ON THE SCENARIO APPROACH TO SIMULATION MODELING FOR COMPLEX POLICY ASSESSMENT AND DESIGN

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PREFACE

One of the recurring interests of most areas and programs at IIASA is the uses of models for policy analysis. This paper represents the results of the experiences of the three authors in the policy-modeling interface in the Food and Agriculture program, the Management and Technology area, the Resources and Environment area, and previous experiences with the Mesarović-Pestel groups in Cleveland and Hannover, as well as the Free University of Berlin.

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ABSTRACT

This paper reviews the major issues posed by scenario-based simulation modeling in the policy process, using agricultural policy as an example of a complex decision arena. Policy is seen as a process by which decision-makers use the instruments under their control to approach the general goals of society. Models can help to choose instrument settings, evaluate policy option, and assess their appropriateness to a particular situation. But they cannot design policy; the interactions between policy-makers and models are critical if modeling is to be useful in the policy process. Policy models must be oriented to the factors that focus and constrain judgements in the real world, as well as toward the substantive problems motivating analyses. These include the actors within the system, as well as the geographic and disciplinary contexts of the problems. Scenario-writing provides a way of ordering understanding and judgement about different phenomena to help users interact most effectively with a model and to insure that the perspectives of the model are most appropriate to the needs of the decision-maker. It is an iterative and evolutionary process which can provide a great deal of insight into the assessment phase of policy design.

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MODELING IN POLICY ANALYSIS AND DESIGN

Quantitative policy analysis with the use of simulation models is a young art whose outlines are only beginning to show some contours. In several countries modeling for policy assessment and design is being used increasingly, while early and premature applications in others have led to setbacks, as high expectations which had been aroused were not met. This is especially true for applications to complex policy questions involving complex power structures and multiple interest groups with diverse and often conflicting objectives. The role of modeling in policy analysis and design has been obscured by disagreements regarding the scientific rigor of models intended for policy application, their relevance to the policy arena, and their accessibility to decision makers in business or public office.

Modeling for the purpose of supporting policy assessment and design will always remain an art to a certain degree (Quade, 1975). But in order to attain its full potential in this area, it must develop a sound epistemological base oriented toward the policy process as well as a clearly defined view of both the substance of particular policy issues and the organizational framework within which policy outputs are to be implemented (Jenkins, 1978). That is, it must adopt a holistic view which includes the concerns of the natural and social sciences in the same context as the governing values and institutions of a society and the hard-nosed considerations and tradeoffs which policy-makers make in the real world.

This paper is a contribution to the epistemological base for modeling in the policy process. It concentrates on the scenario approach (see below), coupled with simulation modeling, using the management of agricultural systems as an example of a complex policy application. However, much of what we say should also be pertinent for other modeling approaches and applications to other specific areas.

The Nature of Policy

It is useful to distingush between "policy" as a generic term and "a policy" as a specific decisional scheme. The generic term "policy" denotes the basic process by which decisions are mapped out, weighed, implemented, and adjusted. It implies goals to be met or motivations for change, a basic strategy and sequence of tactics for dealing with them, and a set of instruments available to the policy-maker through which he can exercise his mandate. It also includes the processes by which different goals, strategies, and tactics are weighed against each other and translated into actions as well as the ways in which the system is monitored and adjustments are made to compensate for errors in the original assessment.

The motivations for policy tend to be qualitative and are generally rather loosely defined outcomes which the policy-maker would like to see as the result of his actions. These include things such as better health, greater happiness, more food, and a higher standard of living. A typical decision-maker also has a more personal motivation, such as the desire to maintain or advance his own status within his bureau or that of his bureau within the wider political framework. Different individuals have different motivations for their actions, and the overall constellation of motivations within a policy-making institution is generally characterized by an uncertain, and perhaps unstable, consensus. The instruments of policy are specific "handles" through which the policy-maker can influence the system. No complex system is completely controllable. Indeed, relatively few factors can be consciously adjusted by a decision-maker. Those that can include things like taxing schemes and rates, savings rates, allocation mechanisms, quotas, tariffs, technology support through research and development, legislation, and the way in which police powers are used.

Strategy and tactics are mappings between goals and instruments. Strategy is the overall view within which problem solutions are perceived. It is more general, and it allows for problems which arise along the way. Tactics are the specific short-term responses to conditions as they are perceived. They are more limited, and they utilize the actor's special abilities to manipulate certain instruments. The process of translating goals into strategies and strategies into tactics, given an available set of instruments, is one of the main sub-processes of policy. There is no general way to do it, and the process is closely related to the policy-maker's perception of the set of instruments available to him, as well as their relative potency. Not all decision makers perceive the usefulness of the various instruments in the same way; nor need they even see the same set of instruments as being available to them. So this aspect of policy is a very open and individual process. Any attempt to use models to aid in policy asessment and design must recognize this fact.

"A policy" is a much more restricted term referring to a given goal set, a set of strategies for these goals, and the associated sets of tactics and instruments for each actor involved. A given goal may be reachable (at least in principle) through a wide range of alternatives, some of which may be radically different or even antithetical in places. In general a given policy will allow limited variation of instrument settings within a tactic, of tactics within a strategy, and so forth.

Policy design is the process of generating and assessing alternatives and choosing from among them (Figure 1). Each alternative has different implications, which must be understood so that the most appropriate can eventually be chosen for implementation. Alternative strategies are determined for a given goal set. Tactics must be generated, assessed, and chosen for each strategy. Then instruments must be fixed in the same way. This process is likely to lead to a relatively large number of feasible alternatives within the framework of a given goal set, and the implementation of any one may foreclose options on later development of others.

The resulting multiplicity of options must be assessed and filtered to narrow the field so that one can ultimately be chosen for implementation in the real world. Ideally, this policy will be capable of meeting its associated goals, or at least of moving the system toward them. The alternatives discarded along the way may also be useful in helping to improve the efficiency of policy generation and assessment procedures, and they may also have some effect on modifying the goals directing the policy design process (Mendell and Tanner, 1975).

The Role of Models

Mathematical models are a formal way of organizing and presenting policy-relevant information (Quade, 1975). They have a role both in the generation and in the pre-implementation stage of the policy-design process. They can be used in the places in Figure 1 indicated by a double arrow, but the types and purposes of models at each position are different. Those which calculate instrument settings are generally normative models which calculate ways of reaching social optima or which assess the trade-offs that must be faced by decision-makers (e.g. Haimes et al., 1975; Heady, 1978). The structures of such models limit strategic considerations to a very narrow set with limited tactical capabilites. If the structural assumptions of the model (generally that the strategy and tactics of goal-seeking can be represented adequately by maximizing some identifiable welfare function) correspond to those of the decision-maker, then they border on irrelevance (Arnaszus, 1974).

Other models provide estimates of the impact of policy options on the overall system. These tend to be large-scale descriptive simulation models which project the implications of particular instrument settings (e.g. Mesarovic and Pestel, 1974; Goeller et al., 1977). Such models serve to consider a wide range of strategies. The policy-generation step must precede their use so that instrument settings can be specified, and they have no policy generation capabilities of their own. Still other models can evaluate the estimated impact of policies. These tend to be relatively simple, abstract ways of relating structural changes to goal-seeking (e.g. Dinkel and Erickson, 1978, Kantor and Nelson, 1979).

But no model can embody the policy design process, and no model can design policy. Too many judgements and interpretations must be made both by the analyst and the policy-maker. Modelers tend to be different kinds of people than policy-makers, with different outlooks and styles of operation. This places strong constraints on the use (or at least the acceptance) of certain analytical techniques and approaches (Martino and Lenz, 1977). No policy-maker would ever turn over primary policy-design responsibility to a computer-oriented analyst. The function of modeling is to assist the policy-maker, and it is a rather subsidiary role at that.

The criteria for judging the usefulness of a model are properly those of the policy-maker, not those of the modeler. Modelers commonly judge models on the basis of whether they are sophisticated, accurate, precise, realistic, general, or theory-based. These considerations are important for the process of modeling, but they are hardly related to the values of the decision-maker, which are oriented toward the end result. If a model of low sophistication and even low precision makes it easier for decision-makers to filter the options open to them, then it is more useful (or at least it is perceived to be so, even if the results of its use are pathologic) than a sophisticated, precise model for which the decision-maker does not readily see its role in the policy process as he perceives it. The "best" model in the world would be useless as a policy tool if policy-makers could not relate it to specific policies they wanted to assess or if it made assumptions which did not fit the realities of the political institutions associated with the problem (Majone, 1976).

This implies two features that are basic to policy models. First, the model structure and the way in which it fits into the policy process must be capable of reflecting the standards and values of the policy-maker, as well as the realities of his associated institutional structure (Biswas, 1975). It must consider at least his motivations and the instruments of interest to him, and it must recognize the constraints on his intensity, freedom, or speed of actions (e.g. Wall, 1976). It must be capable of considering or designing a constellation of instrument settings which corresponds both to his strategic and tactical inclinations. If it cannot, then it cannot deal with problems as the policy-maker visualizes them. Secondly, the model must be usable in the policy process. A model in this context is no more than a tool for people with wider interests, and they must be able to use it (Quade, 1971).

