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Health Care Systems Modeling at IIASA: A Status Report

Shigan, E.N., Hughes, D.J. and Kitsul, P.I.

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INTERNATIONAL INSTITUTE
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THE AUTHORS

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FOREWORD

The focus of the Human Settlements and Services (HSS) Area at the International Institute for Applied Systems Analysis (IIASA) is *people* – their number and geographical distribution, their needs and demands for resources and services, and their impact on the environment. Research in the Area is divided into three themes: urban systems management, human resources and services, and human settlement systems. This report describes work that has been carried out up to autumn 1978 by the Health Care Systems (HCS) Modeling Task, representing the human resources and services theme. It focuses in particular on the submodels that have been developed and tested and on the collaboration that has been established with similar research teams in a number of countries around the world.

Governmental policies in all countries strongly influence the medical services available to society. It is therefore essential that decision makers be aware of changing demands and needs for health resources and services. In light of this, the HCS Modeling Task has set a goal of creating a model that will assist national decision makers in formulating policy. This model consists of a number of linked submodels dealing with various related topics from population growth to resource allocation. Some of these submodels have already been tested, and collaborating national research centers have started to implement them with their own data. The resulting experience of the past several years is described in this review, which has been prepared by members of the HCS Modeling group. By sharing our aims and achievements with a wider audience, we hope to facilitate future international collaborative work on this research.

ANDREI ROGERS
Chairman, HSS Area

ACKNOWLEDGMENTS

This paper reports the work of many other scientists who have been associated with this task in different ways. Their names are found in the list of supporting references and in Appendix A. Not found there are the names of Rebecca Crow and Alduild Fürst, who typed several drafts of this paper and to whom we express our thanks.

CONTENTS

APPENDIXES

Chapter 1

INTRODUCTION

HISTORY OF THE TASK

"Biological and Medical Systems" was one of the first eleven research projects undertaken at the International Institute for Applied Systems Analysis (IIASA), and the IIASA Planning Conference that took place in August 1973 identified a large number of possible research topics within the context of this theme (Biomedical Project, 1973). A year later Dr. Dimitri Venedictov (USSR), the Deputy Minister of Health of the Soviet Union, was appointed leader of the Biomedical Project; because of his responsibilities in Moscow, Dr. Venedictov was represented in Laxenburg by his deputy, Dr. Alexander Kiselev (USSR). Dr. Kiselev, following the recommendations of the 1973 planning conference, formulated a research program designed to develop a methodology for the dynamic modeling of national health care systems, as well as to complete research on other topics begun previously.

In 1974 a second biomedical conference was held, the proceedings of which were published (Bailey and Thompson, 1975), and it was concluded at a third conference in December 1975 that IIASA should concentrate on the development of universal models of national health care systems (Venedictov, 1977). In 1976 the old Biomedical Project was merged with the Urban Project to form the Human Settlements and Services Area; the work of the Biomedical Project is carried on by the Health Care Systems (HCS) Modeling Task within that Area. Since then, two IIASA workshops, one held in March 1977 (Shigan and Gibbs, 1977) and the second in November 1977 (Shigan, 1979), have reaffirmed the aim of developing universal models of national health care systems.

Since November 1976, the leader of the HCS Task has been Dr. Evgenii Shigan (USSR), and scientists from Austria, Japan, the United Kingdom, and the Soviet Union have served as research scholars. Particularly close links have been established with the Institute of Control Sciences in Moscow and the Operational Research Services in the UK Department (Ministry) of Health and Social Security in London. Several scientists from both groups have worked at IIASA, thereby maintaining continuity both in research and in East-West collaboration despite changing personnel.

PROBLEMS IN HEALTH CARE SYSTEMS

The starting point of the HCS Modeling Task is well summarized by the following observation of its first leader:

> Health care is a complex social dynamic functional system created and used by society for carrying out social and medical measures for protecting and improving health and for the continuous accumulation of medical knowledge. (Venedictov *et al.* 1977, p. 43.)

