A MULTIDISCIPLINARY APPROACH TO THE MODELLING OF A SOCIOECONOMIC SYSTEM

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ABSTRACT

Multidisciplinary teamwork involving six widely different disciplines is described within the context of a dynamic model of northwest Ontario, Canada. This project is aimed at the application of dynamic modelling to the study of telecommunications development in Canada. Suggestions are made as to how multidisciplinary projects can be usefully undertaken in universities. The basic concepts of dynamic modelling are reviewed and the relation of these mathematical concepts to an actual socioeconomic system is clearly explained. Dynamic modelling is shown to provide an effective way to focus the attentions of the members of multidisciplinary teams, enabling many diverse disciplinary viewpoints to be brought together.

I. INTRODUCTION

The phrase, "Socioeconomic System", is still capable of arousing intense and hostile reactions among some writers schooled in the more literary descriptions of human affairs. Yet the word "system" is innocent enough, being typically defined as "a complex whole, a set of connected parts forming an organized body of material or immaterial things". Even more likely to arouse violent and emotional attacks is the concept of "modelling" such human affairs. But, as has been well pointed out by Forrester [1], among others, we all use models of some kind to aid us in conceptual thought. Mathematical modelling is the very core of engineering and the physical sciences and has proven to be of great value in the understanding of complex physical systems. It therefore seems well worth the attempt to see whether such mathematical modelling techniques can be applied usefully to the much more complicated socioeconomic systems that describe our human activities. Certainly, the non-mathematical methods applied in the past to the planning of our human environment cannot be said to have met with uniform success.

A major difficulty, when compared with physical systems, at once arises: the problem of performing controlled experiments to test the validity of the models. Apart from the mere complexity of such systems, there is the ever-present danger of the observer disturbing the experiment, as well as the important additional aspect of ethical considerations. What, then, are the alternatives? We can say all such studies should be avoided as impossible and unethical; or we can try to do the best we can to explore what is possible with full consideration of our limitations and of the ethical implications.

It becomes immediately obvious that a training in systems analysis alone, however supplemented by the individual's natural sympathy with his fellow-creatures, cannot possibly be adequate; nor can any one or more persons be expected to become competent in each of the disciplines involved. Clearly, any such attempt to investigate the feasibility of modelling a socioeconomic system must be made by a multidisciplinary team.

During the course of the next decade or two new disciplines will no doubt emerge in our universities and institutes that appropriately combine subjects from those presently considered as more or less independent areas of study. But this will only be a temporary and apparent solution as they too, in their time, will become the frozen orthodoxies of their age, just as modern engineering has largely become fixed in those moulds that were appropriate at the end of the last century. Thus there will always be a pressing need for people trained in different disciplines to work constructively together as teams, with an immediate need being apparent for such teams to cross what might be called the socio-technical demarcation boundary.

This paper describes a particular ongoing project, now in its third year, being carried out by a multidisciplinary team that includes six different disciplines: biology, business administration, electrical engineering, political studies, psychology and sociology. Its object is to investigate the application of dynamic modelling to the study of telecommunications development in Canada. While studies of the impact of technology on society are becoming increasingly numerous, with some concentrated on telecommunications impact in particular, there does not yet seem to have been any widely reported study on the use of dynamic modelling to assess telecommunications impact, although the authors are aware of a new study recently started at the University of Queensland, Australia.

The project described here is presented as an example, written with a strong tutorial intent, of how a multidisciplinary team has combined to work on a study of a socioeconomic system, having the building of dynamic models as a central focus, but with no pretence being made that this is on its own an exhaustive review of the entire subject.

In the subsequent sections of this paper a background discussion is presented of the project and how the multidisciplinary team is coordinated, followed by a review of the modelling process and its use in multidisciplinary research. A description is then given of the main model completed so far (of an entire region), with comments included on how it is planned to adapt this experience to models of individual communities, within the overall goal of assessing the impact of telecommunications technology.

II MULTIDISCIPLINARY TEAMWORK

The region under consideration is that of northwest Ontario, as shown in Fig. 1. This region is not untypical of much of Canada in that it has its own metropolis, Thunder Bay, within which lives the great majority of the population, and a vast hinterland containing few people spread among a large number of small communities of varying degrees of isolation. The impact of telecommunications on such a region is of great importance as, quite suddenly, even some of the remotest communities are about to have, or already have, modern wide-band telecommunications facilities for the very first time. Part of this drastic change is due to the availability of Anik, Canada's domestic communications satellite. Part is due also to the rapidly growing interest in the region, provoked to a considerable extent by the increasing political awareness of the local population, which is largely native in the more remote areas. This growing interest has already led, for instance, to the installation of a modern high-frequency single-sideband radio telephone network for intercommunication among twenty-five small native communities. In addition, the availability of radio and television broadcasting is being dramatically changed with the advent of wideband distribution networks even in quite remote areas. Apart from the Canadian Broadcasting Corporation's radio and television networks, there is an increasing demand for truly local radio stations, as well as a developing interest in the possible use of videotape as a communications medium in outlying communities.

The mutual dependence between telecommunications and the economics of a region has long been a basis for the planning of telephone networks. Similarly, broadcasting has made much use of audience surveys, which constitute one of the many examples of sociological studies. These, and many other aspects of communications, on a world basis, are very usefully surveyed by Cherry [2]. Political considerations are also of great importance in any study of telecommunications planning, especially in relation to the regulation and licensing of services, as well as to the nature of policy-making itself. What is not so obvious, perhaps, is where psychology and biology enter into the study.

As is indicated later in this paper, it was rapidly found at the start of this study that any wide-ranging dynamic model of telecommunications impact would have to include what essentially became an overall dynamic model of the entire region or community under consideration, if all the major interactions were to be identified and investigated. At first sight, in fact, the telecommunications itself became a relatively small part of the model of the region or community. Once this step had been taken, the additional aspects of demography, health and education services, transportation, mail, tourism, natural resources, environmental, cultural and psychological factors, all became important in addition to the more obvious categories of telephones, broadcasting, income and capital investment. Hence arose the particular choice in this study of a team made up of expertise in the six disciplines shown in Fig. 2, with experience in both communications technology and systems analysis being provided by electrical engineers.

A. Coordination

What follows is not intended as a universal recipe for successful multidisciplinary cooperation but is, nevertheless, a description of how one such team has managed to combine to produce useful work over a fairly lengthy period of time.

This project is being performed within a university under a contract with a Canadian government agency. Surely, if anywhere, multidisciplinary cooperation should be easy to arrange in a university where almost all conceivable disciplines are being studied concurrently within one overall institution. Unfortunately, this is not so. Universities have their own rigidities and, without some support from the higher administration, it is difficult to organize anything of significant size involving many different departments and faculties. In most North American universities the department is the key unit and there is still a strong tendency on the part of some members to criticize as a waste of time and effort any work that cannot be classified as belonging to any one department, and hence to any one discipline. Even if such a multidisciplinary team can be organized, universities, like many other institutions, sometimes have a tendency to impose their own paralyzing bureaucracy on the activity, in the form of over-elaborate advisory committees and reporting procedures. These committees are no doubt well-intended, but their effect can be to put the smothering blanket of caution and delay, which some interpret as wisdom, on the lively but delicate flame of enthusiasm of the actual participants in the project. However, if universities have their difficulties, it is probably much easier to perform multidisciplinary work in them than in government or industry, not least because they have a continuing core of permanent staff from many disciplines, usually on full-time appointments, as well as a repeated influx of fresh and talented potential participants in the form of students, both undergraduate and graduate, and young research assistants. Universities are probably unique in their potential for undertaking relatively short-term projects, with personnel of the very highest calibre having the possibility of coming together for a particular project, then dispersing at its end to other projects, possibly in combination with yet other and different disciplines.

Such is undoubtedly the potential of universities. Once the organizational and structural problems of the university as a whole have been overcome, how can the individual persons be brought to work together productively? Professorial staff are well known for their independence; even within their own individual departments it is usually impossible to coerce them into research projects not of their own choosing. Clearly, an elaborate vertical pyramid of command and responsibility, with precisely defined reporting procedures, is not the most appropriate, especially if the project is of only moderate size (i.e. not more than 20 people, including all students and assistants). In these cases, a horizontal rather than vertical pattern is both possible and desirable - a band of equal co-investigators. If possible, one co-investigator then acts as overall coordinator, but without taking unto himself any of the elaborate trappings of status or titles ("Director", etc.). If such an individual can gain the trust and respect of the other co-investigators it is probably far more efficient than having all decisions made in sub-committees or committees of the whole.