Many modeling techniques involve optimization mechanisms of one sort or another. These have proven very useful, both for designing policy where the strategy is clear and as a way of endogenizing behavioral responses which can be modeled fairly accurately and which are important factors affecting policy acceptance in the real world. Such behavioral modeling is often essential to following the proliferation of policy-generated impacts through the system (e.g. Spofford et al., 1976). However, a warning must also be entered: one must be very careful when endogenizing behavior in a model. The rules for this behavior must be well understood and accepted. But these rules are themselves subject to change as the result of policy and other feedbacks within the society. Incorporating phenomena subject to changing rules within the structure of a model is extraordinarily difficult.

A useful policy model, then, must be more than a running computer program. It needs to be a part of a system including not only the model but also a capacity for generating alternative policies or policy scenarios, as well as the capacity for translating goals and instruments into model input and interpreting the results in such a way that they are relevant and understandable to policy-makers. The sophistication of the model is a constraint mainly on the detail of policy analysis that can be done using it. Indeed, the sophistication of the overall system really refers to the way the model is embedded into a method of use. There is an important distinction between quantification and sophistication. Quantification is only one instrument of mathematical sophistication, albeit a very important one. Mathematics in its larger sense deals with relations among concepts, magnitudes, indices, systems, etc. The pretention and attempts of many model-builders to quantify the whole socioeconomic process of a society is not only unrealizable; it is not even reasonable (Rapoport, 1979).

TAXONOMY AND COMPLEXITY IN AGRICULTURAL PRODUCTION POLICY

Let us confine ourselves hereafter to descriptive policy assessment models, using agricultural production policy as an example. This is already an extraordinarily complex system. Food production must compete for variable inputs with all other sectors of the economy. It deals with biological, pedological, and hydrological spheres of the natural environment to which the farmer falls prey. These include the population genetics of crop varieties, the community ecology of pests and weeds, and the effects of weather perturbations, climatic change, and the "downstream" effects of other producers. His efficiency is limited by the technological tools available to him and by the state of the economy into which his production feeds. Moreover, a moderately complete description of the crop production system would have to consider at least half-a-dozen different actors' viewpoints. And this is only for crop production: in order to describe the overall agricultural situation in any country, we would also have to consider livestock production, marketing, commodity utilization patterns, the competition between the agricultural and non-agricultural sectors of the economy, and so forth.

A model which attempted to deal directly with any of these sectors might have to consider several of them because of their tight interconnectedness. But some of the most significant policy questions are related to goals not of any specific area but rather to those of several areas as they interact to comprise a larger system. Such an analysis must focus on the interrelationships between the constituent issues and disciplines as well as those issues and disciplines per se. And the most important expressions of problems are likely to be in the interrelationships between various subsystems rather than in the subsystems themselves. How many times, for example, have well-meaning decisions been made in which the true nature of the system was not understood, and whose results bordered on disaster? For example, the governments of several Andean counries have moved people out of their very crowded highlands to lowland areas, because living conditions were frankly quite bad in the highlands. But after a few years of slash-and-burn agriculture in the lowland areas for which they were not really prepared culturally or technically, the soils were no longer able to support the population, the people were worse off than they had been in the highlands, and the country's natural soil resource base was permanently damaged.

The analysis of policies affecting complex situations such as this is an extraordinarily difficult and complicated undertaking which must necessarily be done by people trained not only in various substantive areas but also in understanding and dealing with the interrelationships among them. No one person can be trained in all of these things, or even in very many of them. No single body of theory will ever cover everything involved. Indeed, any attempt to use a single disciplinary approach or single body of theory to do an analysis of complex policy would be committed to failure even before it started (Dillon, 1976).

Actors

In the same way, no single viewpoint is suitable for assessing or designing policy. Any decision-maker who is the primary user of a model will have a single viewpoint (his own). It may be complex and not entirely self-consistent, and it may change somewhat with his changing perceptions (Quade, 1975; Biswas, 1976). But a model which is capable of dealing with complex policy notions is likely to have multiple users with multiple viewpoints. And even if this is not the case, any system on which a policy is being imposed contains different actors with different goals, roles, viewpoints, and impacts on the overall system. These are real people and real institutions, and their interrelationships are themselves complex and dynamic. We seldom wish to analyze the policy decisions of all of the actors in any real system. But all do affect it, and one cannot wish away their impact simply because an analysis focuses on the decisions available to a single key actor.

Actors' roles tend to be best understood in qualitative terms, and few model-builders are equipped to understand their place in a quantitative analysis. One of the first interactions between the modeler and his client must therefore be to develop a clear-cut identification of the actors in the system and the relations of each to the key actors on whose policy decisions the analysis will concentrate (Royston and Perkowski, 1975). Figure 2 shows some of the actors that might be involved in a typical agricultural system. They are shown as a hierarachy with certain lines of communication between adjacent levels. Decisions made at high levels can be frustrated by the actions of those lower in the hierarchy, or they may be amplified by concomitant decisions of those lower actors. The same is true in the opposite direction (e.g. Jenkins, 1978, Chapter 7).

The goals of different actors may be the same, different, or overlapping. Some can be expressed easily, others only with extreme difficulty (Donald, 1976). There are commonly some agreed-upon national goals to which all actors would submit, but these tend to be quite fuzzy. As we identify actors more specifically, their role differences begin to stand out, and their goals diverge until those of one actor may conflict strongly with those of another. They can be of a very different character, and some are dominant over others (Bossel, 1977). To decide which of these types of goals are relevant to a given modeling effort is a difficult task, but it must be carried through conscientiously, as goals underlie the motivations for different actors' actions in a given situation, and they are a basis for evaluation of the results of those actions. This becomes even more complex when results begin to affect the goals.

Actors are always decision-makers, even if they affect only a very small portion of the system. Even the small ones identify sets of instruments, tactics, strategies, and goals. But their decisions are always oriented toward their role in the system, and their impact is conditioned upon their position in the hierarchy. The decision to neglect a given actor generally means either that we want to ignore the instruments at his disposal or that we wish to lump them in with somebody else's instruments that are already being considered. But instruments gain their importance by their strategic location and by the sensitivity of the overall system to their use. Important instruments -- and hence important actors -- cannot be neglected (Schultze, 1968).

Focusing on Real Problems in a Model Context

Models are inherently abstractions and seldom contain elements that are exact replicas of the phenomena found in real life. So the use of a model involves a translation from the goals, strategies, tactics, or instruments which are of greatest relevance to the policy-maker into terms which are compatible with the model. The translation from instrument settings into model input is as critical and difficult a phase of using models for complex policy analysis and design as the formulation of specific policies from generalized goals.

The most difficult step in the translation process is often specification of analytical boundaries. Policy in the real world operates in an infinite context. Models cannot. Clear decisions must limit the extent of the system to be considered and define the remainder as the environment or the context of that system. There are many ways of looking at this question in any given analysis. Perhaps the simplest is the multidisciplinary view suggested by a Venn diagram of the various disciplines pertinent to an analysis (Figure 3). This is one way of determining the range of substantive areas which must be considered in order to carry out a meaningful analysis. If any given discipline or approach does not intersect significantly with other disciplines, then it need not be considered.

There are also ways of focusing on a problem by decomposing the system along hierarchical rather than along disciplinary lines. A Venn diagram can identify the areas which must be considered and some of the questions which must be asked. But how deeply into any of these disciplines need analysis go? What bodies of theory should be used in each, at what detail, and for what purpose? Most mature disciplines comprise sets of issues and subdisciplines that can be arrayed hierarchically. An example showing a decomposition of economics for a model of agricultural production is given in Figure 4. The central importance of the agricultural portions of the economy is clear, and they are shown within the dashed lines. But it is not clear _a priori_ how much detail of the areas outside of the dashed lines must be included in order to make meaningful economic judgements for this system as a whole. As part of the necessary process of identifying system boundaries, one usually assumes that there is some level within the hierarchy above which one no longer needs to consider processes explicitly. This allows a boundary to be set at this level and is equivalent to saying that information coming down across it into the parts of the system that are considered are constant, known, or embodied in parameter estimations.

But one of the primary features of higher levels of a hierarchy is that they are adaptive (Mesarovic _et al_., 1970). They respond to activities of lower levels. And it is risky to draw system boundaries at points separating the model system from higher levels which are likely to adapt (and therefore to change) to signals from a lower level not included in the analysis. This is especially important for policy models of agriculture, because many of the policies with the greatest impact on agriculture are not directed towards agriculture _per se_, but are rather the adaptive responses of policy-makers to other sectors of the economy. The competition and interactions among sectors may have a greater impact on agriculture than direct policy interventions within agriculture. For example, agricultural policy may favor the use of higher levels of fertilizers and pesticides. As a result, the Ministry of Agriculture will support the development of an indigenous chemical industry, some of whose products would be agricultural chemicals. If the industry is successful, then fertilizer and pesticide production are carried along, with beneficial results to agriculture. But if it is badly managed or otherwise unsuccessful, the agricultural components may suffer, even if their markets are sound. In either case, the prosperity of the overall chemical industry has a much larger role in the success of fertilizer and pesticide production than agricultural input policies.