We are not surprised that the operation of such a system presents problems. As scientists at IIASA, our work includes the building of mathematical models that will assist decision makers in different countries who face similar problems. What are these problems? Here are some examples:

Operational problems include

- Estimation of health status indices, environmental parameters, and resource demands and utilization
- Control of costs of medical services
- Efficient satisfaction of emergency and nonemergency demands

Tactical problems cover

- Short-term forecasting of health, environmental, and resource demand indices
- Construction, commissioning, and management of health care establishments
- Comparative analyses of services for different regions and for different groups of people

Strategic problems embody

- Long-term forecasting of health, environmental, and resource demand indices
- Reorganization of the health care system
- Selection of new directions for research

In addition to the problems themselves, the mix of operational, tactical, and strategic problems facing the decision maker varies according to the hierarchical level of the health care system for which he is responsible. The general practitioner deals mainly with operational problems, while on the national level the decision maker deals mainly with tactical and strategic problems. Both face many problems that must be classified according to their importance and complexity. In some cases, the health manager makes decisions on the basis of his own intuition and experience. In other cases, he consults other decision makers in order to obtain expert advice. He also uses information acquired from routine statistics, special studies or surveys, and natural experiments. For many problems, routine information concerning individuals' health, medical procedures, and administrative policy is enough to allow a decision to be made. For other problems, comprehensive studies of health care or natural experiments on real objects are conducted (e.g., on health centers, hospitals, ambulance services). Such experiments are, however, very expensive and take time, and they cannot be used to test many alternatives for a planning policy.

The situation is much more difficult for health managers at the highest levels. To answer questions of medical resource demand and allocation, it is necessary not only to estimate population change but also to forecast the dynamics of the health of the population. This problem is also complicated by the strong dependence of the health care system on socioeconomic, environmental, and other external systems. And conducting any natural experiments on health systems at the highest level (global, regional, national) is practically impossible. A group of Soviet scientists from different research centers (medical, mathematical, economical, and environmental centers, among others) have designed, under the guidance of Dr. Venedictov, the functional description of a public health system shown in Figure 1. We see that both the HCS and external systems may be divided into subsystems and that the connections between subsystems and their parameters may be direct or indirect, continuous or discrete, strong or weak, changeable over time or constant. It is clear that it is difficult for a manager to estimate all the possible consequences of his decisions using only his own experience. He also needs special means to