It is not often realized by engineers that close cooperation between, for instance, social scientists in two or more different specializations is often as difficult to achieve as is that between social scientists and engineers. To consider a more extreme example, why should a sociologist want to work with an engineering systems analyst? Certainly, it is not because the sociologist wishes to beome an engineer (and vice versa). In most cases, the best that can be hoped for is that, through a desire for cooperation, a genuine sympathy with the broad principles of the other's field of knowledge can be developed. Then the two can work on closely related topics (e.g. demography and a dynamic model of population) with mutual respect, and with a willingness to be receptive to ideas from the other discipline no matter how badly expressed or childish they may appear to be. One of the keys to cooperation then, is that each co-investigator have a subject to pursue, which is of interest within his or her own discipline, while at the same time forming a useful part of the whole project. It is a major mistake to insist that they do only what is dictated by some central "director" 's concept of what, say, "useful sociology" is.

As a result of this more flexible approach, publications arise that fall into two classes: papers describing the work as a whole, presented, or written, by several co-authors and published in relatively unorthodox journals and conferences; papers by individual co-investigators, perhaps with their assistants and students, on particular aspects of the work that are appropriate to presentation within their traditional disciplines.

It should be emphasized, however, that no useful cooperation is possible without every single co-investigator being willing to adapt her or his interests to some extent towards those of the whole team. The point here is that such adaptation need not remove these persons from their disciplines, within which their careers must, to a very large extent, continue to lie.

Undoubtedly a key part of this particular project has been the involvement of a number of young students and assistants. Throughout the work each disciplinary area has had associated with it one, in some cases two, co-investigators, and at least one student or research assistant, paid out of the project's funds. (With the exception of the systems analyst, none of the co-investigators receives any direct remuneration for work on this project.) All the co-investigators are involved in many other activities and the involvement of these assistants and students, under their guidance, is essential, while at the same time fulfilling some of the educational functions of the university.

It is most noteworthy how much easier it is for these students and assistants, than for the established career professionals, to cooperate across the traditional boundaries of their disciplines. In addition to their natural flexibility of outlook, being not yet rigidly committed to wearing one particular professional label (such as "electrical engineer"), they have shown a consistent and exciting enthusiasm for multidisciplinary work, welcoming the opportunity to work in a team with members of other disciplines and to learn other viewpoints. This has been one of the most encouraging aspects of the entire project and points to the need for many more such research opportunities in our universities if the next generation is to be better equipped to handle some of our pressing socioeconomic problems.

Investigation of dynamic modelling as a possible tool in telecommunications planning is the central aim of this work. Experience has shown that quite apart from the usefulness of the model itself when in its final form, the goal of building models of particular regions and communities, has acted as a most valuable central focus for all the participants in the study, helping rather than hindering cooperation between disciplines, without there being a strong need for more than one or two participants to have a detailed mathematical understanding of the structure and operation of the models themselves.

III MODELLING SOCIAL SYSTEMS

In the preceding section, the nature of multidisciplinary teamwork and its attendant problems have been discussed. It was indicated that while there are a number of ways of carrying out a multidisciplinary study of a socioeconomic system, the particular research to be reported here has used the development of a dynamic computer simulation model as a focal point for cooperative effort. As mentioned previously, this cooperation should not only be viewed as being between engineers and social scientists, but between all the disciplines involved.

The increasing involvement of engineers in the development of socioeconomic models can probably be attributed to two facts. First, it is felt that technology, in particular the rapid rate at which technology is being applied, is a major factor in the creation of existing social disorders. Hence it would seem reasonable for technologists to be increasingly concerned with the understanding of these problems. In the case of the modelling of telecommunications impact it would thus be reasonable to expect a useful input from communications engineers. Second, engineers, especially those with a training in systems analysis, can bring considerable expertise to the model building process.

A. Model Types and Their Uses

Since the word "model" can have a wide range of meaning, including the "mental models" described by Forrester [1] which we all use to make day-to-day decisions, it is useful to consider some classification of model types. Mihram [3] has made a comprehensive classification based on two dimensions: the degree of the model's generality and its degree of abstraction. The least general and least abstract models are static replications of the real system; the most general and most abstract are stochastic differential equations. The choice of the degree of abstraction and generality of a model must be based on some knowledge of the nature of the system being modelled, the quantity of that knowledge and the use to which the model will be put. In the case of a socioeconomic system, and with a desire to use the model as an input to the planning process, it will be assumed that a symbolic rather than material model is desired and that a capability to depict dynamic behaviour is required.

The role of models as planning tools is reviewed in [4]. The ability of a model to forecast future behaviour of the real system is of major importance if it is to be used in the planning process. This forecasting ability implies that a suitably high degree of confidence in the model's validity must be established. This validation process is discussed later in this section.

Besides serving as a forecasting tool for planning in a socioeconomic system, a model, or more correctly, a model building task, performs a role in helping to understand the system under study. In other words, the modelling process serves as a vehicle for a form of the so-called scientific method of problem solving. This is an especially important function of the modelling process in a multidisciplinary study where it is to form the central focus for several diverse disciplines. Whether a model which has contributed to the learning process during its development can at some point be used as a planning tool depends on the degree of confidence that can be established regarding the model's ability to mimic the real system. As well, a planner is obliged to use the best available information about the system. Thus whether or not a model is useful as a planning tool depends on the alternative tools that he has. This fact has been pointed out by Forrester [5] in connection with the system dynamics world model.

B. The Modelling Process

In this section we will discuss the process of model building as applied to a socioeconomic system where it is desired to produce a dynamic computer simulation model. Five steps can be identified:

(1) Choice of level of abstraction and generality - The choice of the variables in the system which are of interest is closely related to the questions of abstraction and generality. As previously mentioned, this choice is governed by the state of knowledge available concerning the real system, the use to which the model will be put and the available resources of time and effort.

(2) Collection and analysis of available knowledge - Available knowledge about the real system will take the form of measured data and/or expert opinion. Both can be used to identify the interactions between the variables chosen in step (1). The literature on this subject is extensive. For example, econometric models use regression analysis of time series data

to establish relationships between economic variables. With regard to system dynamics models, Young et al. [6] describe a quasi-linearization identification scheme to determine parameters to which the model appears most sensitive. In the absence of data, relationships between variables are necessarily established based on expert opinion. In these cases, such opinion can best be obtained using a multidisciplinary approach as described here. It should be emphasized that the lack of a complete data base relating to the system does not prevent the model builder from developing at least an exploratory model which can be used to identify areas where further research is required.

(3) Formulation of the system equations -
The dynamic equations describing the desired and/or hypothesized relationships postulated in step (2) represent a mathematical description of the structure of the system. These equations can be viewed as integral or differential equations. Forrester [1] and others [7] have argued that viewing the system states as "levels" which are altered by input and output flows is a more natural way of viewing the real world. Whether this is true or not, this approach has shown itself to be useful in discussing model structure in a multidisciplinary environment where the concept of differential equations is not uniformly well understood. The system dynamics formulation

of the system equations will be reviewed later in this paper.

(4) Model Simulation -

The system equations developed in step (3) are immediately amenable to solution using a digital, analogue or hybrid computer. Generally a digital simulation using an appropriate numerical integration scheme is adequate for socioeconomic systems with reasonably stable behaviour. The choice of a programming language is relatively unimportant but should take into account the background of the personnel involved in this aspect of the model building. Included in this step is the process of verification which Mihram [3] describes as the comparison of the response of the model to a given set of initial conditions and exogenous inputs to that theoretically anticipated. Verification tests often uncover incorrect formulation of the relationships postulated in step (2). Thus modifications to the system equations can be made, followed by further verification tests.

(5) Validation -

The process of validation of simulation models has been dealt with quite extensively (for example, see [8] and [9]). In the case of models which include a large number of postulated relationships based on expert opinion (such as the Forrester world model [1] and that described in this paper), Chen [10] points out that validation would be difficult even if historical data were available. Thus one should not ask whether such models could be validated but how they should be put to use.

