - \sum_{m,p,r,l} P_{il}^{\text{imp}}Q_{mprl} \tag{33}$$

(b) Balance of regional agricultural production expressed in monetary terms, i.e., according to unified prices and without costs:

$$\sum_{i,p,r,s,\alpha} P_{il}X_{iprs\alpha} + \sum_{m,j,k,p,r,s'} P_{ml}h_{mjkps'}X_{jkprs'} - \sum_{i,p,r,l} P_{il}^{\text{imp}}P_{iprl} - \sum_{i,p,r,l} \bar{P}_{il}^{\text{imp}}Q_{iprl} - \sum_{m,p,r,l} P_{ml}^{\text{imp}}Q_{mprl} \tag{34}$$

(c) Regional agricultural production expressed in nutrition units:

$$\sum_{i,p,r} n_i \left(\sum_{s,\alpha} X_{iprs\alpha} - \sum_{l} (P_{iprl} + Q_{iprl}) \right) + \sum_{m,p,r} n_m \left(\sum_{j,k,s'} h_{mjkps'}X_{jkprs'} - \sum_{l} Q_{mprl} \right) \tag{35}$$

Objective functions (b) and (c) are applied in cases when there are important deviations from cost structure in the price system and when agricultural commodities are obviously in short supply.

(d) Regional trade balance of livestock products in monetary terms:

$$\sum_{m,p,r,l} P_{il} R_{mprl} - \sum_{m,p,r,l} P_{ml}^{\text{imp}} Q_{mprl} \tag{36}$$

(e) Production of livestock products in nutrition units:

$$\sum_{m,j,p,r,s'} n_m \left(h_{mjkps'} X_{jkprs'} - \sum_l Q_{mprl} \right) \tag{37}$$

(f) Export production in monetary terms:

$$\sum_{\substack{i,p,r\\ l=3}} (P_{il} R_{iprl} - \bar{P}_{il}^{\text{imp}} Q_{iprl} - P_{il}^{\text{imp}} P_{iprl})$$

$$+ \sum_{\substack{m,p,r\\ l=3}} (P_{ml} R_{mprl} - P_{ml}^{\text{imp}} Q_{mprl}) \tag{38}$$

Since for particular purposes it may prove necessary to construct special problem-oriented functions, (33) to (38) should be treated as an initial proposition.

5 IMPLEMENTATION: GRAM-GEN

The purpose of this section is to present briefly the computer implementation of GRAM as it was carried out at IIASA – the generation of the model, basic options of the LP system, etc. The text is far from exhaustive; its aim is merely to show the reader some basic principles, modes of operation, etc.

5.1 Computer and System Environment

The dimensions of GRAM (about 3000 variables, and about 11 000 rows for the application described in the present report), and its density (*ca.* 2%) do not imply a need to use a special LP system and an extremely powerful computer. However, due to the anticipated "tightness" of the model and the need to obtain results in a very short time period, an advanced interactive LP system was considered to be very important.

Such a system, which fulfilled the above requirements and was easily accessible, was the SESAME/DATAMAT LP system designed by William Orchard-Hays (1977). This system is operating in Pisa, Italy, on the CNUCE's IBM Series 370 computer, which is connected with IIASA through a telex line. The computer is an IBM 370/168, working under a system that provides virtual machine and interactive mode of operation. Therefore, any user (usually about 100) logged in would appear to have all the computer facilities (disks, core, output devices, etc., except for tapes) at his disposal. The normal core allocation of IIASA is 500 or 680 kbytes, and this may be extended to 2000 kbytes.

The Pisa installation is connected with IIASA through a leased two-channel telex line. The first channel of 2400 baud transmission speed is intended for data transmission (output printing files), and is controlled by a TPA-70 minicomputer. The second, low-speed channel of 112 baud transmission speed is used for the interactive communication and is connected to a display terminal at IIASA. Some basic information about the software organization will be of use for understanding better the place and operation of SESAME/DATAMAT. The basic operating system is CP (control program), which runs the real computer.

Generally speaking, the CP system enables the user to log into (or off) the installation, enter his password to be verified, send a message to the Pisa operator, display states of the system's facilities, etc. The next higher-level operating system is the CMS, which handles the *virtual* machine. Its basic tasks are to define an appropriate core storage allocation, attach disks to the virtual machine, specify the files to be used, manipulate the files, compile and run programs, carry out text editing (change of characters, deletion or addition of lines, sorting of files, etc.), and so on.

The SESAME mathematical programming system is a program in CMS, and, in turn, DATAMAT is a part of it – or better still, its extension. Since they are both crucial in the generation and running of GRAM, they will thus be described in more detail below. However, we will begin with DATAMAT and then proceed to SESAME.

5.2 DATAMAT and the Generation of GRAM

DATAMAT, an interactive data management system for linear programming applications, is a part of the SESAME LP system. The primary purposes of DATAMAT are as follows: (1) to create and maintain primary data in the form of arrays containing numerical values, symbolic values, or strings; (2) to generate, revise, and manipulate models; (3) to generate reports (including the calculations, arranging the print-outs into appropriate formats); (4) to perform additional calculations with some data; and (5) to inspect and display various quantities. The first three points will be described in more detail.

(1) In the creation and maintenance of primary data, the main possibilities are as follows: (a) construction (masking, extending, filing, etc.) of tables identified by column and/or row; (b) construction of empty tables with proper masking, selection, etc.; (c) input and updating of card-image files; (d) filing tables; (e) listing tables; (f) erasing tables; (g) deleting tables; (h) naming tables; and (i) arithmetical calculation tables.

(2) In generating, revising, and manipulating models, the main possibilities are as follows: (a) access to any coefficient in an existing model for testing or changing; (b) recall of an existing model for revision (the whole model or a submodel can be dealt with; merging of different models is possible); and (c) creation and change of new and/or existing model components.

More specifically, the main creation and change possibilities are as follows: (i) definition of row and column identifiers; (ii) definition of right-hand side identifiers; (iii) definition of range sets; (iv) definition of bound sets; (v) insertion of new columns, rows, right-hand sides, etc.; (vi) creation of linear combinations of two rows, columns, etc.

(3) The main possibilities are as follows: (a) definition of a suitable output format; and (b) definition of headings and footnotes.

DATAMAT is called from SESAME and is controlled by statements typed at the user's terminal. The following types of programmed subroutines may also be used:

(i) *Macros.* These are composed of strings of ordinary DATAMAT statements with the provision of argument substitution, looping, and branching. Macros make it possible to build highly specialized functions of great complexity. They are called by names. The main macros used concern: (a) definition of specified columns; (b) searching for a variable class name; (c) filling specified rows, columns, and tables; and (d) generation of specified parts of the model.

(ii) *DATARUN deck.* Here the whole DATAMAT program is read from a file. To run such a program, the file and deck names are specified. The main decks concern: (a) definition of appropriate set-up (file names, storage, etc.); (b) setting up parameters and files for merging; (c) preparation for solving the model by SESAME; (d) preparation for a modification or revision; and (e) extraction of submodels.

The DATAMAT data base consists of five main components (plus CR – the SESAME communication region):

1. The SESAME model whose name is in the CR file given in SDDMODEL. This model may be revised in DATAMAT and then refiled.
2. One or more SESAME LP result cases whose names are specified within DATAMAT. The result file is never changed by DATAMAT.
3. The SESAME file MAPSFILE, which is only read and only used for limited purposes related to models and results.
4. A table file, which contains the primary data on which DATAMAT operates. Its name is specified within DATAMAT. This file is created and used by DATAMAT only.
5. A working data base (WDB), which is either in the core storage or on scratch file. It disappears upon exit from DATAMAT.

Moreover, DATAMAT can read or write some additional data tables.