Problems and Processes

The taxonomies presented so far are basic to any model designed for complex policy analysis. But the hierarchies shown in Figure 4 or the interrelations among disciplines shown in Figure 3 seldom appear explicitly in policy-oriented models. We model processes. Whatever resemblance exists between the processes modeled and the disciplines considered is generally because model-builders have been trained in one or more specific disciplines, and the outlooks or perceptions of those disciplines provide them with the easiest entry into their description of a system.

Conflicts between the perspectives of different approaches often affect the types or philosophies of a modeling exercise. One of the most critical is between simultaneity as commonly assumed within econometric studies and strict contingency relationships as assumed within systems dynamics and related approaches. In most real-world agricultural systems, both type can be perceived, and realism requires retaining the differences.

Neither type is simple. For example, the contingency relationships in the system can be as illustrated in Figure 5. For the sake of simplicity, we shall assume that each of these processes is represented by a model which is drawn from the appropriate body of theory from some discipline. If the output of process "a" is the input of process "b", then this means that "b" depends on "a" in order to operate. This is commonly a time dependency, but it may be a political or threshold effect as well. For example, process "a" might be the decision-making process by which the farmer allocates his variable inputs to production, and process "b" might be the production process by which these variable inputs are converted (with a certain amount of help from the sun, rain, soil, and similar phenomena) into salable commodities. Conversely, many processes, such as market clearance, represent decisions made on the basis of a great deal of information generated at different points in time but considered simultaneously. The difference is critical, and one must build a system in such a way that there is never any danger of including factors whose contingency order is not correct within a single process or treating specific information flows seriatim within which simultaneity of decision-making is important.

There is another critical dimension to policy-oriented models: policy represents control. And the interaction between controlled and controlling systems can often be effectively represented in a hierarchical system such as that shown in Figure 6. In such cases, information flows in both directions, but it is asymmetric. The general pattern is for control input to lead to a system response which is monitored by the controller. The controller then adapts his inputs to reflect his increased understanding of the system and its relationship to his own goals (Figure 7). These relationships are never simultaneous, and to consider them so is always misleading, if not incorrect. As a general rule, policy inputs into a model are never simultaneous with their results, and the responses of subsidiary actors to policy inputs at the highest level are always of a contingency sort (Mesarovic et al., 1970).

If policy represents control, it is also true that no system such as agriculture is fully controllable. Some processes cannot be influenced by available policy instruments, while others can be affected in several ways by different actors. A diagram such as Figure 8, which connects controllers and actions associated with the processes, can be very revealing. Such a diagram is implicit in any model of policy analysis, although it is seldom explicit.

We previously touched on the question of how one determines which actors must be considered in a complex policy analysis and which ones may safely be neglected. We can now answer it much more effectively. Any model is ultimately a framework for interacting processes. As such, the significance of any given actor can be measured by whether or not his adaptive responses are sufficient to affect the behavior of some process which the key actors are trying to control. If so, then these adaptive responses -- and hence the actor making them -- must be considered. If his responses do not alter the suitability of the key actors' chosen control tactics, then he can be neglected, at least with respect to this process. Of course it may be possible to neglect a given actor by this criterion for one feasible policy with regard to a given goal set, but he may still have a significant role in an alternative policy. The importance of an actor in a policy analysis situation depends on the policy in question, less on the goals to which it is directed.

SCENARIO ANALYSIS

The picture given here is one of immense complexity, with several taxonomies needed simply to describe the complexity, much less to deal with it. In order to build policy-oriented models at all, one must recognize a gradient of simplification. At the extremes, one must either reduce complexity to fewer aspects of the problem, retain the number of aspects but reduce the complexity of interactions, or retain the complexity of the system within the analysis but external to the model. The first is mathematically more elegant, but the latter two are probably more generally useful and can be carried out using the technique of scenario analysis.

If a simulation model is an excellent device for examining the impact of policies on a larger system, it is well adapted to the pre-implementation assessment phase of policy design. Multiple runs simulating different policy altenatives show the sensitivity of different combinations of instruments as well as the effectiveness of *a priori* chosen policy options. Each run represents a set of assumptions (i.e. a policy set), or scenario (Knauer, 1978; Carr, 1976; Vanston *et al*., 1977.

Exogenous vs. Endogenous Considerations within Scenarios

Scenario analysis of policy problems is becoming increasingly widely used, and some variant is probably essential to the pre-implementation assessment loop shown in Figure 1 (Kahalas, 1977; Committee on Water Resources Planning, 1976; Goeller *et al*., 1977). It recognizes that policy represents an attempt by decision-makers to respond to explicit problems and that the evolution of policies at any point in time need not be a continuation of past policies. At the extremes, policies may change rather radically with changes in government or ministers, or policy evolution may be a series of small increments that respond to problems of the moment and show a minimum of concern either for the future or for continuity with the stimuli which have governed policy steps in the past. In any case, goals of societies change, as do the instruments at their disposal for reaching them. It is obvious that policy at this level cannot be endogenized into a model, but must rather be supplied exogenously by a decision-maker or a user simulating a decision-maker (Mesarovic and Pestel, 1974). The user and the model are linked during the scenario analysis process, so that the user is in essence a "model of himself". 4

This should not be taken to mean that the effects of policies which are consistent with the past cannot be endogenized and that approaches which attempt to do so, such as econometrics, are not successful. Such models have too good a track record to allow this to be said. But econometric estimation can embody only the results of policy, not policy itself. And policies which may change radically in the future are not reflected in past time-series or cross-sectional data. More important, perhaps, when a policy is assumed to be embodied in an estimation procedure, it is not accessible for evaluation. The trajectory of actions and instrument settings implicit in the data and which have been assumed by the estimation procedures are fixed in the model. They can form only a marginal part of any set of tactical alternatives involved in policy design.

Scenario analysis is not a single or a simple technique. There is a gradient of how much should be considered exogenously. At one extreme, policy is entirely exogenous, (Mesarovic, Pestel, et al., 1974; Clapham, 1977). Scenario policy specification must be very complete, all-inclusive, and highly realistic. It is not acceptable for important factors to be neglected. An exogenous scenario must represent a thoughtful assessment of the patterns of available instruments. This is one of its great strengths as well as its greatest difficulty: the user must know what he is talking about. Where the policy instruments are relatively straightforward, and where their use is a thoughtful response to conditions and represents a commitment of the government (or other actor) to a changed way of dealing with a problem, this can be a highly useful approach.

The exogenous scenario is also useful where the rules of actors' behavior cannot be delineated. In this sense, the scenario no longer represents a thoughtful policy commitment from the actor in question. Rather it represents a guess about the composite behavior of a number of different actors. In most cases, the exogenous scenario as it is used in practical policy modeling represents a cross between these two modes. The disadvantages of exogenous scenarios are also significant and must be specified. They do not respond directly to changes in the structure of the system. Only by close interaction between user and model can the learning process proceed. This is costly both in user time

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4 This is a characterization by Prof. Peter D. Junger of the School of Law, Case Western Reserve University, Cleveland, Ohio. The same argument is implicit in the caveats about "hard" and "soft" variables and the role of judgement in Mendell and Tanner (1975).

and in computer time.

At the other end of the gradient, much policy may be considered endogenously by the model. Behavioral equations may represent societal behavior which cannot be controlled, policy decisions, or anything in between (Kopelman and Weaver, 1978). The advantage of this approach is that simulation of behavior is dynamic and responsive to changing conditions, just as in the real world. Such policies and their associated instruments are not evaluated by the model. But if the rules of generation for such policies are sufficiently well understood that endogenization is possible, then this would not be necessary. There are many examples where policy rules are understood and where endogenization is appropriate, such as pricing behavior for agricultural commodities within the European Economic Community. The same may be true of the behavior of key actors in a system. But rules which apply to one society may not apply to another. For example, it is appropriate to assume that farmers in North America or Western Europe act in such a way as to try to maximize their profit. But the farmer in most poor developing countries does not act to maximize profit, but rather acts to satisfice between profit and survival. Any agronomist with field experience in developing countries can tell stories about farmers planting many lines of crops, often in the same field, so that individual yields of all were depressed. The results did not lead to profit maximization in any sense. Rather they led to a meager profit in a good year and enough food for the farmer and his family to eat in a poor year.

It is likely that some factors will be endogenized and some will be exogenized in any useful scenario-based policy model. Many tradeoffs must be carefully considered during the model design process. These include detail of systems response, transparency of model structure to the user, and breadth of analysis.