C. The System Dynamics Formulation

From several standpoints, the state space formulation used by Forrester in modelling industrial [11], urban [12] and global [1] systems, possesses a number of advantages over other modelling techniques. As previously mentioned, the concept of viewing the dynamic behaviour of the system states as arising from the integration of input and output flow rates has shown itself to be helpful for researchers in the social sciences who have no background in system theory or mathematics. In formulating the model structure, the question can be asked - "What factors (i.e. what variables) are likely to affect the increase in a particular state?". As a result of asking this type of question for each flow rate, the dynamics of the system are dealt with directly compared with, say, a regression model which may not reflect the true "structure" of the system. The emphasis of the system dynamics formulation on system structure rather than data is described by Schroeder [13]. This feature is a vital one both for increasing understanding of the system and in the planning process.

The mathematical formulation of system dynamics has been discussed elsewhere [6], [14] and will only be summarized here. Each state or "level" which is chosen to represent a salient characteristic quantity in the real system is described by an equation of the form

$$x(t) = x(0) + \int_0^t [r_i(\tau) - r_o(\tau)]d\tau \qquad (1)$$

where $x(t)$ is the value of the level at time t, $x(0)$ is the initial value, $r_i(t)$ is the input flow rate as a function of time and $r_o(t)$ is the output flow rate as a function of time.

The input and output flow rates are functions of the state of the entire system and define the interactions postulated in step (2) of the modelling process. In particular, most system dynamics models use a multiplicative formulation for the flow rate equations which, for the kth state, is of the form

$$r_{ik}(t) = \hat{r}_{ik}\, m_1(x_1)\, m_2(x_2)\, \ldots\, m_n(x_n) \qquad (2)$$

where $\hat{r}_{ik}$ is the "nominal" or "normal" value of the input flow rate (corresponding to the nominal state of the system) and the multiplier functions $m_1, \ldots, m_n$ are functions of the n system states $x_1, \ldots, x_n$. Thus when $r_{ik} = \hat{r}_{ik}$ all the multipliers have the value of unity. One can then ask the question - "If state x_j changes by a particular amount, what will be the effect on rate r_{ik}?". The quantified effect of this change is reflected in the form of $m_j(x_j)$ which in general will be nonlinear. If r_{ik} does not depend on x_j, then $m_j = 1$ for all x_j.

It should be noted that for some levels, such as population, the rate $\hat{r}_i$ will be expressed as a per unit value and the flow rate will be determined by multiplying this value by that of the level in question. Also, in most models of this type, a large number of non-dynamic variables, which are functions of other such variables and/or of certain system states, are defined for convenience, or because they represent real-life quantities for which data are available. Such a variable might be the ratio of food supply (a level) to population (a level). The multiplier functions in (2) can then be functions of these variables. In state space terminology these "variables" (termed "auxiliary variables" by Forrester) might be called output variables which are functions of the system state.

The simulation of a system dynamics model corresponds to the solving of the integral equations (1) for each state, the rate equations (2) and the variable or output equations. Normally, a first order numerical integration scheme is suitable and (1) can be changed to a difference equation of the form

$$x(t+\Delta t) = x(t) + [r_i(t) - r_o(t)]\Delta t \qquad (3)$$

where Δt is a suitably small step size.

Since, in a multidisciplinary environment, only the systems analyst is directly concerned with the formulation of the above equations and their solution, an important facet of the modelling technique is the symbolic representation of the model structure. Figure 3 summarizes the symbols used in the model development described in this paper. In this figure, the two levels (rectangles) are x_1 and x_2. The input flow rate (valve) for x_1 is given by

$$r_{i1}(t) = \hat{r}_{i1}\, m_1(v_1)\, m_2(e_1) \qquad (4)$$

where $\hat{r}_{i1}$ is the nominal value, v_1 is a non-dynamic variable (large circle - a function of x_1 and x_2) and e_1 is an exogenous variable (oval) not affected by the system. The other flow rates are similarly defined. Note that solid lines represent flows of level quantities and dotted lines represent information flow.

A system dynamics model described by the above equations is deterministic although some parameters may have been identified using statistical techniques. In other words, the level trajectories generated by a single computer simulation run convey no information as to the uncertainty of the model behaviour. Although a range of possible trajectories can be obtained by perturbing individual parameters, an exhaustive study of this type for a complex model would be very time consuming. Clearly a need exists for research into at least a partially analytical technique for determining the sensitivity of model behaviour to parameter perturbations. In this way some of the criticism relating to the deterministic nature of system dynamics models would be answered.

IV A REGIONAL SOCIOECONOMIC MODEL

In the previous two sections we have presented a discussion of a multidisciplinary approach to the modelling of socioeconomic systems. In this section we will outline the development of such a model with the object of providing a tool for planning regional telecommunications development. The main purpose of presenting the model here is to illustrate how the multidisciplinary modelling process was applied in this project and the type of results which have been obtained.

First, a brief discussion of the geographic scale of a social system and its relationship to the modelling task will be useful. A possible classification of geographical scale would use the terms (i) global, (ii) national, (iii) regional and (iv) community.

In the modelling of a socioeconomic system on a global scale one is concerned with a closed system in which inputs to the system are generated by the system itself. For this reason, it would appear that viewing such a system in terms of a feedback structure is valid and useful. The problems encountered in global modelling centre around the lack of information available on a world-wide level of aggregation. It would thus be reasonable to expect such models to be more useful as learning than as planning tools.

As one moves from the global to the national and regional geographic scales, the systems encountered tend to have closed-loop feedback structures in some subsectors but to be strongly affected by inputs generated outside the system. Information concerning such systems may or may not be more abundant than for global systems depending on the level of aggregation and the geographic boundaries chosen for the model.

When modelling a community-scale system, one will generally be concerned with variables closely related to the social and psychological behaviour of groups of people. Information about such variables may best be obtained from first-hand studies of the community itself augmented by the relevant literature. To a great extent, the behaviour of the economic and demographic sectors of community systems are due to influences generated outside the community; thus feedback structures may not prove overly useful in modelling such systems.

A. Sectors of the Regional Model

As outlined previously, the overall objective of the modelling study to be described is to investigate the feasibility of using dynamic modelling techniques in a multidisciplinary environment to describe the role of telecommunications in a developing region in Canada. It was quickly evident that telecommunications, and communications in general, have the potential to interact with each of the social, political, economic and environmental sectors of the region. Thus, in order to assess the role of communications, it was realized that a general model for each of these sectors would have to be considered.

The concept of viewing a complex system as a number of interacting subsystems is perhaps artificial in the case of a social system because it is not always clear what groups of variables are most closely related. In some cases, it might be useful to use a cross-impact analysis such as proposed by Love [15] to identify meaningful subsystems. In the multidisciplinary context it was decided that a classification of subsystems relating to the disciplines of the personnel involved would prove most workable. A block diagram of the regional model showing the six subsystems considered is shown in Figure 4. A description of each follows:

(1) Demographic Sector: This sector attempts to relate the regional population size in the age groups 0-14 years, 15-44 years, 45-64 years and 65+ years to changes in education level, health service level and regional attractiveness.

(2) Economic Sector: This sector includes levels of private and government regional investment and relates employment levels to labour supply and demand.

(3) Resources Sector: This sector includes the three main regional resources: mineral resources, timber resources and tourism. The rate of development in each of these areas is related to labour demand and wage rates in the region.

(4) Communications Sector: This sector includes the use and possible impacts of telephones, television, radio, newspapers and magazines, mail service, and various transport modes. As indicated previously, these variables are treated in greater detail than would be the case if the purpose of the modelling task were not to investigate the role of communications.

(5) Environmental Sector: This sector models the aggregate level of pollution related to resource development, population and tourist activity.

(6) Policy Sector: Originally, a submodel relating to the political decision-making process was envisioned. After considerable discussion and investigation of the literature on this subject, it was decided to remove most of the political structure from the model and to identify points in the model where government policy could influence the system. Thus, the model would eventually need to operate in an interactive mode, with the policy-maker supplying policy inputs based on his perception of the state of the system relative to his implicit or explicit goals and values. These policy inputs, together with a number of exogenous variables, comprise the policy sector of the model.