We shall now briefly show the use of DATAMAT in the case of generating GRAM. First, a diagram is devised corresponding to Table 2, which shows the general structure of the model in terms of row and column tables, left-hand sides, objective functions, etc. The names here are specific to the model generation program – GRAM-Gen – and correspond to the original GRAM notation given in Section 4, as follows:

1. Sets of indices:

GRAM-Gen	GRAM
I	i
I^{ω}	I^{ω}
J	j
K	k
M	m
R	r
N	n
L	l
P	p
S	s
A	α

GRAM-Gen (*continued*)	GRAM (*continued*)
T	s'
F	f
BETA	β_i

2. Decision variables:

GRAM-Gen	Table 2	GRAM
XI.PRSA	X	$X_{iprs\alpha}$
YY.PRSA	Y	$Y_{iprs\alpha}$
ZI.PR. .	Z	Z_{ipr}
UJKPRT.	U	$X_{jkprs'}$
VI.PR. .	V	W_{ipr}
W.MPR. .	W	W_{mpr}
O.MPR. .	O	Z_{mpr}
PI.PR.L	P	P_{iprl}
QI.PR.L	Q	Q_{iprl}
R.MPR.L	R	R_{mprl}
SI.PR.L	S	R_{iprl}
T.MPR.L	T	R_{mprl}

3. Constraints:

GRAM-Gen	GRAM bounds
EL.PR.	L_{pr}
BL.PRA	$L_{pr\alpha}^{\min,\max}$
BL.PR.	$L_{wpr}^{\min,\max}$
BLSPRA	$L_{prsx}^{\min,\max}$
AM.PR	L_{pr}^{m}
CIYPR.	ϕ
LIIPR.	ϕ
LJMPR.	ϕ
CNNPR.N	ϕ
CNNPR.M	ϕ
CNNP. .N	ϕ
CNNP. .M	ϕ
BII. . .	$F_{i}^{\min,\max}$
BJM. . .	$F_{m}^{\min,\max}$
AB.PR	B_{pr}

GRAM-Gen (*continued*)	GRAM bounds (*continued*)
AB. . . .	B
AD.PR.	D_{pr}
AK.PR.	$\hat{D}^1_{pr}$
AY.PR.	$\hat{D}^2_{pr}$
AD. . . .	D
AK. . . .	$\hat{D}^1$
AY. . . .	$\hat{D}^2$
BFF. . .	M_f, G_f
BFFPR.	M_{fpr}, G_{fpr}
KPI. .L	H_{il}
KQI. .L	I_{il}
KRM. .L	I_{ml}
KSI. .L	$\bar{I}_{il}$
KTM. .L	$\bar{I}_{ml}$
AC.PR.	C_{pr}
AC. . . .	C
DW.PR.	$W_p B_{pr}$

Other corresponding tables of coefficients, lower and upper bounds, etc., may be found in Orchard-Hays (1979). An example of the DATAMAT generation program is shown in Appendix A.

As can be seen from this condensed description of DATAMAT, it is a really powerful system and its availability has contributed to some extent to the short time devoted to numerical implementation.

5.3 SESAME LP System and its Potential

SESAME is an interactive system for solving large linear programming problems. The system is highly sophisticated, but in the description below, only those issues of interest to readers are mentioned, namely: (1) SESAME command language; (2) SESAME procedures; (3) SIMPLEX algorithm and parametric solutions; (4) solution print-outs.

(1) The SESAME command language is a simple language to control the run of the system. The main command groups concern: (a) entitling the outputs; (b) determination of proper output form and contents; (c) display of specified cell(s); (d) starting, finishing, etc., the run; and (e) reporting and correction of errors.

(2) The main SESAME procedures concern: (a) on-line browsing through the model; (b) specification of values of symbolic coefficients for studying nonlinearities or sensitivity; (c) static sensitivity; (d) file maintenance; (e) model input and output; (f) model set-up; (g) solution (primal and dual simplex algorithm, basis reinversion); (h) parametric simplex algorithms; (i) LP solution and tableau generation; and (j) LP basis and map manipulation.

Most of the above procedures are interactive for greater flexibility and convenience.

(3) The main simplex algorithms are evidently the most crucial part of SESAME. The system provides both primal and dual solutions. Moreover, the following parametric solution options are available: (a) parametrization of right-hand sides with a specified base column, change column parameter; (b) parametrization of objective function with a specified change row and parameter; (c) both (a) and (b); (d) parametrization of a specified structural column with a specified change column and parameter; (e) parametrization of a specified structural row, with a specified change row and parameter.

The above parametrization facilities are very powerful.

(4) The following basic selection options for the solution print-outs are available: (a) full solution; (b) solely basic variables; (c) solely nonbasic variables; (d) no listing; (e) infeasibilities. These differ considerably in volume, and hence should be chosen carefully.

The purpose of this short description of SESAME has been to give some insight into its potential. As can be seen, the system has great capacity and flexibility, and – extended with DATAMAT – it is a valid procedure to facilitate effective, efficient implementation of large and complicated linear programs, as was the case with GRAM.

6 APPLICATION: THE UPPER NOTEC REGIONAL AGRICULTURAL POLICY ANALYSIS AND DESIGN

The model, whose general form and software implementation were described above, was first applied to the agriculture of the Upper Notec watershed region in central-northwestern Poland. In fact, the work on this application has had an essential influence on the final outlook of both the general model (Albegov *et al.* 1980) as presented in Section 4, and its software implementation (Section 5).

Before describing the model version for the Upper Notec region and the results obtained therewith, a brief outline of the first object of the application will be given.

6.1 The Upper Notec Watershed Region and its Agriculture

The region in question (see Figure 3) is located somewhat to the northwest of the center of Poland, and encompasses the watershed of the upper part of the Notec River, i.e., down to its confluence with the old Bydgoszcz Channel (Figure 4). The Notec River belongs to the Odra watershed system, although it runs relatively close to the Vistula River. The Bydgoszcz Channel, linking the middle of Notec with the Vistula, therefore links the two main river systems of Poland, those of the Odra and the Vistula (Wisla).

The Upper Notec watershed region coincides largely with the historically important region of Kujawy (Cuiavia) and contains the smaller traditional area of Pakuly. Owing to the long tradition of social organization and cultivation of crops in this area, a number of characteristics have evolved which distinguish it from others in Poland. For example, the forest cover is significantly lighter than elsewhere in the country, the quality of agricultural expertise of farmers is higher than average, and the region has a long tradition of dealing with water economy in agriculture. As early as the beginning of the eighteenth century important drainage works were carried out.

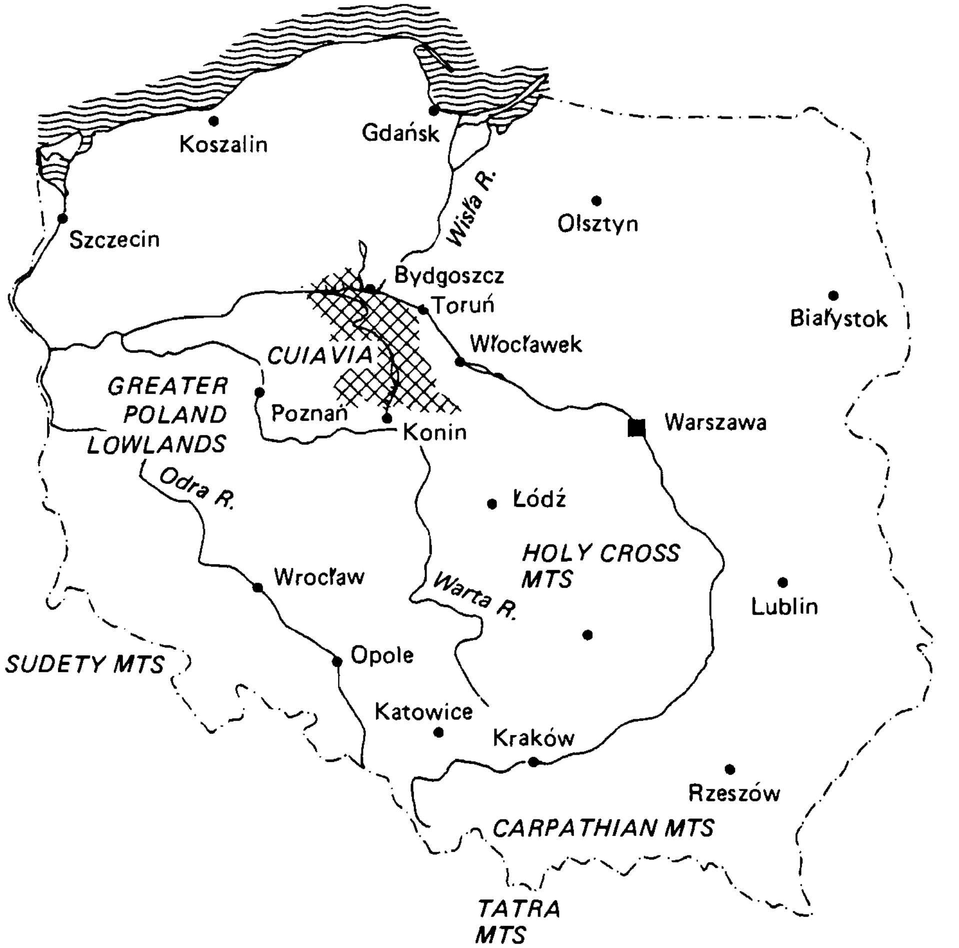

FIGURE 3 Location of the Upper Notec watershed region (the area is denoted by cross-hatching) in Poland. The watershed overlaps the Cuiavia region. From Albegov and Kulikowski (1978a).

In connection with the above characteristics, but also related to more general climatic changes, there has for several decades been a growing awareness that the region has been becoming drier, or more steppe-like (Kostrowicki 1978). Because of the relatively high quality of soils in the area, the experience of farmers, and a large proportion of cultivable land, the regional agriculture has a high productive potential.

The realization of this potential has to a large degree been hindered by the need to economize water resources, however. The region contains a large number of natural water bodies such as post-glacial ribbon lakes. There are also some areas where humidity is too high, but because of the generally low level of precipitation (as low as about 450 mm per annum in Pakosc, in the center of the region), there is an essential water deficit for most of the potential crops.