The Technique of Scenario Specification

The scenario specification process can be summarized in Figure 9. The basis of the analysis is the motive scenario, a set of motivations which determines the purposes, directions, and boundaries for the analysis. These goals can be regarded as the problem set. Once the motive scenario is chosen, a set of preferred strategies and tactics are determined for the actors who are considered in the analysis, and the instruments and instrument settings are chosen.

A specific scenario comprises a set of instrument settings which is thought appropriate to realize the motive scenario. In principle, an infinite number of specific scenarios might correspond to any motive scenario, and in practice the number may be very large (Biswas, 1975). The analyst must generate a large number of possible scenarios and filter out all but the most useful. The mechanism may be entirely intuitive, or it may involve the use of special techniques. The result of this is a relatively small number of scenarios which will actually be assessed using the simulation model.

Implementation requires first that the scenario be translated into model input so that it can be handled by the computer. This is possible only to the degree that the parameters of the model are appropriate "handles" for policy actions. The various elements of the policy set must be identified with model variables and then translated into numerical inputs. When the input set is complete, the model can be run, and the output reflects the calculated responses of the system to the policy actions simulated by the inputs. Any scenario then consists of an input set reflecting actions of the policy-maker and an output set reflecting the behavior of the system. This relationship is summarized in some detail in Figure 10.

After the model has been run, the results must be interpreted, both for the performance of the policy scenario and for the adequacy of the model. The first refers to the degree to which the policy scenario is capable of realizing the motive scenario; the second refers to the model validity and the degree to which the model and its associated software are capable of assessing scenarios of interest to users. Interpretation in both of these dimensions considers both the policies being tested and the capacity of the model to assist in their design. Scenario analysis may show that the goals cannot be met or that they are not sufficiently ambitious, so that the motive scenario should be changed. It may suggest changes in the method of generating or building specific scenarios, and it may lead to new strategies or tactics. It may lead to different methods of translating policy scenarios into model input, and it may even lead to changes in the structure of the model itself.

Perhaps the most difficult part of a scenario-based policy analysis is the construction of the reference scenario. This is a summary of all of the default policy sets of the "highest-probability" or "status-quo" sort. Here is done most of the research on "knowing what you're talking about," as the analyst develops a basic feeling for the policy situation in the society. Calibration and historical validation of the model are generally carried out as part of the reference scenario process, and the structure of the model is brought to a level where it can recapitulate the past. But policy analysis and design are seldom done successfully with regard only to the past: they are inherently future-oriented. Therefore historical validation is not sufficient. The reference scenario is also a set of default parameters for future projection. It thus requires sufficient understanding of the qualitative causes of the patterns of the past that they can be extrapolated into the future, given the perspective and realities of the present. Only then have we devised an adequate reference scenario.

The function of the reference scenario is to serve as a basis against which other scenarios can be judged, knowing that directed and informed change is likely to be more socially acceptable -- and therefore more likely -- than stasis. There are many ways of generating scenarios. The types of motive scenarios considered as well as the breadth and intensity of actions depends on the purpose of the analysis. Different actors have different roles, and the number and positions of actors considerd has a major effect on the analysis. To a degree at least, the strategy-tactic-instrument set is actor-specific, and the analysis may be fairly straightforward once the actors to be considered have been specified. But in some cases, actors can change their alliances, their coalitions and their relative roles. These may be subtle changes, but they may have profound effects.

Conflicting Goals of Modeling Efforts: Multiple Clients

Simulation models of complex policy are generally very large interdisciplinary multi-actor models. Such models can generally have many potential clients, especially those models which treat international problems or problems with international implications. But it is not always possible for potential clients to agree on model structure or analytical approach. It is not even always possible for people working on the same model or within the same group to agree on these factors. If the usefulness of a model is any criterion of its worth, it would seem that a model which could serve more than one client effectively would be more worthwhile than a model which could serve only one client.

The disagreements between people in the modeling process can occur at any phase of model development. If the disagreement is over scenario specification, then it can be resolved by allowing different clients to establish different scenarios. This is to be expected and is often useful to modelers, as different clients often represent different actors within the system, and their differences can point out important factors of system structure. The different actors operate from different motive scenarios, and they have different instruments available to them. It is only reasonable that their different interests result in different specific scenarios.

But the differences may also be in the interpretation of the processes which should be considered and in their relative importance. These too can be resolved, at least to a degree, through building flexibility into the model so that different modules can be substituted for different clients. Indeed it may be possible to alter structure efficiently through alteration of parameters. Interpretation of processes may be a very important problem, but it is likely to be most serious if the proper foundation for the modeling effort was not laid, if the various actors and instrument sets were not identified, and if no effort was paid to accomodating potential users at future points in time. An effort to develop a model by a strategy that allows for maximum flexibility should make it possible to work out process disagreements by substituting modules on a process-by-process basis.

The most serious disagreement which can come up in a modeling effort is with respect to model focus. It is very difficult to resolve problems which come about because people disagree on the way system boundaries should be set. This disagreement does not involve processes or modules within a construct which can be "unplugged" and "plugged in" but rather the fundamental rationale behind the construction of the model. But even this can be ameliorated if a committment is made to disagree but to accommodate at the same time. In this case, we need to identify both the "lowest common denominator" and also the "highest common denominator." The former refers to those parts of the model which can, in fact, be common to the various multiple clients. Ideally, this will be all or at least most of the simplest version of the model. The "highest common denominator" is a hypothetical model with specifications which would enable it to meet all requirements of all clients even though it might be impossible to implement and almost certainly would not be very useful. One must then identify the options that must be left open for each client. As the "lowest common denominator" model is being built, care should be taken to close as few options as possible. If this is done, the modeling effort can generate a family of models with a common core and the capability for disparate application.

A PLAN FOR MODEL DEVELOPMENT

Computer simulation models can process vast quantities of information, data, and judgements to bring them to a form useful for policy assessment and design. That is their power, but unless they are constructed and presented so that they can be used, they have no role whatsoever. Model-building is a highly dynamic process where the state of a model at any point in time is determined by clients, model-builders, and technical factors such as the information available to both and the available computer capacity.

The key to the usefulness of policy-oriented simulation models is the relationship between the model-builder and the policy-maker. Some care must be given to building this relationship early in the exercise. The model-builder must understand what the policy-maker needs, and the latter must have a feeling for what the former can provide him and how it will fit into his decision-making structure. Neither of these points can be generalized. The policy-maker may need help in assessing the differences between available options, getting a feel for the wider implications of options he has already chosen, or designing new and unique options. But what he needs depends on the nature and dynamics of the particular problems at hand as well as his own personality and position. In the same way, model-builders can deliver advice, predictions, projections, or interpretations at varying levels of sophistication and detail. These are also in accordance with their personalities and backgrounds.

Policy modeling is an iterative process. The model-builder must proceed on the basis of tentative understandings of the system as the policy-maker sees it, and his view of the system and the nature of the model he builds are updated through interaction with his client. These understandings must be tentative, both because complex policy systems in the real world are constantly changing, and also because it is unrealistic to expect that a model-builder's perception of the system is good enough that he can build the right model the first time.

Perhaps the first basis that needs to be agreed on concerns the taxonomies of the overall analysis. What actors must be considered? For agricultural policy, this clearly includes farmers and numerous government agencies. It probably includes marketers for agricultural chemicals and machinery, if they affect farmers' decisions on uses of fertilizers and pesticides. But the system may respond very strongly to people who have no direct role in agriculture and who would almost certainly be overlooked by a modeler. Examples are pressure groups and agencies regulating agricultural inputs or commodities. Next, what is the problem as perceived by the policy-maker? How does this perception correspond to that of the other actors, and what do the differences in perception say about the nature of the system? Are there instruments which might be available for solving the problem but which are not being used, or which could be used better? What constrains people's actions? We are commonly aware of the legislative constraints, but the indirect constraints which stem from culture, tradition, or the structural interactions among actors or institutions may be equally important.

It goes without saying that no model is ever complete; nor can any model be expected to show complete correspondence with the real world. Simply because the model-builder is aware of the important actors, their perceptions of the system, and the instruments available and the constraints on their use, does not mean that he should or even could include them in his model. Indeed one of the greatest advantages of the scenario approach is that it enables model-builders to build simple models for which data are sufficient for parameter estimation, and for which the critical questions can still be addressed within the context of the overall analysis. If the model is built in a modular fashion, then it is relatively easy to make technical changes or even to have multiple groups working on a single model. In this fashion, the shared expertise of various groups of modelers and policy-makers can be brought to bear for the benefit of all of the constituent groups, while the different missions, approaches, and biases of the groups remain separate and mutually supportive, while allowing checks on each other.

FIGURE CAPTIONS

Figure 1: Schema of policy process

Figure 2: Examples of policy actors involved in food systems in a typical country, arranged by decreasing power from top to bottom, showing some types of interactions among actors. Emphasis is more on "downward" or "horizontal" actions. "Upward" actions (e.g. a strike) are only left out in order not to confuse the diagram.