The above descriptions give some idea of the nature of the variables considered in the regional model and hence give an indication as to the levels of generality and abstraction deemed appropriate in this study. These choices, which can be talked of collectively as the level of aggregation, are largely based on the amount of information available about the region being modelled. For example, since the geographic boundaries for the region are not uniformly accepted for purposes of data collection, not all available historical statistical information is directly usable for parameter identification purposes. Also, the diversity of life styles within the region due to the existence of the metropolitan area of Thunder Bay makes it impractical to attempt to include many social and psychological variables describing the region as a whole. In fact, such variables would be closely related to those in any metropolitan area. Of greater interest in assessing the role of communications in the region are the more isolated northern communities. The choice of variables thus reflects a desire to model what is both within the realm of possibility and meaningful for the region as a whole.

B. Data Collection and Analysis

Based on the six sectors described above, data collection and analysis werecarried out by subgroups of the multidisciplinary team. Each subgroup was comprised of a systems analyst and members from the appropriate disciplines including undergraduate students, graduate students and full-time assistants. Preliminary meetings were held to discuss not only modelling techniques but fundamental concepts related to all the disciplines involved. Thus began a process of sharing information which is essential for the development of trust between members.

The first step in the modelling process as applied to one of the six sectors was to decide on a preliminary list of relevant levels and variables around which to develop model structures using available data and information. For example, in the demographic sector, a list of variables is as follows: Levels include regional population in the four age groups previously described, level of education (measured in years of education) and level of health services (measured in time required to receive attention). Variables include those relating to expected levels for regional health and education services, the resulting demand for increased services and the expenditures on improved services. Exogenous variables deemed relevant include levels of health and education services in southern Ontario.

The choice of relevant variables then made possible the asking of questions relating to how these variables and levels are related and how they are linked to other sectors of the model. In the case of the population dynamics, for example, each level has several flow rates associated with it. A simplified flow diagram is shown in Figure 5. Each level has an aging rate approximated by the inverse of the age spread for that level, a death rate and a migration rate which can be either an input or output flow. In addition, the 0-14 age group level has the birth rate as an input flow. Nominal values for each rate were taken to be those observed in 1971 and factors thought likely to modify these values were then considered. For example, the birth rate was defined in terms of the fertility rate (births per unit population per year). That is,

$$BR = (FER)\ (P2) \qquad (5)$$

where BR is the birth rate (births per year) and FER is the fertility rate for population age group P2 (15-44 years). The variable FER was then assumed to be primarily a function of the regional level of health service and the regional education level. Thus,

$$FER = (FERN)\ (F1)\ (F2) \qquad (6)$$

where FERN is the nominal fertility rate (1971), F1 is a function of education level and F2 is a function of health service level. Both functions are equal to unity for 1971. Unfortunately, no historical data concerning education and health service levels were available for the region which, taken together with available data concerning the fertility rate, would permit identification of F1 and F2. However, by comparison of fertility rates and education and health service levels with those presently observed for southern Ontario and based on experience of the group members, the functions F1 and F2 were postulated as shown in Figure 6.

The death rate for population level P1 (0-14 years) is given by

$$DR1 = (DRIN)\ (P1)\ (F3) \tag{7}$$

where DRIN is the nominal per unit death rate in 1971 and F3 is a function of the level of health services. The aging rate for P1 is given by

$$AGR1 = BR\ (t-15;\ DR1) \tag{8}$$

In other words the number of 15 year olds entering age group P2 is equal to the birth rate delayed by 15 years and the accumulative death rate for the 15 year time period. Using the form of equation (3), the difference equation for level P1 is

$$P1(t+\Delta t) = P1(t) + (BR-DR1-AGR1+MIGR1)\ \Delta t \tag{9}$$

where MIGR1 is the migration rate for this age group which is directly related to the migration rate of age group P2.

The above explanation should serve to indicate the manner in which the system equations (i.e. the system structure) can be obtained and the roles played by data and expert opinion in the identification of parameters. At the present time the model contains nearly 100 functions, the majority of which are not based on numerical data. Nevertheless, the relationships are based on the best current information concerning the region and have proved to produce reasonable behaviour during the verification runs reported below.

C. Model Simulation and Verification

During the first year of the study the individual subgroups developed a model for each of the six sectors. Although some models necessarily developed more quickly than others, at the end of the year it was possible to consider consolidating the six sectors into a working simulation model for the region. Based on the computing backgrounds of the team members involved in the computer programming aspects of the modelling process, the computer programme was written in FORTRAN. During initial debugging and verification runs, a batch mode of operation employing a Burroughs B6700 digital computer was used. As will be described later, an interactive mode is presently under development employing a DEC PDP-15 digital computer.

The purpose of the verification process is to ensure that the model response to a variety of initial conditions and exogenous inputs is of the type intended. In other words, by studying the behaviour of individual variables it is possible to locate parameters which have a greater or lesser effect than desired and to readjust these parameters until the model behaviour is reasonable in light of the assumptions made concerning the system structure. Also during these runs, an appraisal of the model's ability to accept and respond to the types of policy decisions that are made by "planners" can be obtained.

The role of the multidisciplinary team in the verification process is then twofold. First it can act as a feedback mechanism between the model behaviour and the alterations in the model structure which need to be made. In this respect, it is important that each team member have a clear understanding of the meaning and significance of the variable trajectories obtained from the various computer runs. It is too easy for engineers or economists to assume that the graphical presentation of data is a universal concept.

In order to illustrate the type of results obtained from verification tests, the model response to two policy inputs will now be described. This example will illustrate the model response to a change in government policy toward subsidization of mineral resource production particularly with regard to employment, income and telephone usage. Figure 7 shows trajectories for the important economic variables for an 80 year time interval beginning in 1971. The solid line trajectories correspond to a policy of no subsidy of the cost of resource production and the dashed line trajectories correspond to a policy of a 15% subsidy (a lowering of costs by 15%) beginning in 1991. The levels of regional proven resources, regional undiscovered resources, mining technology utilization and private capital investment are plotted in Figure 7. It is assumed for this run that undiscovered resources total 5 times the proven resources for 1971.

Figures 8 and 9 show corresponding trajectories for employment variables and telephone usage variables, respectively. Referring to the three figures, it can be seen that the subsidy produces interesting but reasonable effects. With subsidization, resources are developed more rapidly and hence private capital investment increases. The reliance on mining technology is less with subsidization since the subsidy acts to keep costs down without the use of labour-saving technology. What does this mean in terms of employment, wages and telephone usage? Figure 8 indicates an increased demand for labour when the subsidy is in effect. As a consequence, wage levels are slightly elevated so as to cause sufficient immigration to satisfy the labour demand. The regional population necessarily reaches a higher level. Figure 9 indicates a slight increase in telephone density and a significant increase in total calls (due in part to a higher disposable income).

The above example illustrates the type of question which can be asked of the model by a policy maker. In the interactive mode, the simulation run can be halted in any year and changes made to any or all policy inputs (such as the subsidy considered in the example) and the simulation run resumed.

While the regional model is currently undergoing further refinement based on sensitivity and verification tests, its usefulness as a multidisciplinary focus and as a learning tool has been proven. It is in fact unlikely that any formal validation can be attempted for this model. Nevertheless, the regional model, or a further refinement of it, may still prove useful as a carefully applied additional input to the planning process, especially in the area of telecommunications development. It remains the duty of the model builders to ensure that policy planners understand the limitations and advantages of using such a model. One way to accomplish this is to encourage the use of the model in a multidisciplinary environment similar to that in which the model was developed.

V. CONCLUSIONS

One particular multidisciplinary project, focussed on the building of dynamic models, has been presented here with tutorial intent. The aim of the paper has thus been twofold: to survey some of the difficulties and advantages of multidisciplinary teamwork; to show clearly one way in which system dynamic modelling is being applied to a particular goal - that of assessing the impact of telecommunications in northwest Ontario, Canada.

A key aspect of the cooperation between disciplines in this moderately sized project is that the team consists of a band of equal co-investigators, one acting as coordinator, with suitably informal administrative arrangements. Even more important is the association with each disciplinary area of one or more highly capable and enthusiastic young research assistants.

A dynamic model of the entire region of northwest Ontario has been produced and is intended for use as a planning tool among planners of telecommunications systems. This model does not predict the only possible future for the region; rather it enables a wide range of alternative possible futures to be discussed, according to the particular external decisions applied to the model, with these decisions being essentially political in nature. These concepts are now being extended further to the dynamic modelling of individual communities within the same region of northwest Ontario.