The Upper Notec watershed region was therefore included as the site for a prototype water and agriculture system in the Polish government's research and development program

FIGURE 4 The Upper Notec watershed region. From Albegov and Kulikowski (1978a): –·–·–· watershed region boundary; – – – – voivodship boundaries; —— artificial waterways.

for water resources (Somorowski 1978). The work aimed to design and implement a prototype system, including studies of the water resource system in the area, as well as of its agriculture and its needs. This work was complemented by a modeling project (see Gutenbaum *et al.* 1980) comprising models of water system expansion, of agriculture, and of general resource distribution. Since industry is not greatly developed within the Upper Notec region and the demographic situation is fairly stable, it was not deemed necessary to proceed with these models in the first stage of the work.

Precise delineation of the Upper Notec region for the purposes of systems analysis and design followed the existing administrative boundaries. Thus, the region as the object of the study encompassed 32 of the lowest administrative divisions (*gminas*) and was therefore not identical to the hydrographic watershed region, but the differences were not vital. These 32 gminas constituting the Upper Notec region belong to three higher administrative divisions (*voivodships*), although they do not make up the major portion of these three voivodships (see Figure 5). Such a situation certainly posed difficult

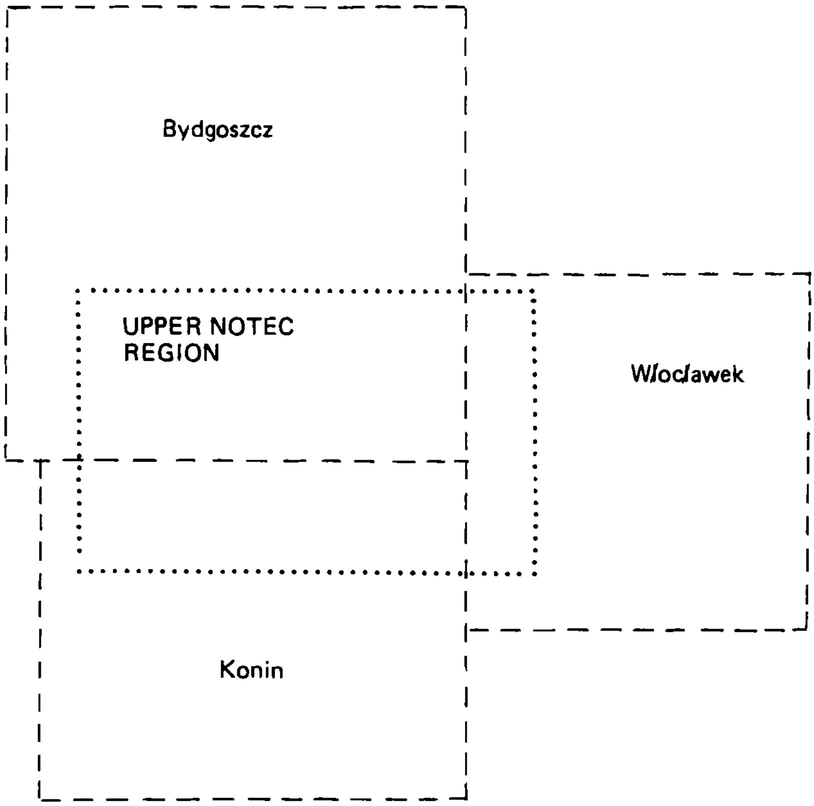

FIGURE 5 Relation of the Upper Notec delimitation to the boundaries of the voivodships involved: – – – – , voivodships; . . . . . . , Upper Notec watershed region.

decision-making problems, which were additionally aggravated by the organization of agricultural activities.

Three forms of land ownership coexist in Poland, particularly in the Upper Notec region: large state farms, usually covering several thousand hectares each, accounting for about 15% of the agricultural land; somewhat smaller cooperative farms, accounting for about 5% of the agricultural land area; and small private farms, averaging 5–7 ha, which together account for about 75% of the land area. Thus, decision-making in agriculture occurs within a very intricate set-up, whose structure is schematically shown in Figure 6.

Even if the models proposed for such agricultural systems cannot take into account all aspects of the decision-making organization, they should at least show differences between the three types of agricultural economy, so that decisions can be made after consideration of all of these differences.

The main goal is to obtain from the region the optimal production of the most essential agricultural goods with the most efficient utilization of available resources, while simultaneously ensuring adequate incomes for producers. Such a formulation does not, of course, preclude a specific form of the objective function; it defines, however, the

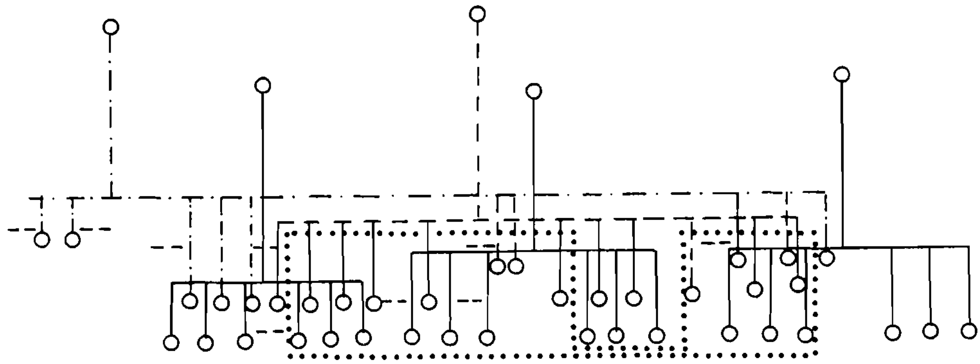

FIGURE 6 Illustration of the overlapping of some of the various managerial levels pertaining to the region. o—o, administrative; o– – – –o, state farm board and individual state farms; o–·–·–, water system cooperatives' management and cooperatives; . . . . , boundary of the regional system.

perspective form in which the various results obtained, using various objective functions, should be viewed.

As far as specific farming activities were concerned, fruits and vegetables were deemed to be marginal for the regional agriculture. The three land-ownership types, the feasibility of irrigation, the variety of soil types, and the different purchase and sale markets were seen as the most important aspects of the regional agricultural economy. The potential limitations of some of the resources (labor force, capital, but also fertilizers) necessitated a precise analysis of the impact of these resources on agricultural production.

6.2 Specification of the Model for the Upper Notec Region

The particular form of the general model that was applied to the Upper Notec region will now be described in terms of concrete sets of items – mainly indices – appearing in the model, and the concrete formulation of constraints therein.

Indices

$i \in I = \{1, \ldots, 13\}$: crops:

$i = 1$, wheat
2, rye
3, barley
4, oats
5, other grains
6, sugar beets
7, potatoes
8, maize
9, forage root crops
10, beans, etc.
11, clover, lucerne, etc.
12, industrial crops for oil and fiber
13, meadows and pastures (grasslands)

$\omega : \{\omega\} = \{1, \ldots, 6\}$: crop rotation groups:

$I^1 = \{i \mid i = 1, 2, 5\}$
$I^2 = \{i \mid i = 3, 4, 12\}$
$I^3 = \{i \mid i = 7, 8\}$
$I^4 = \{i \mid i = 6, 11\}$
$I^5 = \{i \mid i = 9, 10\}$
$I^6 = \{i \mid i = 13\}$

$j : \{j\} = \{1, \ldots, 7\}$: animal type:

$j = 1$, milk cows
2, other cattle
3, sows
4, other pigs
5, horses
6, sheep
7, poultry (X 100)

k : livestock breeding specialization (undifferentiated), i.e., there is only one k for each j; say, $k = 1$

$m : \{m\} = \{1, \ldots, 5\}$: type of livestock product:

$m = 1$, meat
2, leather
3, milk
4, eggs
5, wool

$r : \{r\} = \{1, 2, 3\}$: subregions, In the version implemented as of January 1980, there are three subregions corresponding to portions of voivodships belonging to the Upper Notec region (see Figure 5):

$r = 1$, Bydgoszcz voivodship
2, Włocławek voivodship
3, Konin voivodship

$n : \{n\} = \{1, \ldots, 11\}$: feed components in forage:

$n = 1$, grain units
2, proteins
3, dry mass
4, volume
5, fodder
6, preserved
7, straw and other rests
8, starchy root crops, other than potatoes
9, potatoes
10, other crop components
11, milk

l : $\{l\} = \{1, 2, 3\}$: type of market:

$l = 1$, internal state market (prices totally controlled by the state, the products are usually ordered from producers prior to the season)

2, internal private market

3, world (export/import) market

p : $\{p\} = \{1, 2, 3\}$: type of farm (according to land ownership):

$p = 1$, state-owned farms

2, cooperative farms

3, private farms

s : $\{s\} = \{1, 2, 3\}$: technology of crop raising:

$s = 1$, present, good

2, intensified – more fertilizers, machines, etc.