Figure 3: Venn diagram showing a few important interactions among several disciplines with respect to agricultural production questions. Disciplines considered are agricultural production, development economics, water resources, ecology, and soil science. The interactions point out at least 12 issues or foci which might be considered in a comprehensive view of the problem. The descriptions below are only suggestive of these issues. There are many more. Likewise, there are many other possible patterns for intersections among the disciplines.

A. Effect of technological growth on agricultural production.
B. Effect of technological growth on irrigation technology and response to irrigation.
C. Competition for water between agricultural and nonagricultural sectors.
D. Pest control and other ecological aspects of agricultural production.
E. Pest control and fertilizer responses of irrigated agriculture.
F. Soil pollution in irrigated agriculture; production response to changes in soil biota.
G. Soil erosion, production response to soil pollution.
H. Soil erosion, fertilizer leaching.
I. Salinization; waterlogging of soils.
J. Assessment of irrigation potential.
K. Soil biota and salt content of irrigated soil.
L. Yield responses of irrigated crops.

Figure 4: Diagrammatic disaggregation of an economy showing agriculture in a broader sense (inside dashed line) in relation to the rest of the economy.

Figure 5: Diagrammatic system showing process a through g and the flows of information among them. While the figure is abstract, it may be helpful to associate f and g with market and allocation processes, respectively, a and e with land use and technological inputs, respectively, c with inputs to livestock, and b and d with crop and livestock production, respectively.

Figure 6: Diagrammatic system showing processes a through g arrayed in a hierarchical system with three levels, I through III. If the processes are the same as in Figure 5, then level II refers to the functions of the farmer as governed to some degree by society (level III); level I refers to the field-level processes which result in production. For the nature of the connection, see text and Figure 7.

Figure 7: Interactions between controlling and controlled systems.

Figure 8: The simplified system shown if Figures 5 and 6 illustrating some of the actions possible for some of the actors in the system. The actors included are as follows:

G: Government: national and local
I: International agencies, moneylenders, and corporations
M: Manufacturing firms within the country
L: Landowners: large and small
F: Farm operators: tenants, owner-operators

The actions noted are as follows:

1: Taxing and incentives
2: Competition: both market-oriented and political
3: Investment patterns
4: Technological R&D support
5: Market responses and assessment of future development
6: Land-use patterns
7: Care provided, expertise, services available
8: Market manipulation, control
9: Support for farm-market transportation

Figure 9: Schema for the scenario analysis process.

Figure 10: Schema for user-model interaction within the scenario analysis process. A scenario policy constellation Po is specified as an exogenous input so that it operates on (*) the model system So. The model is then run,

and its state changes from So to Sl. From this altered system state, we can deduce certain indicators Il which allow the user to determine the effectiveness of his policy scenario Po to meet his goals. In general, it will be useful to compose a new policy scenario Pl based on the increase in system understanding, and repeat the process.

REFERENCES

Arnaszus, H., 1974. Spieltheorie und Nutzenbegriff aus marxistischer Sicht. Frankfurt am Main: Suhrkamp-Verlag, KG.: 262 pp.

Biswas, A.K., 1975. Mathematical Modelling and Environmental Decision-Making. Ecol. Mod. 1:31-48.

Biswas, A.K., 1976. Systems Approach to Water Management, New York: McGraw Hill, Inc. xvii + 429.

Bossel, H., (ed.), 1977. Concepts and Tools of Computer-Assisted Policy Analysis. Basel: Birkhaeuser Verlag, 3 vol.

Carr, A.B., 1976. Use of Scenario Writing in Assessing Technology. Jour. Int. Soc. Tech. Assessment, Fall 1976, 27-30.

Clapham, W.B., Jr., 1977. National/Regional Agriculture Production Model. Cleveland: Case Western Reserve University SRC Report 77-1, 4 vols.

Committee on Water Resources Planning, Water Resources and Management Div., 1976. Forecasts and the Role of Alternative Futures. Jour. Water Res. Plan. Management Div., Proc. Am. Soc. Civil. Eng. 102 (WR2): 365-383.

Dillon, J.L., 1976. The Economics of Systems Research. Agric. Syst. 1: 5-22.

Dinkel, J.J., and Erickson, J.E., 1978. Multiple Objectives in Environmental Protection Programs. Policy Sci. 9: 87-96.

Donald, A., 1976. On the Stating of Goals. Jour. Syst. Engineering 4: 89-95.

Goeller, B.F., et al., 1977. Protecting an Estuary from Floods--A Policy Analysis of the Oosterschelde. Vol. 1: Summary. RAND Corp. Publ. R-2121/1-Neth.: xxxi + 153.

Haimes, Y.Y., Hall, W.A., and Freedman, H.T., 1975. Multiobjective Optimization in Water Resources Systems. Amsterdam: Elsevier Scientific Publishing Company, xiv + 200.

Heady, E.O., 1978. Personal communication regarding extensions and uses of Stoecker et al., 1978.

Jenkins, W.I., 1978. Policy Analysis: A Political and Organizational Perspective. London: Martin Robertson, x + 278.

Kahales, H., 1977. Long-Range Planning--An Open Systems Review. Long Range Planning 10: 78-82.

Kantor, P., and Nelson, R.J., 1979. Social Decision Making in the Presence of Complex Goals, Ethics, and the Environment. Theory and Decision 10: 181-200.

Knauer, P., 1978. Zur Aussagefaehigkeit und Anwendbarkeit der Szenario-Methode. Analysen und Prognosen 55: 13-15.

Kopelman, J.B., and Weaver, N.L., 1978. Energy Modeling as a Tool for Planning. Long Range Planning 11: 25-33.

Majone, G., 1976. Choice Among Policy Instruments for Pollution Control. Policy Anal. 2: 589-613.

Martino, J.P., and Lenz, R.C., Jr., 1977. Barriers to Use of Policy-Relevant Information by Decision-Makers. Tech. Forecasting and Social Change 10: 381-390.

Mendell, J.S., and Tanner, W.L., 1975. In Technology Assessment, Process is More Important than Product: or Throw Out the Assessment and Keep the Assessor. Jour. Int. Soc. Tech. Assessment, Sept. 1975: 22-29.

Mesarovic, M.D., Macko, D., and Takahara, Y., 1970. Theory of Hierarchical Multilevel Systems. New York: Academic Press: 294 pp.

Mesarovic, M.D., and Pestel, E., 1974. Mankind at the Turning Point. New York: Dutton: 184 pp.

Mesarovic, M.D., Pestel, E., et al., 1974. Multilevel Computer Model of World Development System. Laxenburg, Austria: Int. Inst. Appl. Systems Analysis. Special Publ. SP-74-04, 6 vols.

Quade, E.S., 1971. The Systems Approach and Public Policy. Jour. Syst. Engineering 2(1): 23-34.

Quade, E.S., 1975. Analysis for Public Decisions. New York: American Elsevier, ix + 324.

Rapoport, A., 1979. Mathematische Modelle in den Sozialwissenschaften. Wuerzburg/Wien: Physica Verlag.

Royston, M.G., and Perkowski, J.C., 1975. Determination of the Priority of "Actors" in the Framework of Environmental Management. Envir. Cons. 2: 137-144.

Schultze, C.L., 1968. The Politics and Economics of Public Spending. Washington: Brookings Inst.

Spofford, W.O., Russell, C.S., and Kelly, R.A., 1976. Environmental Quality Management: An Application to the Delaware Valley. Washington: Resources for the Future, xxi+188.

Stoecker, A.L., Nicol, K.J., Sriplung, S., 1978. Structure of a Recursive Model for Policy Analysis in Thailand. Ames, Iowa: DAE-CARD Sector Analysis Series, No. 11, v + 56.

Vanston, J.H., Jr., Frisbie, W.P., Lopreato, S.C., and Poston, D.L., Jr., 1977. Alternative Scenario Planning. Tech. Forecasting and Social Change 10: 159-180.

Wall, G., 1976. National Coping Styles: Policies to Combat Environmental Problems. Int. Jour. Env. Studies 9: 239-245.