The project described here is now in its third year of operation. Not the least interesting among the results is the realization that the very act of building dynamic models acts as a valuable focussing agent for the efforts of a multi-disciplinary team. These models thus become very effective as integrating tools for those disciplinary viewpoints of wide diversity that are becoming so important in any study of a socioeconomic system.

ACKNOWLEDGEMENTS

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In a multidisciplinary project of this kind, success depends on the combined efforts of a relatively large number of people. It is only fitting, therefore, that the authors acknowledge with deep appreciation, the contributions of their fellow co-investigators: J.W. Berry (Psychology), G.E. Dawson (Elec. Engineering), F. Cooke (Biology), C.E.S. Franks (Political Studies), K.A. Herman (Sociology), J.G.M. McKirdy (School of Business), P.J. McLane (Elec. Engineering), all members of Queen's University; and all the following students and research assistants who have worked so well on the project, including: R.J. Adomavicius, J. Aitken, R. Cameron, R.J. Chambers, J. Kane, J.A. Love, T.A. Mawhinney, L.N. Mombourquette, R. Romberg, M.P. Rose, H.K. Tang, Y. Vautrin, V.G. Weinreb; and, not least, Mrs. F.G. Kennedy who helps as secretary to hold them all together.

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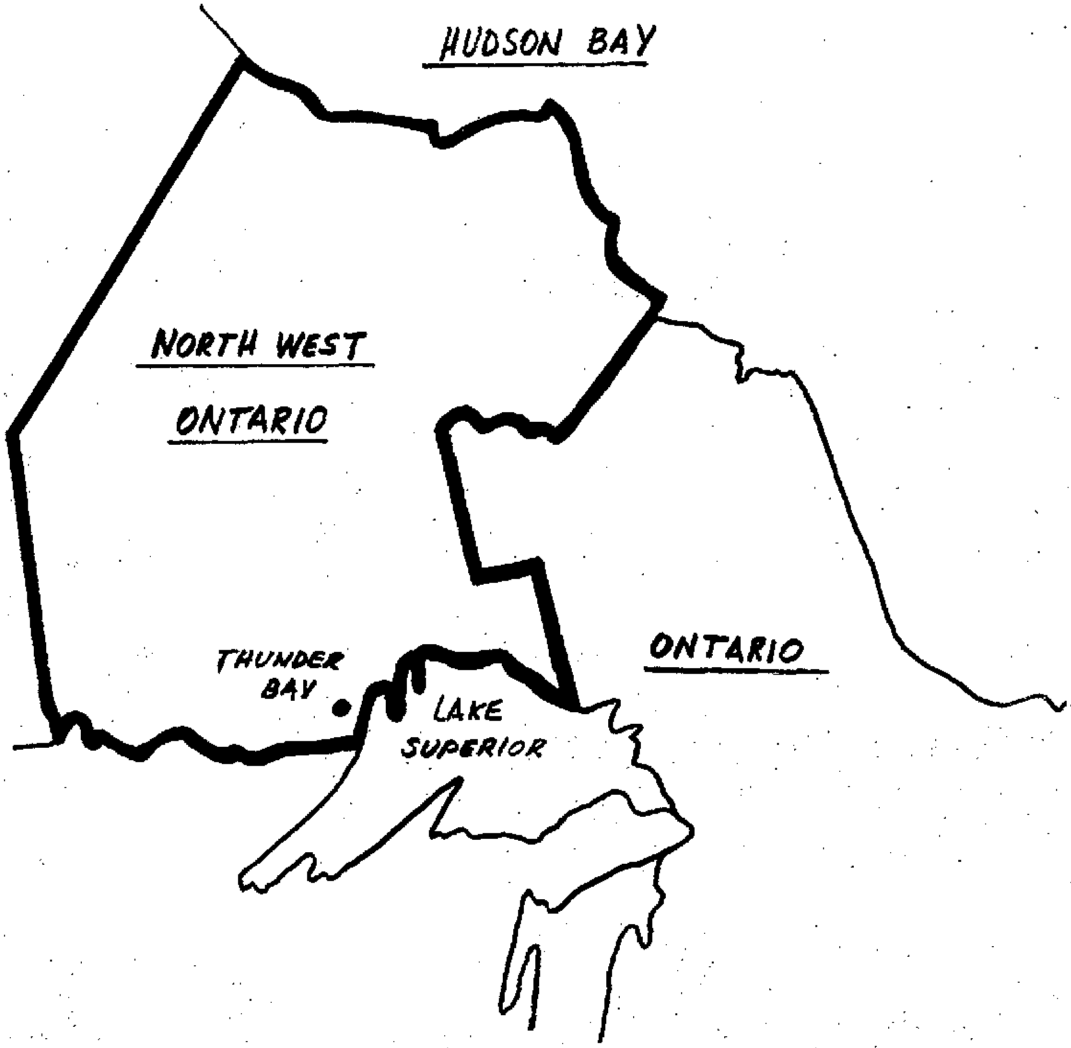
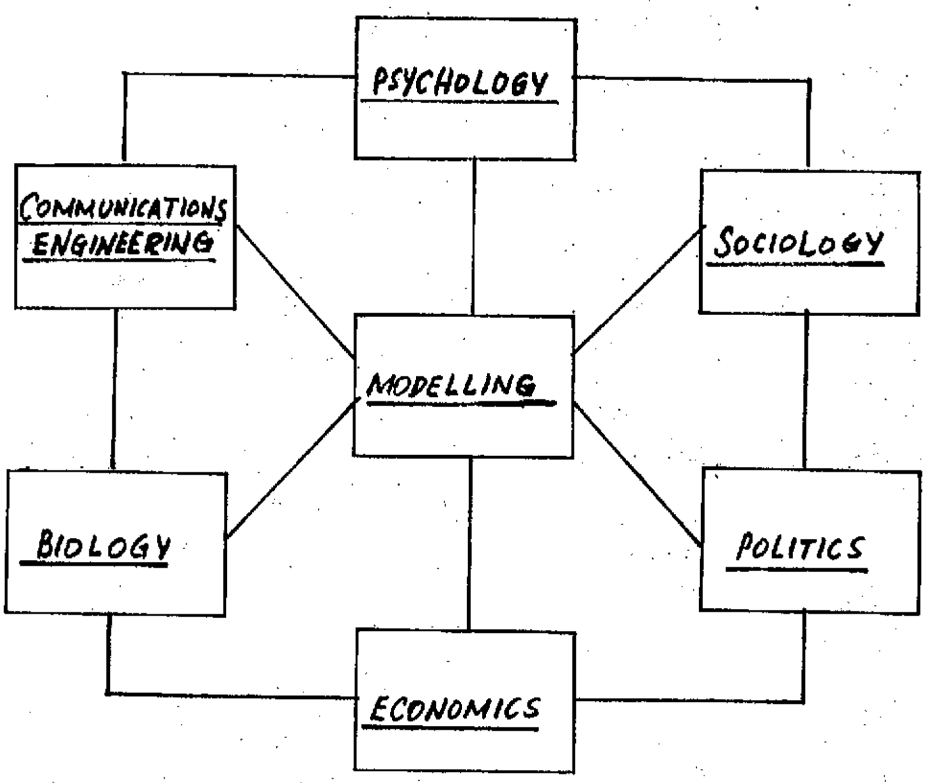
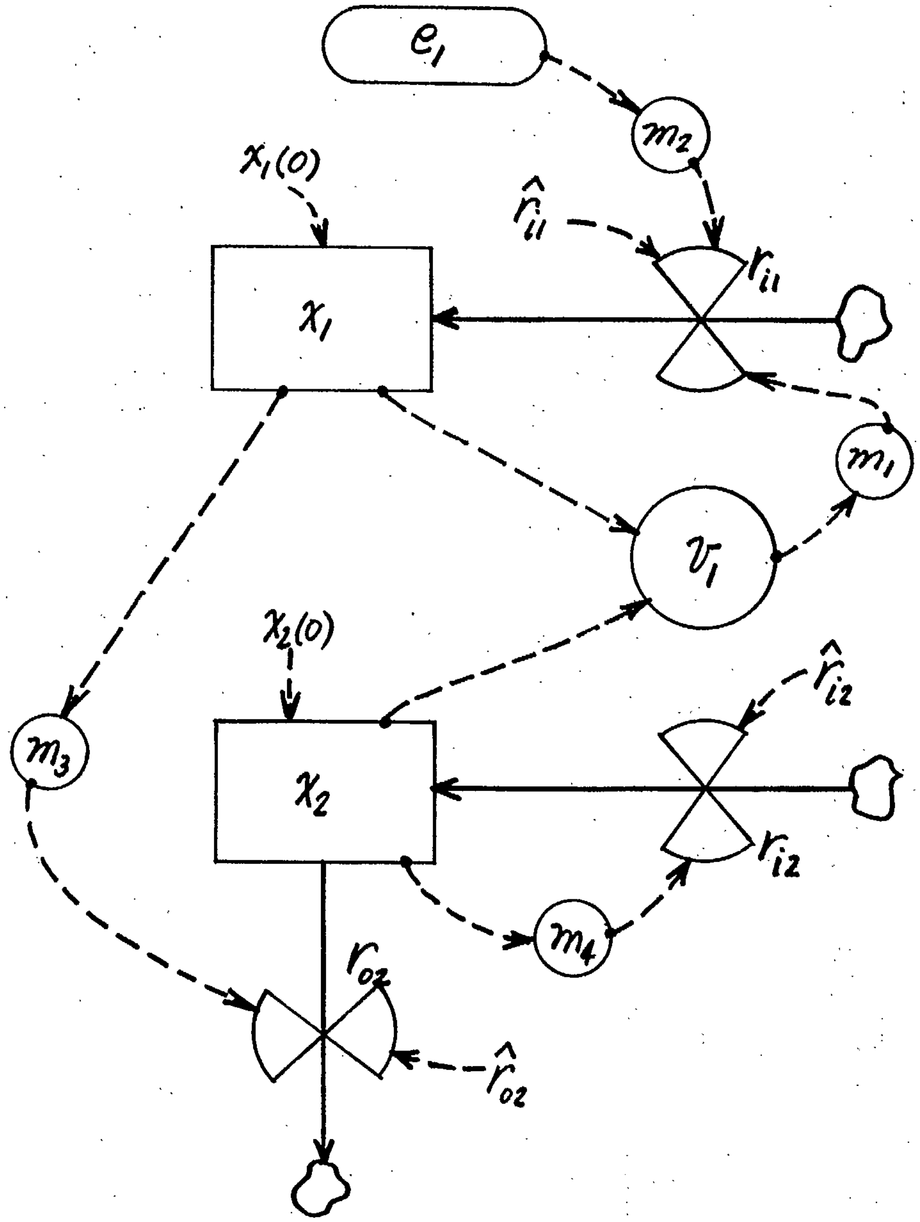
FIGURE CAPTIONS