3, as above, with irrigation

α : $\{\alpha\} = \{1, 2, 3, 4\}$: soil quality:

$\alpha = 1$, weak (light)

2, medium light

3, medium heavy

4, good

s' : technology of livestock breeding (undifferentiated), i.e., there is one livestock breeding technology, $s' = 1$

f : $\{f\} = \{1, 2, 3, 4\}$: type of fertilizer, according to element contents:

$f = 1$, nitrogen

2, phosphorus

3, potassium

4, calcium

β_i : index of crop which may follow the ith one in the same year

$\beta_1 = 11$

$\beta_2 = 11$

$\beta_3 = 2$

$\beta_4 = 2$

$\beta_5 = 11$

$\beta_6 =$ none

$\beta_7 =$ none

$\beta_8 = 5$

$\beta_9 \div \beta_{13} =$ none

The tables of coefficients and the left- and right-hand sides of constraints were formed in accordance with the above specification of items. However, since several of these tables were too large and too detailed to be formed directly on the basis of existing agrotechnical or agroeconomic data (see, for example, $\{a_{fiprs\alpha}\} = A$, containing in this case 5616 coefficients), they were formed indirectly. First, smaller tables of existing initial data were formed and then, based on them, the tables as appearing in the model were set up. Thus, in order to produce a tape containing all model-ready data, another tape containing initial data and the program of data preparation was needed. The data preparation program was carried out, as well as multiplication of elements in the initial tables, and aggregation over geographical space. This was necessary insofar as all data specified geographically were determined for the 32 lowest administrative units, gminas. This breakdown of data made it possible to proceed with further division of geographical space as represented in the model into more than the three voivodship-related areas.

Hence, for instance, the creation of Table A proceeded according to the formula:

$$a_{fiprs\alpha} = a^1_{fi\alpha} a^2_{fs} \frac{1}{\bar{\bar{R}}(r)} \sum_{r' \in R(r)} a^3_{fpr'}$$

where r' are indices of gminas, $R(r)$ are sets of indices of gminas belonging to subregions r, and $\bar{\bar{R}}(r)$ are numbers of gminas in the respective subregions. In this way a crude estimation, but the only one available, is obtained. Utilizing such approaches for setting up the coefficient matrices one should be aware of the risk of degeneracy (i.e., linear dependence), and provide a fair check against it.

In relation to the description of constraints and objective functions, the following remarks should be made here:

superscript $\omega = m$ used for grasslands now takes the value 6;
inequalities (3) hold for $\omega = 1, \ldots, 5$;
inequalities (4) hold for $s = 3$;
inequalities (9) hold for all r, $p = 2, 3$;
inequalities (21) hold for all r, $p = 2, 3$;
inequalities (32) hold for all r, $p = 2, 3$;

otherwise, constraints are in force for all appropriate indices.

Three types of data can in general be distinguished:

(1) constants that are valid over much greater areas than just the particular region (e.g., livestock feed requirements, nutrient and water requirements of plants, prices, minimum income levels);

(2) constants that are valid for the given region only (e.g., crop yields, soil nutrient content, precipitation, population);

(3) magnitudes that are subject to policy decisions (e.g., investment projects, supplies, some prices).

The data of the first type were taken directly from national statistics, agrotechnical tables, etc. The second and largest group of data was obtained from studies made by local design organizations involved in the development project work, and farm records gathered by the Institute of Agricultural Economics in Warsaw. In fact, although these data were not exactly fitted to the model structure outlined, as already mentioned, they turned out to be quite reliable, even after the expansion described above. For example, for crop yield values, a three-year comparative basis was used since it was considered to be more important to preserve inter-coefficient magnitude relations than to try to obtain precise absolute values, which are anyway subject to stochastic fluctuations. As to the third group of data the model's functioning started with the actual values, taken from the official statistical sources. In subsequent runs these values were changed according to needs.

The LP model thus implemented was quite large, comprising approximately 3500 decision variables (columns) and 1100 constraints (rows). The number of elementary nonzero datum items specified for purposes of this implementation was about 55 000.

The final version of the model for the Upper Notec region was run approximately 40 times, for various objective functions and resource limits, as well as for some minor modifications to the coefficients. This number of runs enabled the characteristic features of this particular implementation case, and also to some extent the model itself, to be assessed.

It has proven possible to perform quite a large number of test runs because once an initial optimal solution was obtained starting from scratch, the subsequent solutions could be obtained in no more than 3–4% of the time needed to obtain the initial one, and quite often as little as 1%. This applied equally to constraint parametrization and to changes in the objective functions. Although these statements only pertain to this particular implementation it can safely be assumed that there would be no major differences in other cases, provided the data and model structures were retained and no degeneracy was introduced. The initial optimal solution was usually obtained in 10 000 iterations (major + minor). Approximately the same time was required to generate the model, i.e., to set up the coefficient matrix, variables, right-hand sides, and objective functions.

An example of the SHORT-LIST print-out of a solution is given in Appendix B, together with clarifying comments.

6.3 Results

With regard to the model itself, its application to the Upper Notec watershed region was simply a test of adequacy with respect to the prerequisites presented at the beginning of this report: generality, communication capacities, and representation. Thus, presentation and analysis of the results are not the main purpose of this report. The results will be shown and commented on in relation to the main prerequisites of the model construction.

Some essential features. An example of the results for an optimal point is summarized in Table 3 to give an idea of the production structures and specialization patterns obtained. Such aggregate data are the most important for regional agricultural development planning. It is therefore essential to look at the changes these structures undergo with shifts in availability of resources and for different objective functions. Thus, for instance, a number of runs were performed for various labor and capital availabilities with the net return/net production objective function thus yielding a global quasi-production function* for optimal conditions whose approximate shape is shown in Figure 7. Such analyses were aimed at determining the essential properties of the regional agricultural system, related to resource utilization, efficiency, specialization, bottlenecks, production capacities, etc.

*To obtain the actual production function, the model should be used as a simulation device, i.e., real objectives existing within the system should be identified and applied (see the next section).

TABLE 3 Aggregate illustration of a solution.

(a) Arable land in the region (ha).

	Subregions		
Producer types	1. Bydgoszcz	2. Włocławek	3. Konin
1. State	59654	3173	4133
2. Cooperative	9630	278	1093
3. Private	147240	38016	40961

(b) Crop production and specialization.

Crop	Volume (tonnes)	Producer types	Subregions	Soils	Technologies
1. Wheat	95000	1	1, (2, 3)	1, (2, 3)	1
2. Rye	115000	2, 3	1, 2, 3	1, (2, 3)	1
3. Barley	72000	2, (3)	1, (3)	2, (3, 4)	1
4. Oats	35000	1, 3	1, 3	1, (2)	1
5. Other grains	38000	1	1	1	1
6. Sugar beet	710000	1, 2, 3	1, 2, 3	4	3
7. Potatoes	725000	1, 2, 3	1, 2, 3	1, 2, 4	1, 2
8. Maize (grain)	35000	(1, 2), 3	1, 2, 3	3, 4	1
9. Forage root crops	140000	2, 3	1, (2), 3	3, 4	1
10. Beans, etc.	45000	2, 3	1, (2, 3)	1, 2	1
11. Clover, etc.	150000	1	1, (3)	1	1
12. Flax, etc.	65000	2, 3	1, 2, 3	2, 3, 4	1
13. Grassland	230000	1, 2, 3	1, 2, 3	4	2, 3

(c) Livestock production and specialization.

Livestock	Number	Producer types	Subregions
Milk cows	140000	(1, 2), 3	1, (2, 3)
Other cattle	360000	(1, 2), 3	1, (2, 3)
Pigs	630000	2, 3	1, 2, 3
Horses[a]	38000	3	1, 2
Sheep	22000	3	1, 3
Poultry	4300000	1, 2, 3	1, 2, 3

(d) Uses of crops produced.

Product	Total volume	For forage	For human consumption	Sales	Purchases[b]
1. Wheat	95000	0	45000	50000	0
2. Rye	115000	500	45000	70000	0
3. Barley	72000	20000	12000	40000	0
...					
6. Sugar beet	710000	215000[c]	75000[d]	420000	0
7. Potatoes	725000	75000	100000	550000	0
...					

[a]Still in use as pulling power.
[b]This particular solution was obtained for constraining conditions forcing maximum self-sufficiency.
[c]In terms of rests.
[d]In terms of sugar.

Although the model was run for various objective functions, as will be shown and discussed later on, the main bulk of the analyses was performed for the net return/net production objective illustrated in Figure 7 for capital and labor.

This objective was deemed to enforce the clearest picture of efficiencies, specializations, and resource requirements in the solutions obtained therewith. The optimal characteristics shown in Figure 7 can be communicated to higher-level resource distribution models. From the numerous results, the invariant features were extracted, and these can be summarized together with their causes as follows.

(i) There is a low tendency towards innovation connected with capital investment (technologies 2 and 3 do not exceed 10–15% of total area); i.e., for many runs the capital available was unused, because of the price and repayment structure, which favors industrial goods rather than agricultural products.