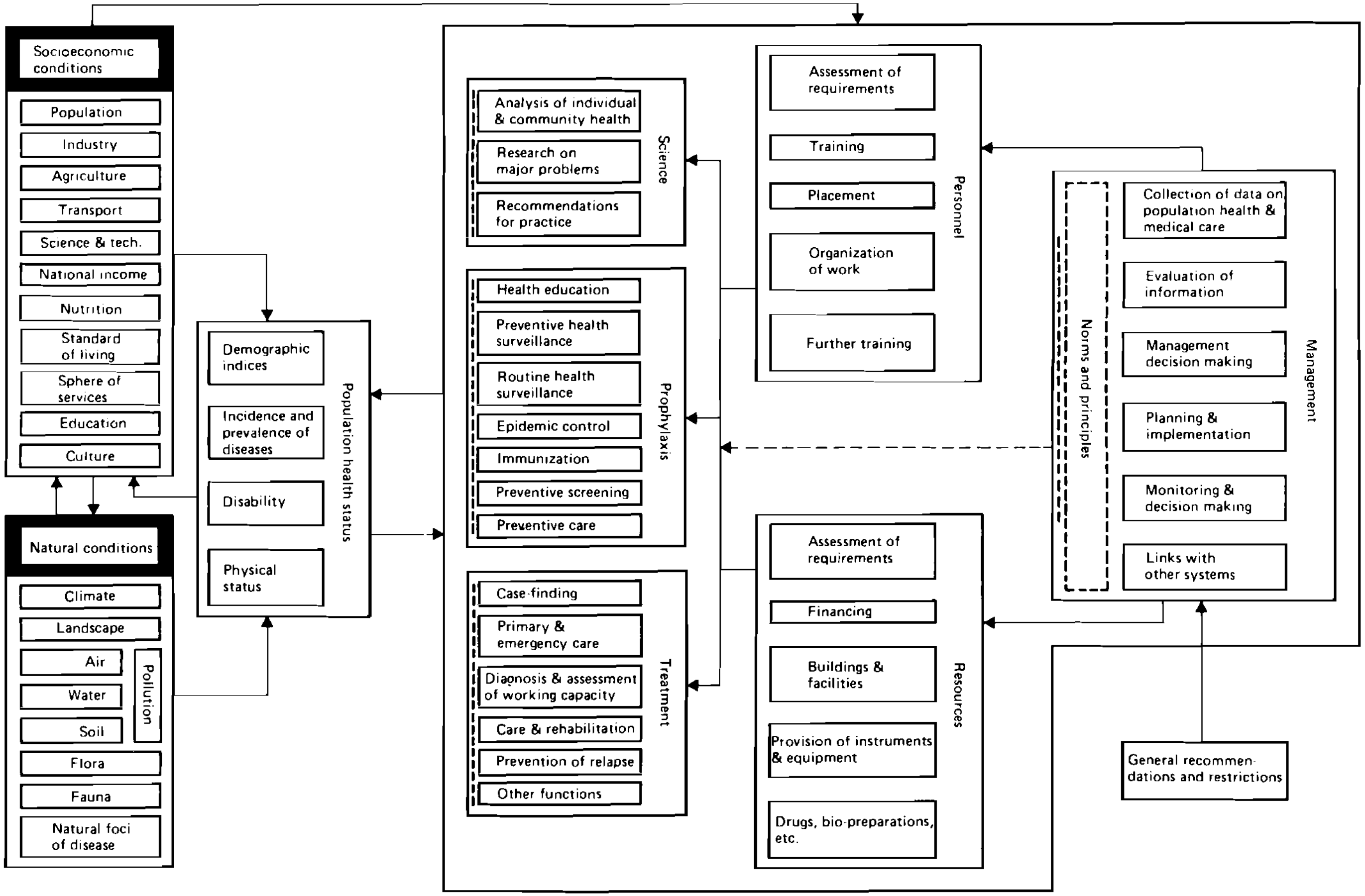

FIGURE 1 Functional chart of a public health system. Source: Venedictov (1976), p. 109.

estimate the behavior of internal and external subsystems, their trends, and so on. Thus, in order to test health care strategy alternatives, the decision maker responsible for the highest levels of the health care system needs a health care system model.

OBJECTIVES OF THE TASK

We do not pretend that we can solve all the problems encountered in a health care system. Instead, the *main goal* of the Task is to develop a model that will reconstruct in mathematical form the principal components of the HCS shown in Figure 1. The result will be a family of submodels describing the main aspects of the HCS and certain strong interactions with other systems. This main goal can be divided into certain *subgoals*, several of the most important of which are presented in Figure 2. Some subgoals are associated with existing submodels; others represent possible future areas of research. The research associated with each subgoal is useful not only as a step toward the main goal but also as independent work. Because the models reported below can be used together or separately, we already have some results, even though we are still far from our main goal. These results include:

- The estimation of unobservable statistics from observable ones, e.g., morbidity from mortality
- The evaluation of the consequences of certain plans and policies, e.g., for resource allocation
- The derivation of optimal policies to achieve certain aims, e.g., for manpower training
- The analysis of relationships between decision makers in the health care system and modelers of the health care system

Our work on model building is wasted unless we represent our models as computer programs and test them on real data. This is one of the important *objectives* set out in our Research Plan (IIASA, 1979). We are collaborating in this work with other groups at IIASA, and especially with the demographers in the Human Settlements and Services Area. Models for predicting demographic changes are well developed, and these provide one basis for predictions in health care systems. At the same time, we are collaborating with scientific groups in other countries that are interested in health care system modeling (see Appendix B), and our models are also