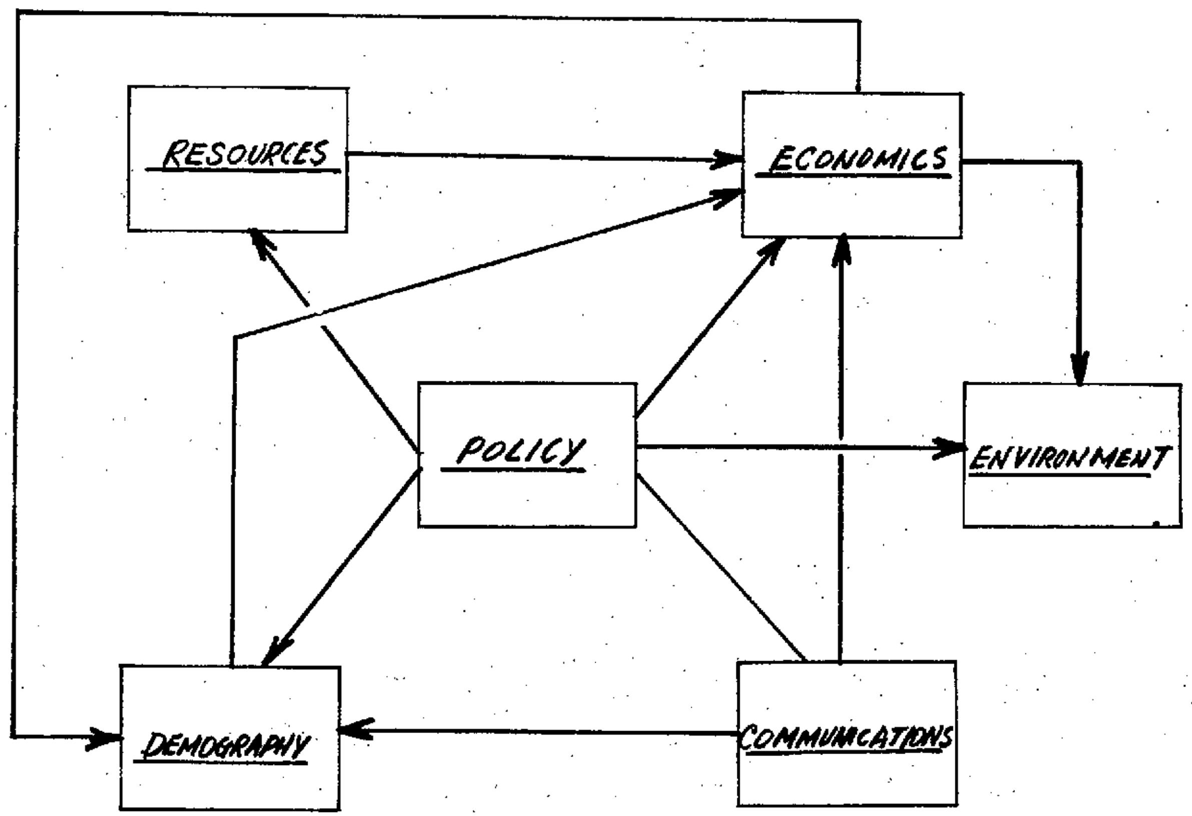
1. Region of Northwest Ontario



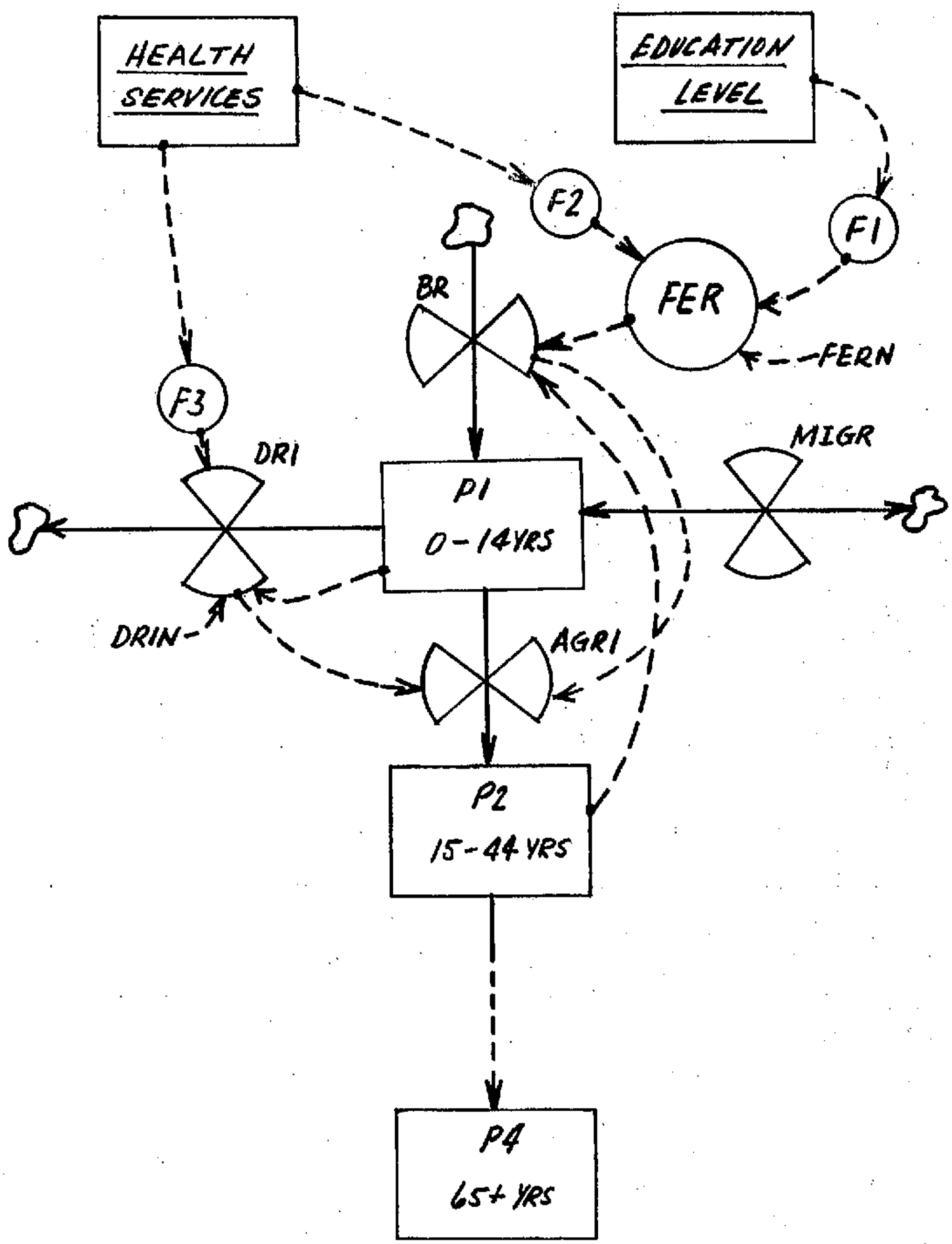
2. <u>Elements of a Multidisciplinary Team.</u>