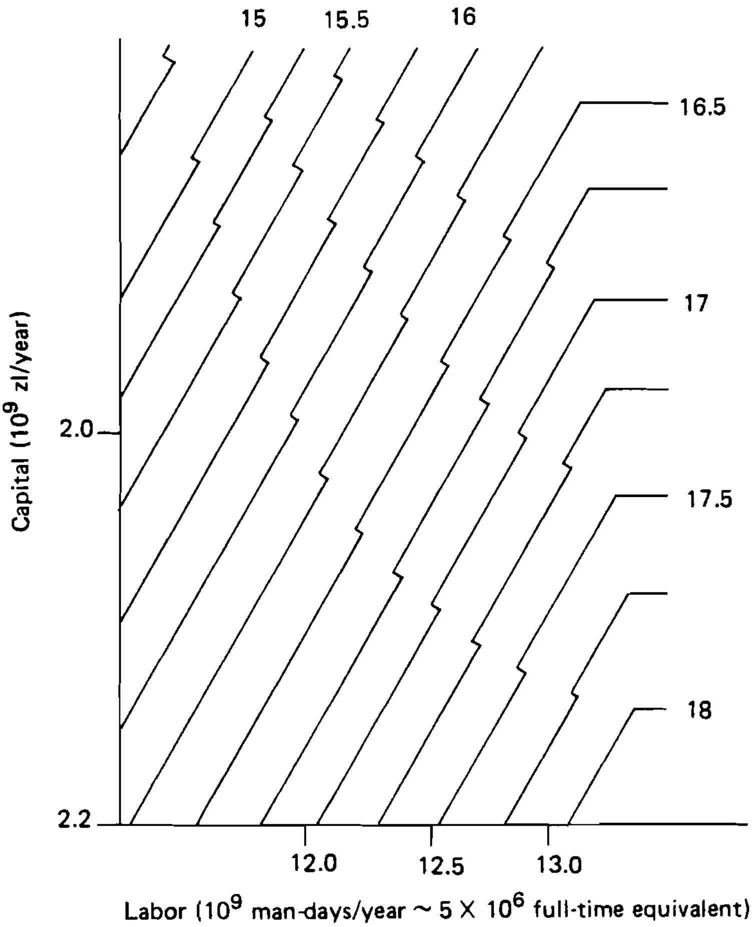

FIGURE 7 Efficiency function for Notec agriculture. Isolines indicate net production value levels in billion zloty/year. Capital is expressed in annual repayments at 3% interest.

(ii) There is a clear specialization among producer types, e.g., state farms grow much more wheat than cooperatives or private farms, mainly because of much higher yields, while private farms specialize, for example, in sugar beet, in the cultivation of which they show higher efficiency, as well as easily providing adequate labor for that crop.

(iii) Inter-subregional specialization is not distinctly pronounced, primarily because the soil and climatic conditions are virtually the same in all subregions; any specialization results mainly from differences in cultivation traditions and various distributions of the three producer types in these subregions.

(iv) There is a fairly high level of intra-regional exchange of commodities, which is not in opposition to the previous statement, since the exchange occurs mainly between and among the producer types (possible exchanges within the producer types not being made explicit in the model), and transfers over subregional "borders" occur mainly when there are imbalances in the production capacities of ownership types in particular subregions.

(v) The region is an important net exporter with only some livestock products being imported. This indicates the large productive capacity of the region when compared with the needs of its small population, the main cause of animal product imports being, again, the price structure.

(vi) There is very little poultry production, which is a direct consequence of the previous result insofar as this phenomenon is also caused by the price structure, this time mainly with regard to preprocessed food for poultry.

(vii) Irrigation is almost entirely limited to sugar beet and grassland, which offer the highest monetary yield value increases in response to irrigation, as measured through overall output, including livestock production, with relaxation of financial constraints, although other crops do enter the irrigated technology.

(viii) An advanced technology with irrigation ($s = 3$) is preferred to advanced technology without irrigation ($s = 2$), when credit repayment conditions only allow for that, technology 3 being much more capital-intensive. This indicates that there is a real water need in the region.

The above results were found to be in general in agreement with the expectations of agricultural planners and decision-makers in the region, although a number of particular phenomena were quite different in their scope and influence than was anticipated. The primary merit was the formulation of a consistent overall picture. The results and their causes pointed out the necessity for modifications in regional agricultural policy.

In the analyses performed, resource limits other than labor and capital were also examined for their influence on the objective function values and on structures. This was done for water resources, and it was shown, in accordance with the conclusion previously formulated, that additional water was necessary for agricultural development in the region. The dimensions of the water system expansion project would have to be carefully assessed, however, since, according to GRAM, the additional water volumes needed varied from approximately 40×10^6 m^3 yr^{-1} for the net production objective to 200×10^6 m^3 yr^{-1} for the maximum output objective.

Another constraint analyzed was the sales and warehouse infrastructure insofar as it is expressed in the inequalities on maximum sales. It turned out that by raising these limits by 30–50% with regard to the actual ones, depending on the commodity, a 50–70% increase in the net production objective was obtained! For the influence of this factor on some features of the optimal solutions see Table 4.

Stability of optimal structures. When performing analyses leading to conclusions on some important features of the system optimized, attention should be paid to the changeability of the optimal production structures obtained. While the optimal characteristic function of Figure 7 is relatively smooth and its shape ensures the expected concavity properties, one is obliged to look at the production structures that correspond to points

TABLE 4 (a) Shares of various technologies in production of individual crops for various solutions (%).

		Objective functions (%)			
		Net production value		Gross production value	
Crop	Technology s	Solution no. 1	Solution no. 2	Solution no. 1	Solution no. 2
Wheat	1	100	100	78	99.3
	2	0	0	4	0
	3	0	0	18	0.7
Rye	1	100	100	41	100
	2	0	0	4	0
	3	0	0	55	0
Potatoes	1	99.7	99.8	99	98
	2	0.3	0.2	1	2
	3	0	0	0	0
Sugar beet	1	0	45	0	56
	2	0	0	0	0
	3	100	55	100	44
Grassland	1	0	0	0	35
	2	0	14	0	51
	3	100	86	100	14
(b) Amount of water needed in optimal solutions ($m^3 yr^{-1}$).		26×10^6	23×10^6	123×10^6	32×10^6

Solution no. 1: Sales-limitations-related storage and transportation capacities increased by 30–50%.
Solution no. 2: Present sales capacities.

on this surface. In general, the smooth changes in the objective function may be accompanied by numerous and essential switches in the structure. Such behavior is often regarded as unstable, and is a cause for indicating inadequate conditioning of the coefficient matrix (see Gutenbaum *et al.* 1980). Arguments can be raised against such inferences, since this "instability" may well reflect the actual state of the technical and economic agricultural system. Suspicions can only be justified when there are returns to the vicinity of previous structures over a straight-line path in the optimal characteristic surface. Aggregate results referring to structure and specialization are shown for three important points in Table 5. As can be seen there are no dramatic differences, which is also true for other points

TABLE 5 Characterization of crop production structures and specializations for three points of the labor and capital optimal characteristic function.