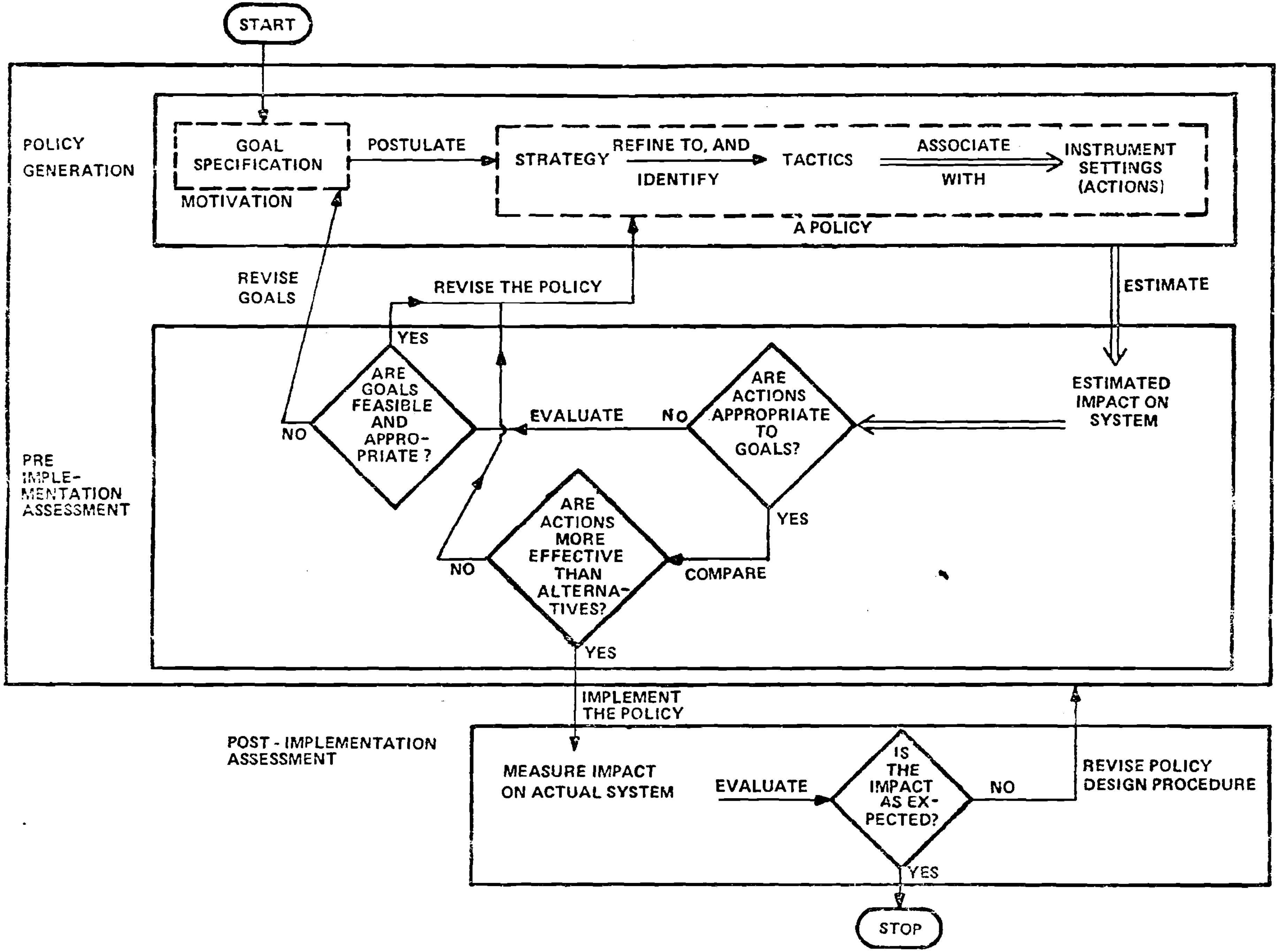


Figure 1 Scheme of policy process.

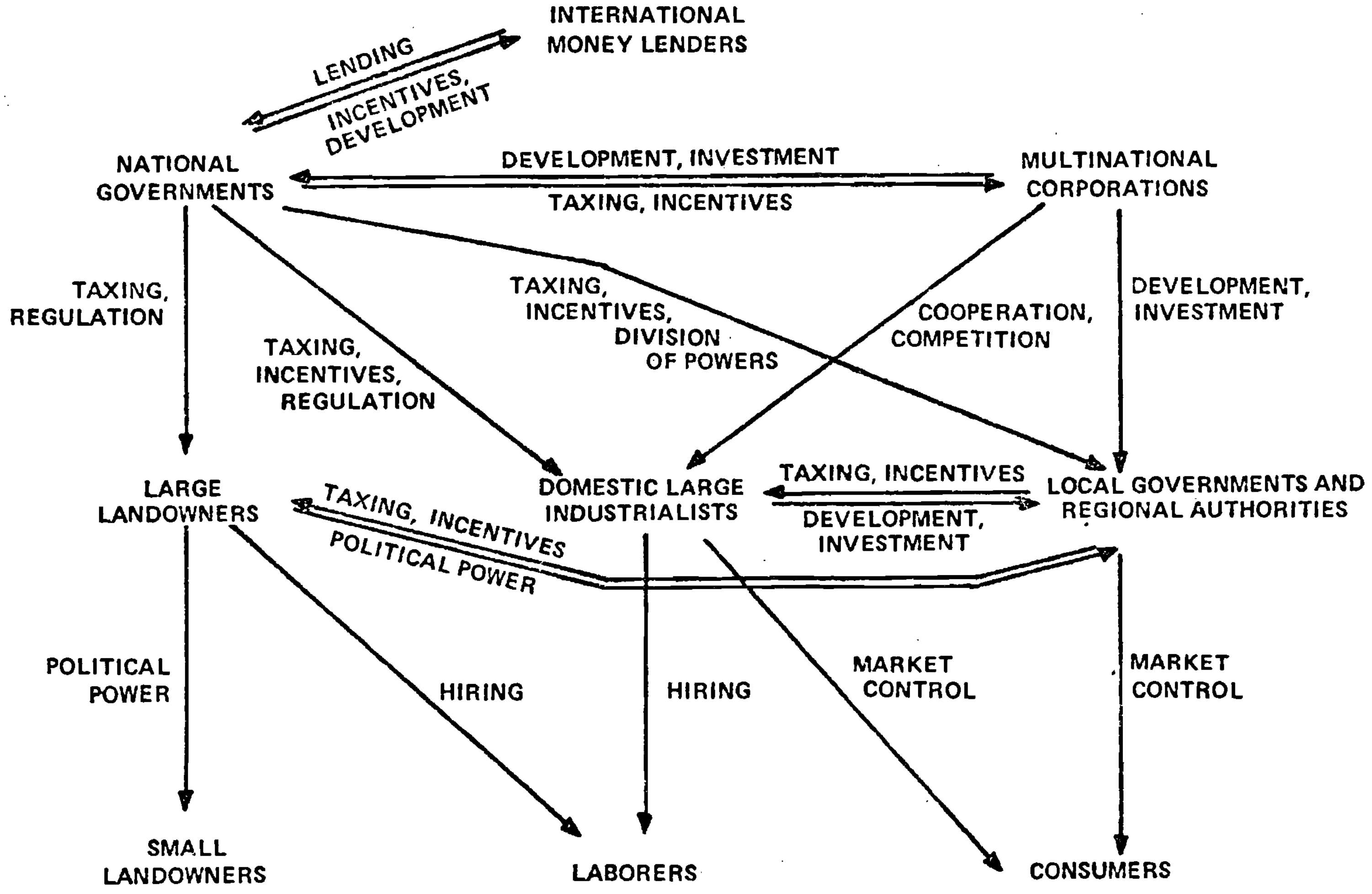
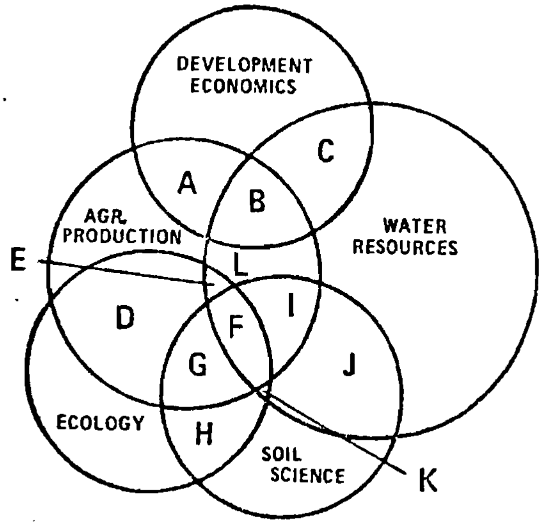


Figure 2 Examples of policy actors involved in food systems in a typical country, arranged by decreasing power from top to bottom, showing some types of interactions among actors. Emphasis is more on the "downward" or "horizontal" actions. "Upward" actions (e.g., a strike) are only left out in order not to clog the diagram.