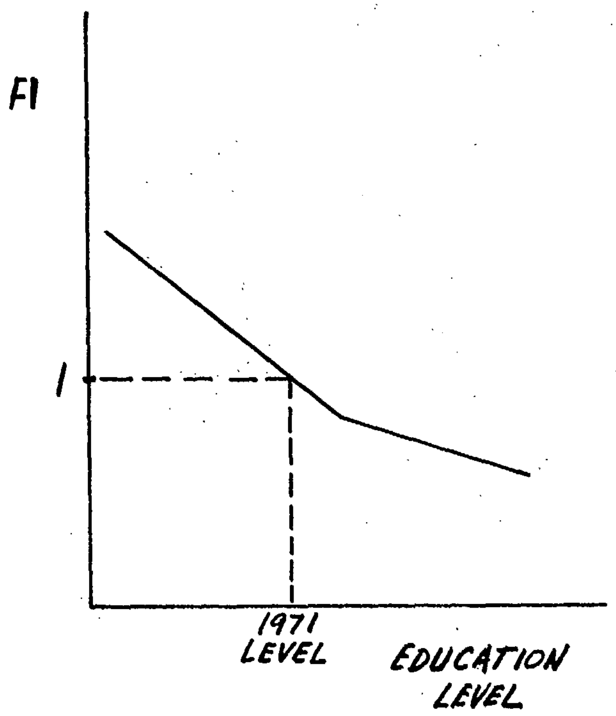
3. <u>An Example of a System Dynamics Structure</u>.