Subregion	Producer type	Technologies 1	2 (Areas/soils)	3	Volume of crops (10^6 tonnes) Wheat	Rye	Sugar beet (volume/technologies/soils)	Potatoes	Clover	Grassland
Point 1. Labor: 12.5 × 10^6 man-days/year; Capital: 1800 × 10^6 zl/year at 3% interest/year. Value of net production: 15 503 × 10^6 zl/year.										
B	1	57925/all	2419/4	665/4	94/1/1,2,3	0	0	0	18/3/4	16.5/1/2
	2	9668/all	404/4	199/4	0	6.1/1/1,2,3	14.1/3/4	19.4/1/2	0	14.7/1,2/2,4
	3	140604/all	1031/2	13096/4	0	53.6/1/2,3	935/3/4	501/1/2	225/1/4	161/1,2/2,4
W	1	2543/all	830/2,3,4	0	5.3/1/1,2,3	1/2/4	0	0	13.3/1,2,3/1,4	4.2/1,2/2,3
	2	273/all	0	8/1,4	0.1/1/3	0.4/1,2,3/1,4	0.2/3/4	3.3/1/1,3,4	0.1/2/4	0.2/3/1,4
	3	38344/all	880/2,4	462/4	16/1/4	0	41/3/4	153/1/2	0	53.4/1,2/2,4
K	1	4049/all	112/4	7/4	7.3/1/2,3	0.5/3/4	0.5/3/4	0	12/3/4	0.5/1/2
	2	1078/all	76/2,3	31/4	0	2/1,3/1,3,4	2.2/3/4	6.8/1/2,4	1/3/4	2.3/2/2,3
	3	40791/all	1369/2	564/4	0	33.3/1/1,2,3,4	49/3/4	98/1/2	0	54/1,2/2,4
Point 2. Labor: 11.25 × 10^6 man-days/year; capital: as before. Value of net production: 14 356 × 10^6 zl/year.										
B	1	54364/all	0	5228/4	110/1/1,2,3,4	0	0	0	0	0
	2	9668/all	437/4	143/4	0	5.1/1/1,2	10.2/3/4	0	0	14.8/1,2/2,4
	3	140680/all	1238/2	13020/4	0	100/1/1,2,3	928/3/4	226/1/2	269/3/4	167/1,2/2,4
W	1	2380/all	382/4	79/4	5.4/1/1,2,3	0	0	0	5.8/3/4	7.8/2/1,2,3
	2	276/all	0	8/1,4	0.1/1/3	0.1/1/1	0.2/3/4	0.7/1/2	0	0.2/3/1,4
	3	38345/all	710/2,4	524/4	0	0	47/3/4	153/1/2	0	48.3/1,2/2,4
K	1	4038/all	275/2,4	112/4	73/1/2,3	0	0	0	0	6.3/1,2/2
	2	1099/all	84/2,3,4	0	0	0.3/1/1	0	6.2/1/2	0	2.4/2/2,3,4
	3	40774/all	1303/2	581/4	0	29/1/1,2,3	50/3/4	99/1/2	0	51.8/1,2/2,4
Point 3. Labor: 13.4 × 10^6 man-days/year; capital: 2200 × 10^6 zl/year at 3% interest/year. Value of net production: 17 825 × 10^6 zl/year.										
B	1	54362/all	0	7497/4	98.5/1/2,3,4	7.8/1/1	38.3/3/4	0	20.4/1,3/4	74.1/3/4
	2	9522/all	475/4	175/4	0	7/1/1,2	12.4/3/4	38.8/1/2	0	14.2/1,2/4
	3	141912/all	0	11789/4	11/1/4	45/1/3,4	790/3/4	678.5/1/2	223.7/1/4	164.6/1,3/4
W	1	2931/all	4/3	548/1,2,4	5.9/1/all	4.1/3/4	18.1/3/4	0	8.7/1,3/4	12.5/all/1,2,4
	2	187/all	76/4	20/4	0	0	0.9/3/4	2.9/1,2/1,2,4	0	0.2/3/4
	3	37946/all	0	790/4	0	0	182/1,3/2,3,4	85.5/1/2	0	44/3/4
K	1	4020/all	18/4	422/1,2,4	7.3/1/2,3	4.7/1/4	8/3/4	0	11.7/1,3/4	11.1/2,3/1,2,4
	2	1039/all	34/2,3	118/1,2,4	0	1.1/3/4	1.6/3/4	11.8/1/1,2	0	2/all/1,2
	3	39716/all	0	2209/1,4	0	28.4/1/1,2	47.8/3/4	90.6/1/2	0	49.6/1/4

obtained, and there is therefore no need to admit that there could be more important structural changes over shorter segments in the surface. In order to account for the varying importance of structural differences across various indices, a measure of "structure distance" could be introduced, here formulated for crops:

$$D(X^t, X^u) = \frac{1}{Ind} \sum_{i \in I_1} \gamma_1 \sum_{i \in I_2} \gamma_2 \cdots \sum_{i \in I_W} \gamma_W \sum_p \gamma_P \sum_r \gamma_r \sum_s \gamma_s \sum_\alpha \gamma_\alpha$$

$$\times \frac{|X^t_{iprs\alpha} + Y^t_{iprs\alpha} - X^u_{iprs\alpha} - Y^u_{iprs\alpha}|}{X^t_{iprs\alpha} + Y^t_{iprs\alpha} + X^u_{iprs\alpha} + Y^u_{iprs\alpha}}$$

where γ's are weighting coefficients, $\gamma \in [0, 1]$, showing the relative importance of differences attached to various index categories (for example, γ_α would obviously be much less than γ_p or γ_r); $I_1, \ldots, I_W$ are subsets of I accounting for equal γ's. $I = I_1 \cup I_2 \cup \ldots \cup I_W$, $I_v \cap I_w = \emptyset$ and t, u are indices of two different solutions for some resource availability. *Ind* is the product of the numbers of items in each of the index sets involved, in this case 8640. As can easily be seen, for all $\gamma = 1$, and no coincidences in the structures, there is $D(X^t, X^u) = 1$, or 100%. Differences between neighboring points in the case considered did not exceed 2–3%, and between the extreme points (90% and 110% of the assumed resource availability) it merely approached 10%. In order to relate $D(X^t, X^u)$ to corresponding changes in the resource availability and/or objective function value, one should apply certain common measures, but such an approach was not attempted here.

Thus, certain relatively invariant features of structures corresponding to the net return/net production objective could be justly formulated.

Multi-criteria analysis. Table 6 presents the action introduced by application of different objective functions. A major shift can be observed where the net production objective is replaced by global, physical or monetary, output indices. This applies especially to investment and innovation issues. In the production of individual commodities, important differences also occur between the global output indices. These results again indicate the necessity of precise specification of the development goals and their structure, as mentioned in Section 3.4.

The question of differing interests within the system is illustrated in the lower portion of Table 6. When an overall objective is optimized, the efficiency aspect prevails and the initial inter-subregional differences tend to sharpen. The question of internal objectives applies not only to subregions but, equally, to producer types. An illustration of different situations of such producer types is given in Table 7. Because of such pronounced differences, the technique proposed by Seo and Sakawa (1979) was applied. The first step in this technique, i.e., decomposition of the overall model into submodels *pr*, corresponding to producer (land ownership) type *p* and subregion *r*, was executed and some of the results, showing differences in resource utilization, are given in Table 8. These differences are due to specific conditions of this subsystem (*pr* = 11), as well as to isolation of this subsystem within the whole system, and therefore the impossibility of internal commodity/financial exchange.

TABLE 6 Some results for various objective functions.

Subject	Specification	Objective function: Profit/net production	Production value	Physical output	Livestock product output
Areas under technologies (%)	Present	96	52	50.9	49.3
	Fertilized	0.1	6.7	7.2	9.4
	Irrigated	3.9	41.4	41.9	41.3
Crop production (10^6 kg)	Grain	347	332	378	377
	Starchy + clover	300	337	332	303
	Grassland	233	350	453	453
	Sugar beet	712	809	814	830
Livestock (10^3 head)	Milk cows	138	211	242	242
	Other cattle	356	451	450	445
	Pigs and sows	642	1018	1002	1043
	Poultry (× 100)	43	9	53	34
Income per capita in subregions (zl/month)	I Bydgoszcz	6484	5583	5732	5731
	II Włocławek	4387	3106	3105	3004
	III Konin	1500[a]	1500[a]	1500[a]	1500[a]

[a]1500 zl/month was the minimal income bound for these runs.

TABLE 7 Average land shadow prices for various producer groups.

Subregion	Producer types: Private farms	Cooperatives	State farms
I	58	114	127
II	83	194	112
III	42	80	∅

TABLE 8 Use of resources in the solution of the whole regional system and for an isolated producer group subsystem ($pr = 11$).

Resource	Total GRAM: Use (%)	Total GRAM: Dual price (zl)	GRAM submodel: Use (%)	GRAM submodel: Dual price (zl)
Arable land	100	319	100	7750
Labor force	88	0	100	1665
Water, total[a]	12	0	25	0
Water, I peak[a]	22	0	25	0
Water, II peak[a]	1	0	34	0

[a]Water bounds in these runs were taken to be very high, to assess maximum consumption.

6.4 Policy Analysis

The various results of the optimization model, exemplified above, can serve as a basis for broader policy analysis considerations. Structure and specialization solutions can therefore be treated as planning indications, while analyses of causes making these optimal structures/specializations appear and of possibilities of changing them, belong to the policy analysis domain.

Regarding the relatively invariant features of structures/specializations reported earlier, several inferences as to their causes and means of dealing with them can be made.

(i) Low levels of investment and innovation for the net production objective are caused mainly by the price and credit structure. This is advantageous for industrial goods and disadvantageous for agricultural goods and for repayment of agricultural infrastructure, so that an essential increase could be obtained if only the repayment conditions were changed appropriately.

(ii) With modern technology the region has a large production capacity, which can be made to work provided the infrastructure and supply conditions are generally improved.

(iii) The narrow and relatively rigid specialization of producer types results from the economic and organizational conditions in which they act, related not only to the price structure, but also to repayment schemes, credit conditions, land appropriations, labor costs, etc. Depending on the objectives to be attained, these conditions would have to be operated differently: for net return/net production the objective should be towards unification of conditions with regard to producer types, while for maximum output some differences should be maintained, whereby unprofitable products would be produced in adequate quantities.

(iv) There may be individual producer types for whom some resources might be essentially limiting (e.g., the labor force), which postulates an analysis of such resources in the surrounding systems as well as a substitution analysis within the system studied.