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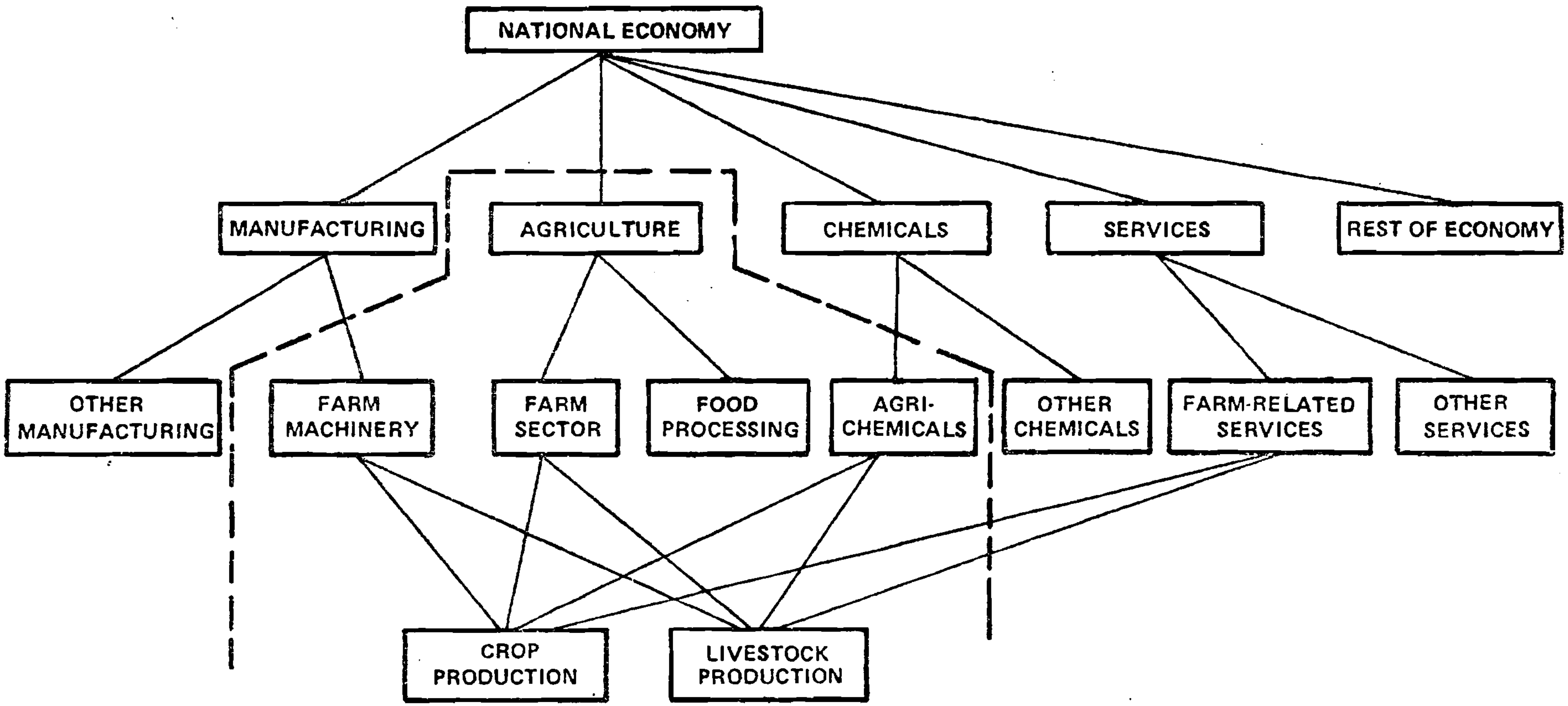

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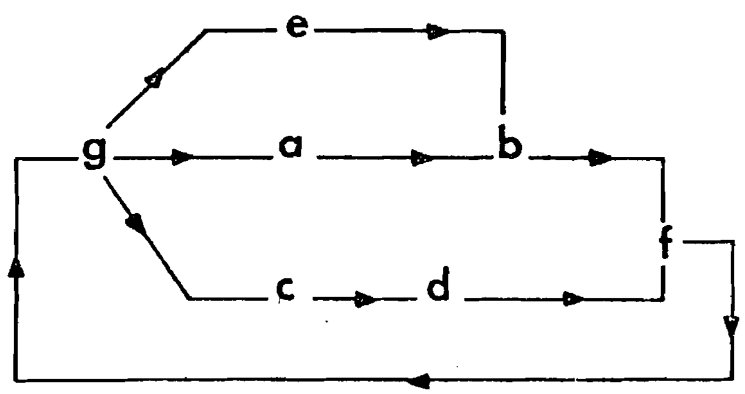

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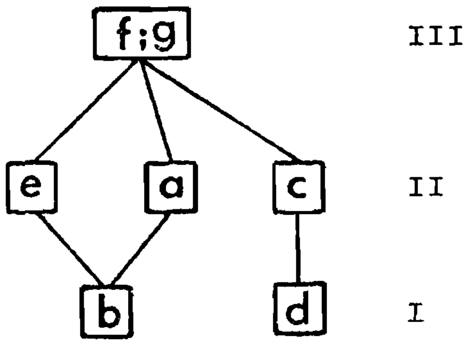

Figure 6 Diagrammatic system showing processes a through g arrayed in a multilevel hierarchical system with three strata I through III. If the processes are the same as in Figure 8, then stratum III refers to the functions of the farmer as governed to some degree by stratum III; stratum I refers to the field-level processes which result in production. For the nature of the connection, see text and Figure 10.

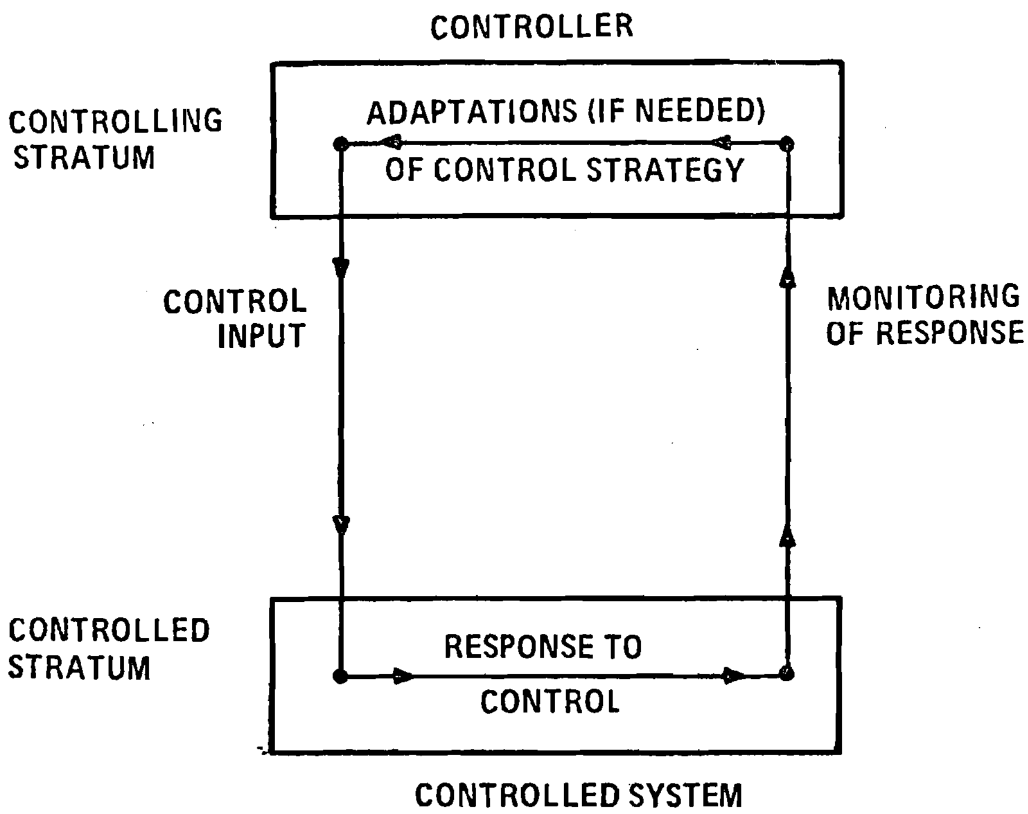

Figure 7 Interactions between controlling and controlled system.