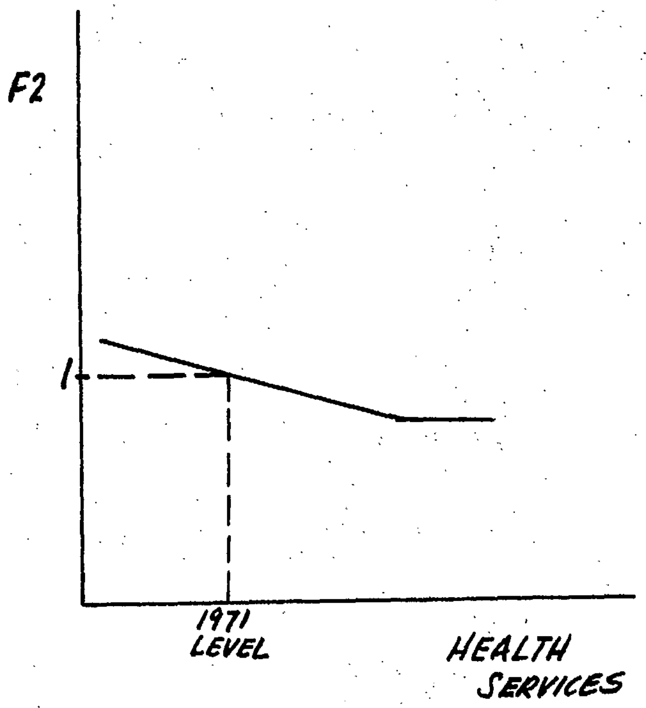


4. Sectors of the Regional Model.

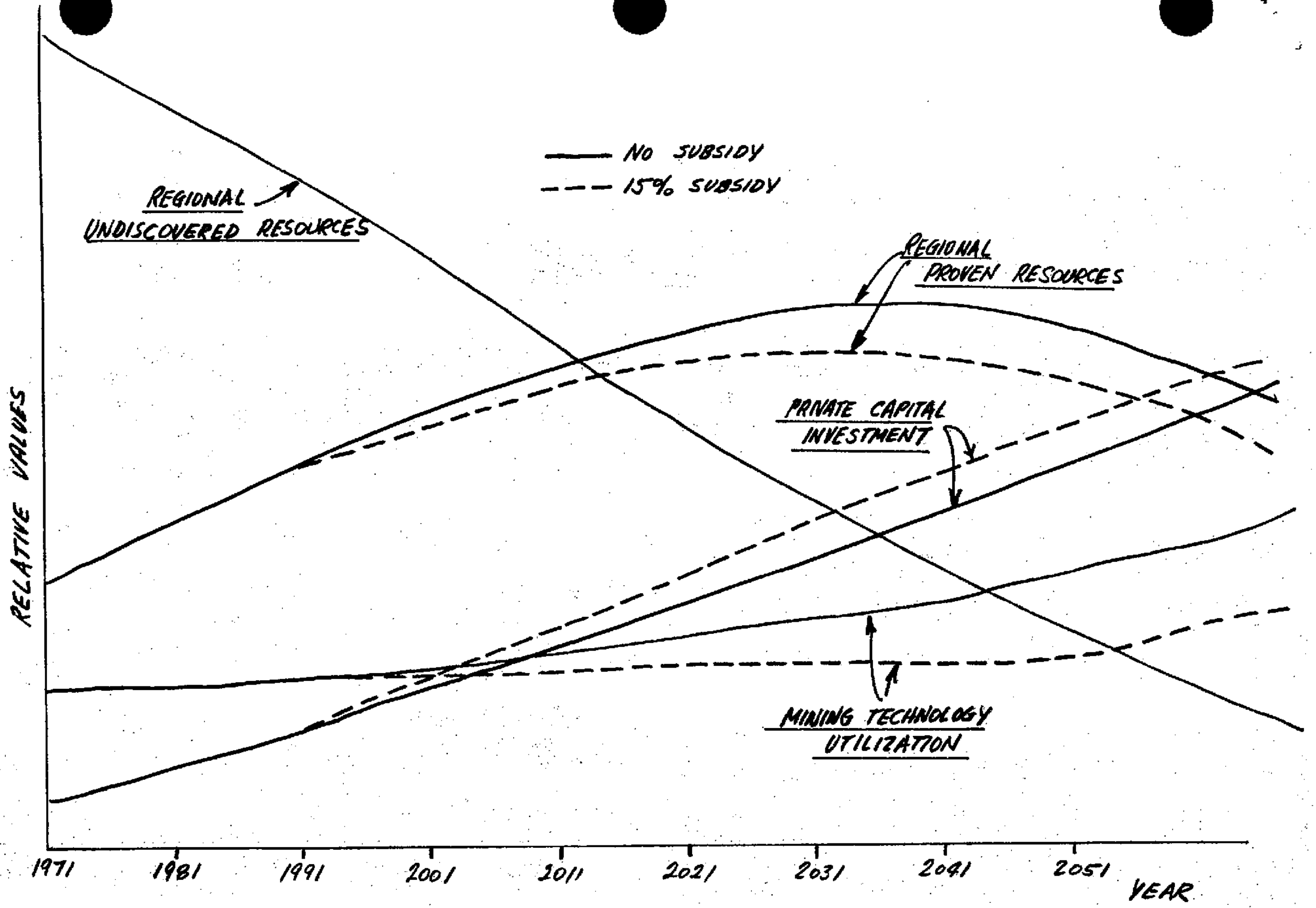


5. Simplified Demographic Sector Model.

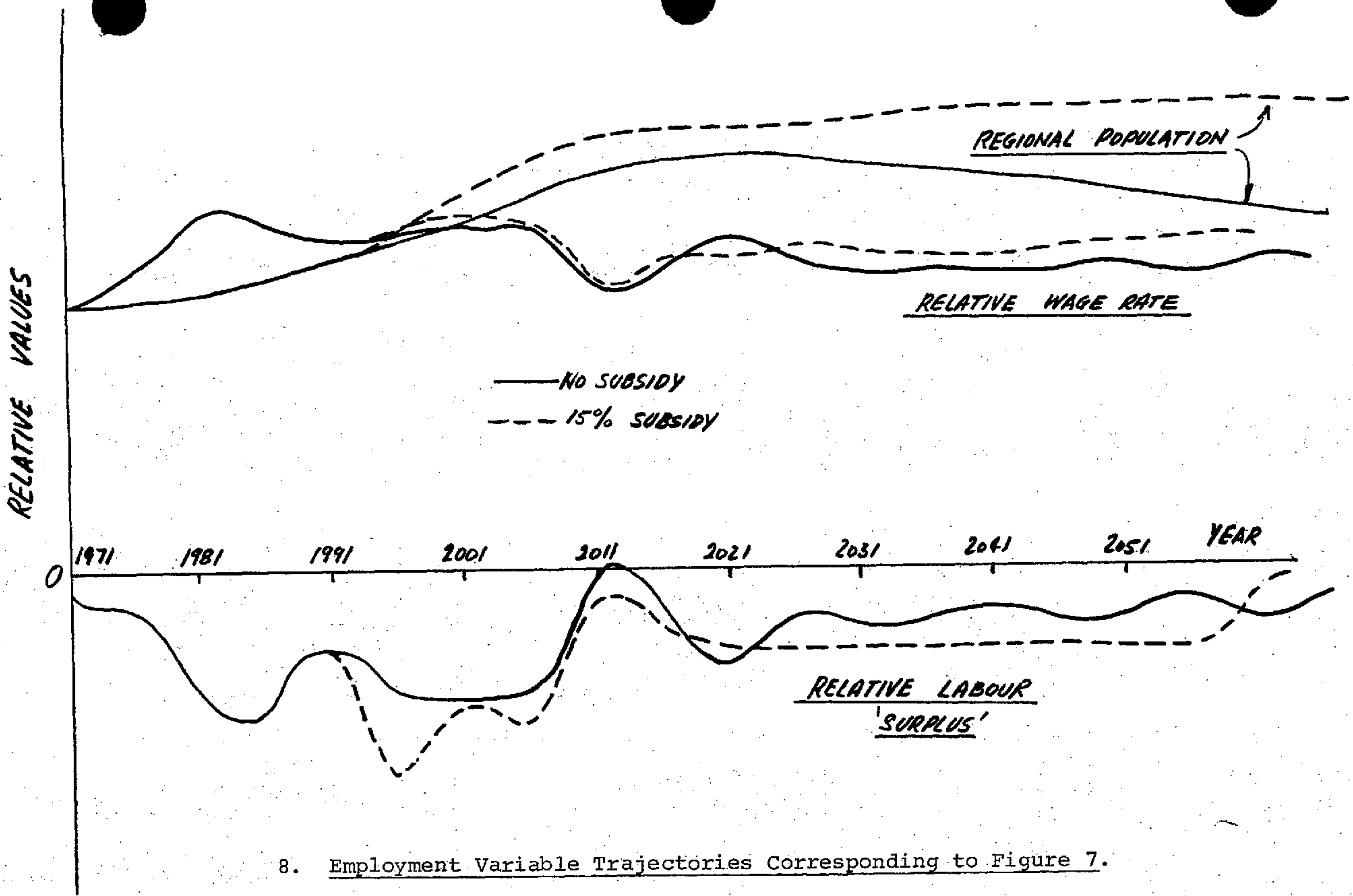




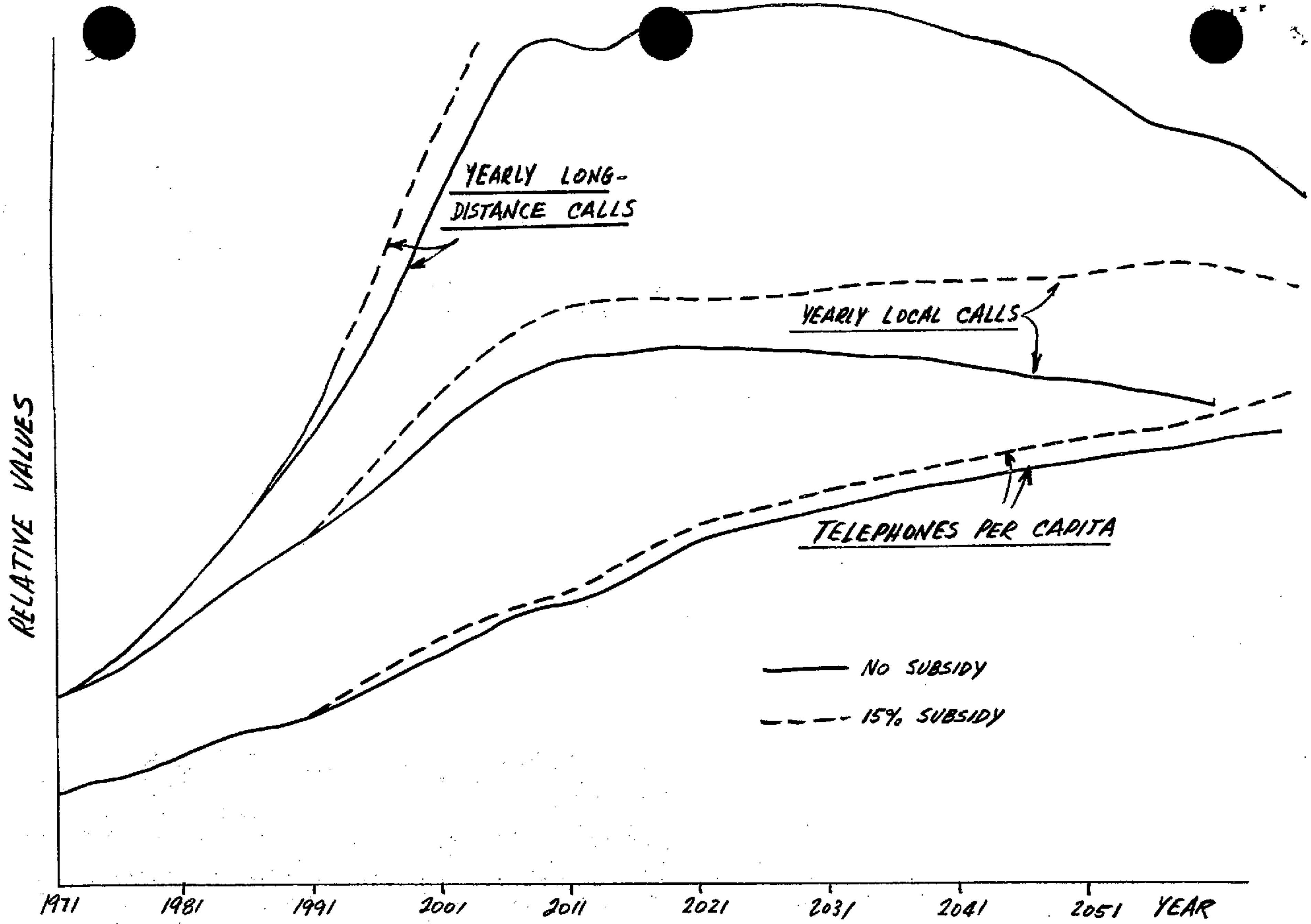
6. Functions F1 and F2 Which Modify the Birth Rate.



7. Trajectories for Economic Variables for a Policy Change Involving a 15% Subsidy of Resource Development in 1991.



8. Employment Variable Trajectories Corresponding to Figure 7.



9. Telephone Variable Trajectories Corresponding to Figure 7.