Besides this, the results again point out the necessity of multi-criteria analysis if an internally feasible policy were to be defined and implemented. Thus, by analyzing the influence of factors relevant to policy-making, one can arrive at values that define the direction of policy improvements, e.g., price levels and repayment schemes that will allow the innovation process to accelerate; infrastructure improvements that are necessary to utilize fully other resources available; suitable scales of activities to ensure maximum efficiency; and minimal incomes of producers ensured by appropriate specialization to balance the effects of differences in efficiency. Furthermore, the substitution conditions for limiting resources need to be established. This would have to be done in the framework of an explicit analysis of the overall goals of the system.

Any policy should explicitly take into account or start from the existing and potential inter-producer-group differentials indicated here. While minimal income constraints can make some equalization analysis possible, deeper insights and policy decisions are required to ensure viable development. It should be noted that redistribution policies could also be addressed with GRAM.

In the elaboration of policies, GRAM was deemed to cooperate with other models in a regional development planning model system, although it was assumed that it could

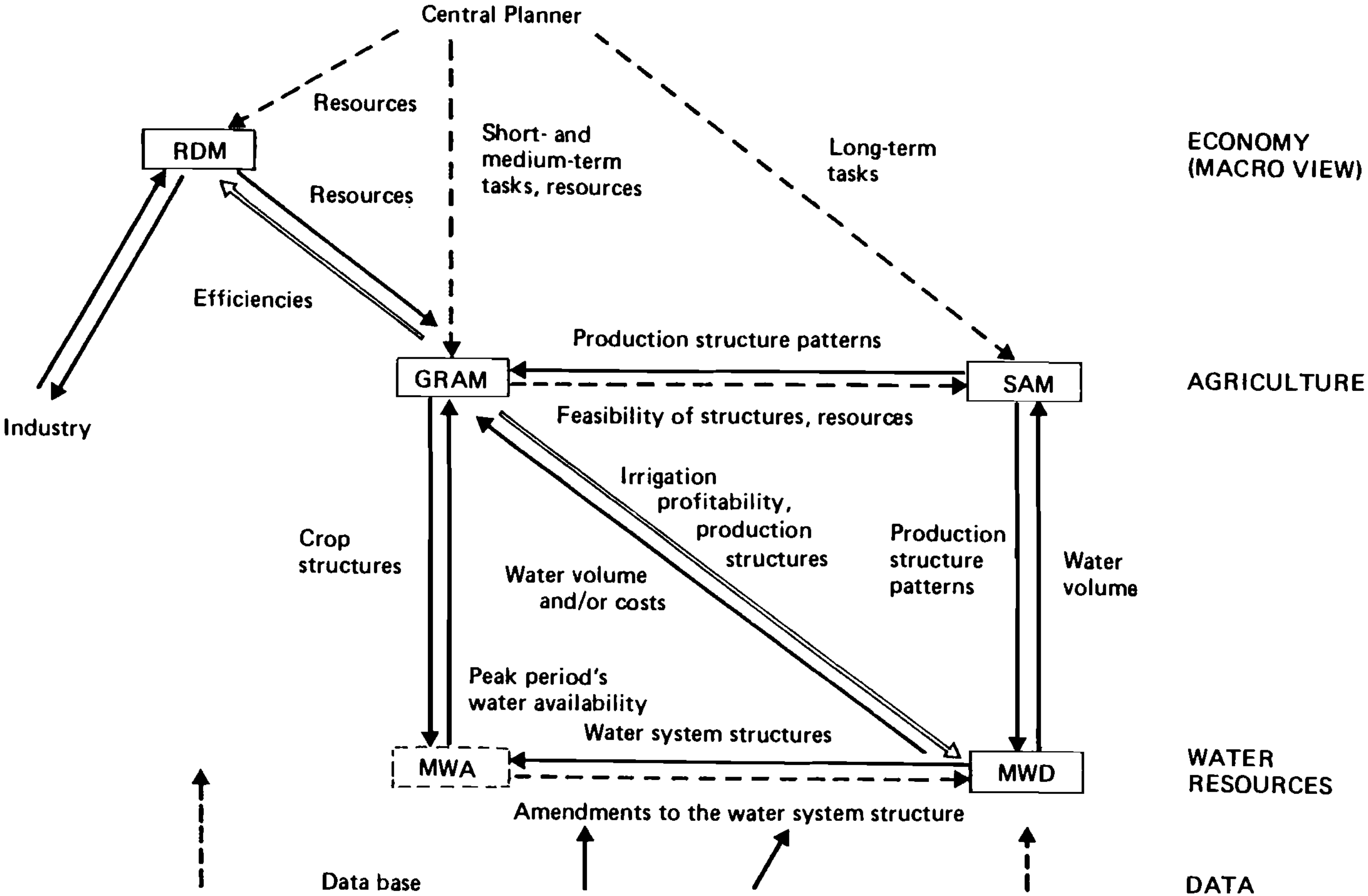

FIGURE 8 Outline of a system of models for a regional agriculture-based development program. ▭, models tested for the Upper Notec region; ⟶, connections necessary for the functioning of the system; ⟹, connections tested for the Upper Notec region.

be an independent planning tool for narrower purposes. Such a system, differing somewhat from the one presented earlier (Figure 1) was proposed for the existing set of models in Gutenbaum *et al.* (1980). It is quoted here with some modifications in Figure 8, together with clarifications as to the functioning of the system.

As can be seen, the agricultural model described here acts as a core. Another core model, on an aggregate level, is the (mainly) capital and labor distribution model (RDM), whose potential cooperation with other models is presented in Kulikowski and Kruś (1980).

GRAM was tested for its role as a core model by indirect utilization of the optimal characteristic function of Figure 7 in RDM and by trying out the MWD model optimizing the water system expansion with agricultural data from GRAM. Its feasibility as an integral part of a model system was thus fully established. GRAM can provide useful information for models whose policy and planning scopes lie outside agriculture.

7 CONCLUSIONS

The purpose of the work described in this report was to test whether a simple and flexible model structure can be developed and implemented to provide, simultaneously, sufficiently detailed information on a regional sector, be able to interact with other regional and inter-regional socio-economic models, and have such general features as would make it possible to apply it to different cases. It was intended that the test should be a difficult one, and the results obtained show that this was passed quite successfully by the model.

GRAM can, in fact, play the role of an independent planning and policy analysis and design tool, when equipped with data preparation and post-optimal analysis software. It can also work as an element of a model system, even in an interactive mode, provided the interaction process does not involve major changes in model coefficients, and that an initial solution is given. These properties of GRAM have been proven by a series of optimal solutions and sensitivity analyses, which provided information on optimal activity directions, limiting factors, and bottlenecks. The information thus obtained was checked with local decision-makers and planners for its validity and it was found to be in reasonable accordance with their experience. (Were it in complete accordance, then might the model perhaps not have been necessary?) The model's main merit was related to its capacity to provide a consistent, holistic quantitative numerical basis for comparing roles of factors and alternatives generated for various objective functions, as well as contributions and situations of various producer groups. It was very important to demonstrate that the model could be made operational even on a relatively small computer. In fact, the most difficult time is the preparatory phase, which would be better carried out on a bigger, faster computer. Once the model is set up, it can be run on a smaller one.

It should be emphasized that although GRAM tries to show the interrelations of the regional agricultural system with other systems, it cannot be extended so far as to comprise all the elements or processes of these other systems. Thus, if one wants to have a thorough review of the situation with a model like GRAM, there should be alternative scenarios generated by other models fed to GRAM. This considers first of all the population and labor force, water, land, and other resources, as well as costs, prices, and technologies, all of which require that GRAM be considered as an integral part of a system of regional models.

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APPENDIX A SEQUENCE OF SESAME/DATAMAT COMMANDS THAT ACTIVATE GRAM-Gen AND LEAD TO GENERATION OF THE MODEL MATRIX ON THE BASIS OF DATA ALREADY FILED

To run the GRAM Notec model (as set up by William Orchard-Hays), several steps are necessary:

(1) Assuming the Pisa line is up, log-in as follows:

- (a) Type *P* and carriage return. On response, type *v*.
- (b) After VM/370 response, hit carriage return. A dot should appear.
- (c) Type *l gram gen.*
- (d) After log-in messages, etc., type *def stor 1m.*
- (e) After message about disabled state, type *i cms.*

(2) After next stop, type *sesame.*
This will activate the SESAME/DATAMAT system. However, if message reading UNABLE TO ALLOCATE D-DISK appears, answer *no* and try later.

(3) After prompt SESAME COMMAND: type *short* for short prompts. Then, if off-line output is required, type

TITLE 'some text' (quotes are mandatory)

and follow instructions appearing on the screen.

(4) The next step depends on what one wants to do.

(a) To change the availability/demand tables, type

run change rhs

and follow instructions appearing on the screen.