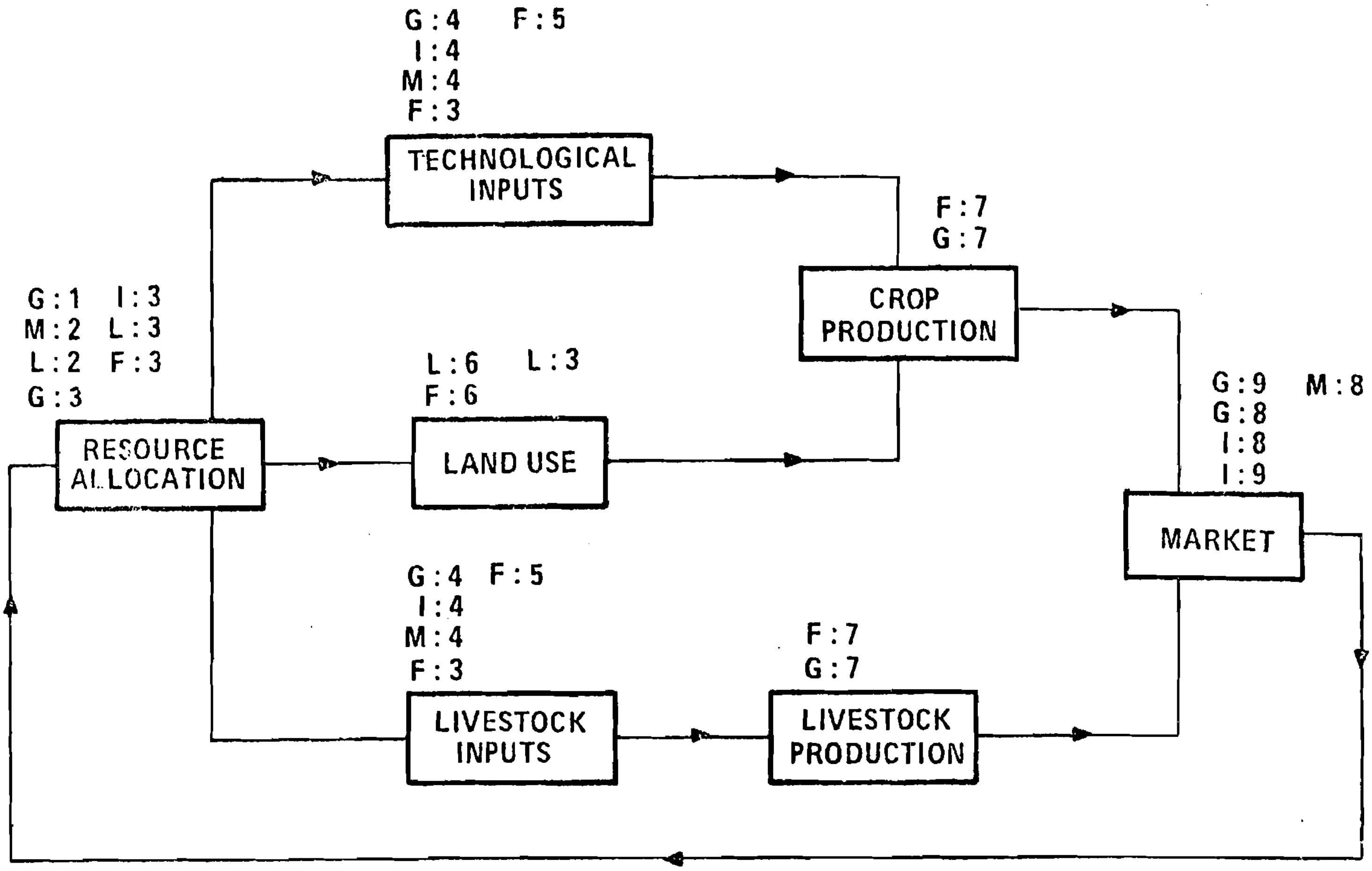

Figure 8. The simplified system shown in Figures 8 and 9 showing some of the actions possible for some of the actors in the system. The actors included are as follows:

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I: International agencies, moneylenders, and corporations
M: Manufacturing firms within country
L: Landowners, large and small
F: Farm operators, tenants, owner-operators

The actions noted are as follows:

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5. Market responses and assessment of future developments
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7. Care provided, expertise, services available
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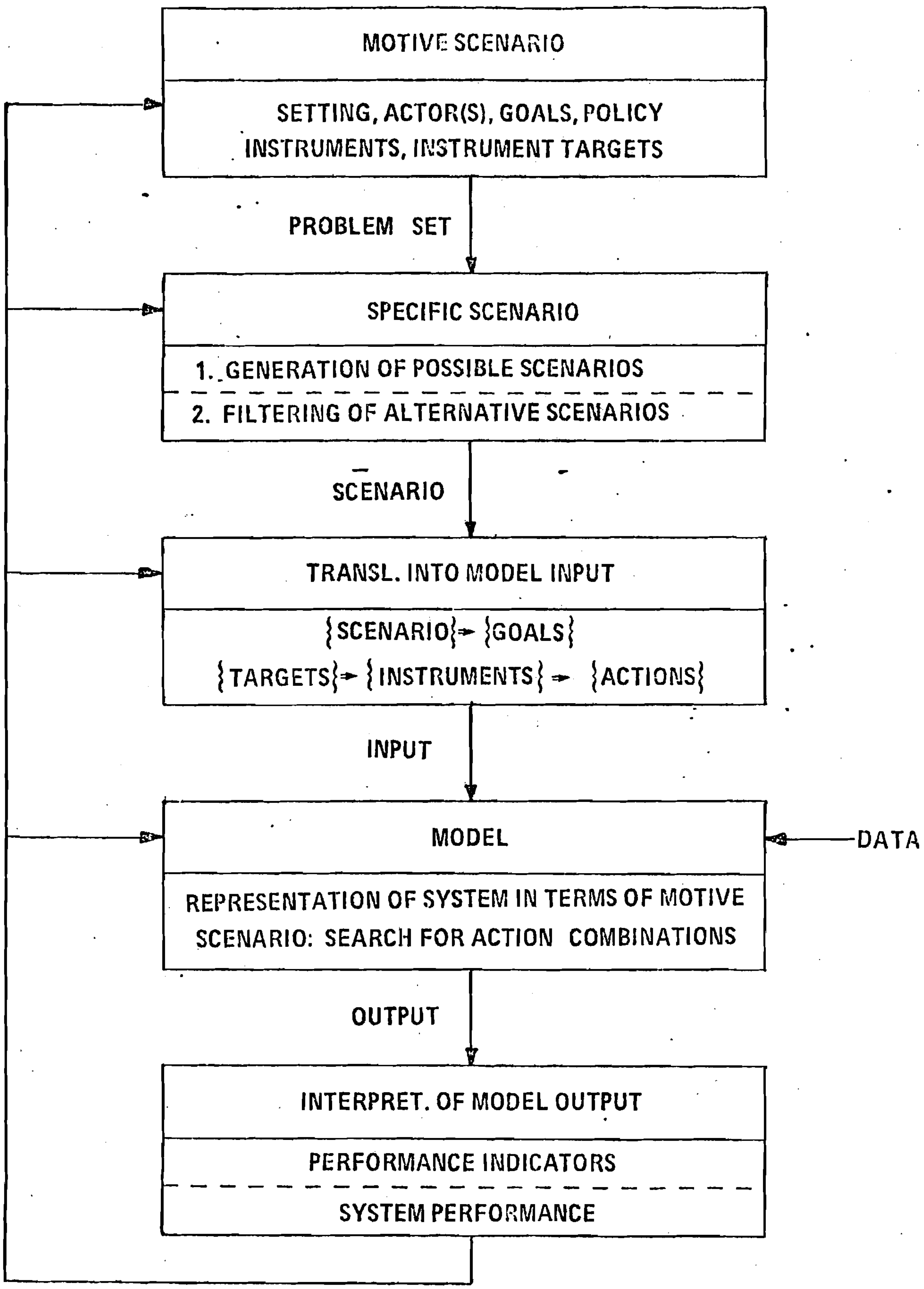

Figure 9 Schematic diagram of the scenario analysis process.

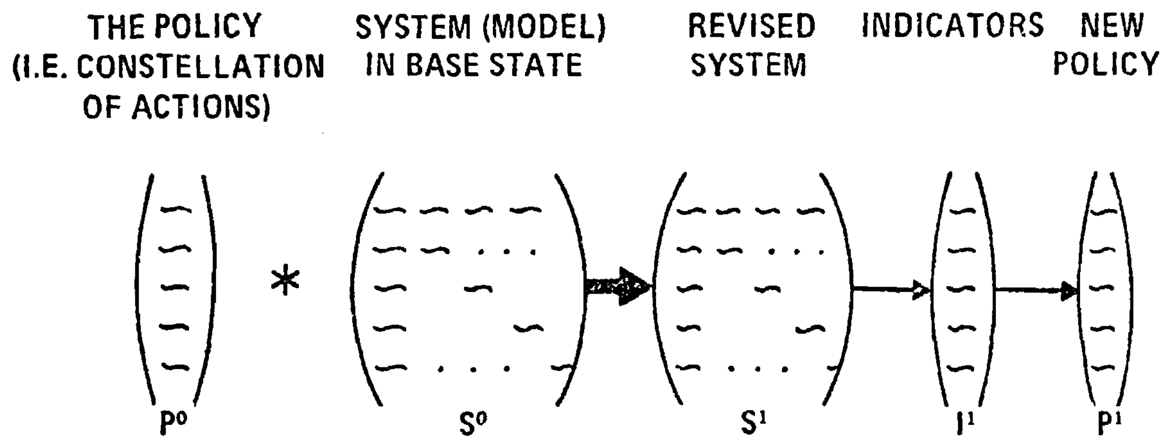

Figure 10 Schema for user-model interaction within the scenario analysis process. A scenario policy constellation P^0 is specified as an exogenous input so that it operates on (*) the model system S^0. The model is then run, and its state changes from S^0 to S^1. From this altered system state we can deduce certain indicators I^1 which allow the user to determine the effectiveness of his policy scenario P^0 to meet his goals. In general, it will be useful to compose a new policy scenario P^1 based on the increase in system understanding, and repeat the process.