(b) To modify the model with changed availability/demand tables, type

run change model

(c) To run LP, type

run auto solve

and then issue normal SESAME commands, e.g.:

call restore name=xxx (*xxx*= name of last basis saved)
$flog=20, $fbreakl=200
call iterate nowt

In case of check errors, first try

call invert 0 – 1 (changes inversion algorithm)

Use step after AT LEVEL 1 message (i.e., not continue)
If error persists, but magnitude not too large, type

$checksw=0
continue

This will only work after ERROR AFTER INVERT. To change error tolerance, type

$tolerr=no. (e.g., *no.* = 1*e* – *4*)

At BREAK1 (caused by $fbreak1 above), type

continue

but every few hundred iterations, save the basis with

call save name=xxx (e.g., *xxx=ito00*)

Use step after LEVEL 1 message.
At optimal or no feasible solution, also save basis for restarting next time. To get full solution, type

call solution active

(Omitting active gives listing of ALL variables, which is very long and the only information is dual values of main variables.)

To see only infeasibilities, use following sequence:

call mapgen map=inf, infeas
msgclass report=both
call solution inmap=inf
msgclass report=off

(Do not forget the last line after solution print or ALL off-line output will continue to come up on screen as well.)
To terminate SESAME, just type

quit

If print output does not start, have someone check the TPA.
If right line on modem is off, type

m rscs1 please start remlax

After several LP runs, MAPSFILE will have a lot of dead space. At start of LP run (after run auto-solve), use the following sequence to clean up the file:

call restore name=xxx (basis wanted)
cms erase mapsfile mpfile
call save name=xxx

This starts a new MAPSFILE with only the single basis on it.
Then proceed with call iterate, etc.
To see how many maps and basis saves are on MAPSFILE, type

call listmaps

APPENDIX B EXEMPLARY SHORT-LIST PRINT-OUT OF GRAM OPTIMAL SOLUTION RESULTS, FOR AN EARLY VERSION OF THE MODEL

AT 16:24:36 ON 11/22/79

SOLUTION

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COLUMNS SECTION

NUMBER	.COLUMN	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT.	..UPPER LIMIT.	.REDUCED COST.
302	XH.1HHG	LL	.	.	.	NONE	119.01943
303	XO.1HPW	BS	49.674799	.	.	NONE	.
304	XO.1HPM	LL	.	.	.	NONE	1.6527842
305	XO.1HPP	LL	.	.	.	NONE	160.30463
306	XO.1HPG	LL	.	.	.	NONE	61.078955
307	XO.1HFW	BS	91.424849	.	.	NONE	.
308	XO.1HFM	BS	54.742567	.	.	NONE	.
309	XO.1HFP	LL	.	.	.	NONE	28.717105
310	XO.1HFG	LL	.	.	.	NONE	49.137794
311	XO.1HRW	LL	.	.	.	NONE	178.89115
312	XO.1HRM	LL	.	.	.	NONE	169.07020
313	XO.1HRP	LL	.	.	.	NONE	177.05921
314	XO.1HRG	LL	.	.	.	NONE	185.65630
315	XL.1HPW	LL	.	.	.	NONE	2019.7228
316	XL.1HPM	LL	.	.	.	NONE	1564.4950
317	XL.1HPP	LL	.	.	.	NONE	1982.7735
318	XL.1HPG	LL	.	.	.	NONE	1033.8365
319	XL.1HFW	LL	.	.	.	NONE	1337.5339
320	XL.1HFM	LL	.	.	.	NONE	727.77726
321	XL.1HFP	LL	.	.	.	NONE	722.19385
322	XL.1HFG	LL	.	.	.	NONE	338.92087
323	XL.1HRW	LL	.	.	.	NONE	770.84982
324	XL.1HRM	LL	.	.	.	NONE	304.45175
325	XL.1HRP	LL	.	.	.	NONE	300.46357

326	XI.1HRG	BS	119.00000	.	.	NONE	.
327	XP.1HPW	LL	.	.	.	NONE	180.33365
328	XP.1HPM	LL	.	.	.	NONE	107.25621
329	XP.1HPP	LL	.	.	.	NONE	326.92841
330	XP.1HPG	LL	.	.	.	NONE	124.28443
331	XP.1HFW	LL	.	.	.	NONE	96.573935
332	XP.1HFM	LL	.	.	.	NONE	5.3203708
333	XP.1HFP	LL	.	.	.	NONE	105.42492
334	XP.1HFG	LL	.	.	.	NONE	14.115747
335	XP.1HRW	LL	.	.	.	NONE	84.769980
336	XP.1HRM	BS	574.70245	.	.	NONE	.
337	XP.1HRP	LL	.	.	.	NONE	105.63684
338	XP.1HRG	LL	.	.	.	NONE	15.731611
339	XM.1HPW	LL	.	.	.	NONE	157.50129
340	XM.1HPM	LL	.	.	.	NONE	127.78004
341	XM.1HPP	LL	.	.	.	NONE	231.07126
342	XM.1HPG	LL	.	.	.	NONE	77.747088
343	XM.1HFW	LL	.	.	.	NONE	69.003513
344	XM.1HFM	LL	.	.	.	NONE	19.412206
345	XM.1HFP	LL	.	.	.	NONE	9.6758941
346	XM.1HFG	BS	104.00000	.	.	NONE	.
347	XM.1HRW	LL	.	.	.	NONE	158.71394
348	XM.1HRM	LL	.	.	.	NONE	101.04476
349	XM.1HRP	LL	.	.	.	NONE	81.353430
350	XM.1HRG	LL	.	.	.	NONE	58.717890
351	XS.1HPW	LL	.	.	.	NONE	428.11504
352	XS.1HPM	LL	.	.	.	NONE	278.24695
353	XS.1HPP	LL	.	.	.	NONE	362.83082

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SOLUTION

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ROWS SECTION

NUMBER	...ROW..	AT	...ACTIVITY...	SLACK ACTIVITY	..LOWER LIMIT.	..UPPER LIMIT.	.DUAL ACTIVITY
209	KSG..P	UL	45.000000	.	NONE	45.000000	741.06270
210	KSG..F	UL	12.000000	.	NONE	12.000000	786.06270
211	KSS..S	BS	1023.4428	176.55718	NONE	1200.0000	.
212	KSS..P	BS	.	60.000000	NONE	60.000000	.
213	KSS..F	UL	240.00000	.	NONE	240.00000	50.000000
214	KSP..S	BS	.	1600.0000	NONE	1600.0000	.
215	KSP..P	UL	120.00000	.	NONE	120.00000	51.056398
216	KSP..F	UL	240.00000	.	NONE	240.00000	71.056398
217	KSM..S	UL	40.000000	.	NONE	40.000000	364.71027
218	KSM..P	UL	30.000000	.	NONE	30.000000	309.71027
219	KSM..F	UL	24.000000	.	NONE	24.000000	547.71027
220	KSF..S	UL	400.00000	.	NONE	400.00000	137.46943
221	KSF..P	UL	90.000000	.	NONE	90.000000	137.46943
222	KSF..E	UL	48.000000	.	NONE	48.000000	207.46943
223	KSV..S	BS	.	40.000000	NONE	40.000000	.
224	KSV..P	BS	.	15.000000	NONE	15.000000	.
225	KSV..E	UL	12.000000	.	NONE	12.000000	143.89007
226	KSK..S	UL	400.00000	.	NONE	400.00000	237.38114
227	KSK..P	UL	150.00000	.	NONE	150.00000	250.38114
228	KSK..E	UL	.	.	NONE	.	300.38114
229	KSL..S	UL	60.000000	.	NONE	60.000000	2964.6154
230	KSL..P	UL	15.000000	.	NONE	15.000000	822.61538
231	KSL..E	UL	24.000000	.	NONE	24.000000	5235.6154
232	KSZ..S	BS	.	.	NONE	.	.
233	KSZ..P	BS	.	.	NONE	.	.
234	KSZ..F	BS	.	.	NONE	.	.
235	KTM..S	UL	140.00000	.	NONE	140.00000	3146.7753
236	KTM..P	UL	50.400000	.	NONE	50.400000	5246.7753
237	KTM..F	UL	18.200000	.	NONE	18.200000	6346.7753
238	KTL..S	UL	1050.0000	.	NONE	1050.0000	6.5000000
239	KTL..P	UL	126.00000	.	NONE	126.00000	6.5000000
240	KTL..F	UL	364.00000	.	NONE	364.00000	15.000000
241	KTD..S	UL	280.00000	.	NONE	280.00000	402.74584
242	KTD..P	UL	75.600000	.	NONE	75.600000	404.74584
243	KTD..F	UL	72.800000	.	NONE	72.800000	424.74584
244	KTF..S	BS	.	21.000000	NONE	21.000000	.
245	KTF..P	BS	.	10.080000	NONE	10.080000	.
246	KTF..F	UL	3.6400000	.	NONE	3.6400000	538.87437
247	KTW..S	BS	.	10.500000	NONE	10.500000	.
248	KTW..P	BS	.	5.0400000	NONE	5.0400000	.
249	KTW..E	BS	.	1.8200000	NONE	1.8200000	.

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SOLUTION

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OPTIMAL SOLUTION AT ITERATION NUMBER 454

...NAME...	...ACTIVITY...	DEFINED AS
FUNCTIONAL	2045426.0	FS.....1
RESTRAINTS		RHS
BOUNDS....		AGG
RANGES....		RNG