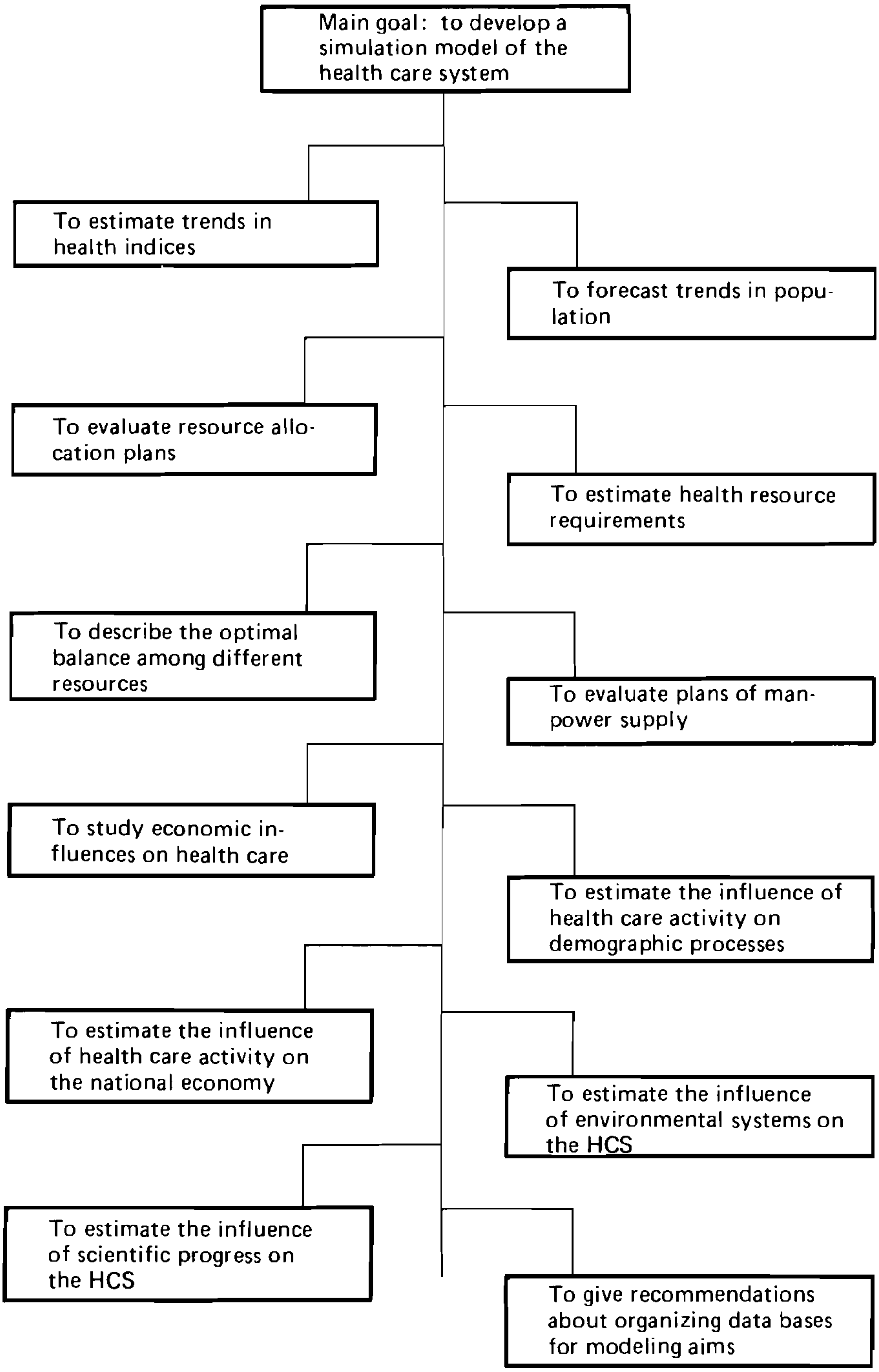

FIGURE 2 Tree of goals of the IIASA Health Care Systems Modeling Task.

of value to the decision maker at the international level (in the World Health Organization, for example), because international comparison of health care systems is more useful than comparison of separate static indices. Finally, we are in contact with decision makers themselves from the health ministries of some of IIASA's national member countries.

THE POSITION TODAY

Where does the HCS Modeling Task stand today (autumn 1978)? First, we have developed views about how to go about modeling mathematically a complex human activity system such as the HCS. These views are summarized in Chapter 2. Chapter 3 summarizes our progress along these lines and gives some details of the various submodels that we have constructed. More information about each submodel is given in other IIASA publications, and a full list of the Task's publications is given in Appendix C. Finally, in Chapter 4 we outline our plans for future work, both to apply the existing models to real problems and to develop new models.

Chapter 2

MODELING APPROACH

HEALTH CARE SYSTEMS

Health care systems have certain features that distinguish them from the more common engineering systems investigated by mathematical modelers. In this chapter, we show how these features have influenced our approach to model building, and we summarize the conceptual framework and methods that we have used.

What is special about health care systems?

- The health care system is a *social system*. Its behavior reflects the participation of individuals – patients, doctors, health managers – and their interrelations with external systems.
- The HCS is often organized *hierarchically*. Not only are the systems in particular regions often managed separately, but there is usually some specialization according to the severity of the disease to be dealt with.
- The HCS is *dynamic*. The number of doctors available today depends upon the training policy of 5 to 6 years ago, and society's health today may depend upon the activity of the HCS during the past half century.
- The main result of HCS activity – the health status of population – can be only estimated, by a set of interrelated *quantitative* and *qualitative indices*.
- Almost nothing in the HCS can be subjected to experiments, even at local levels.

- There are some specific communication problems between the decision maker and the model builder, caused by different education, experience, and approach to the solution of real health care problems.
- Existing medical data bases are adapted mainly to classical medical statistical aims, not to forecasting or estimating the consequences of different policies in health care systems management.

In summary, from the point of view of mathematical modeling, the HCS is a complex, hierarchical, dynamic, large-scale system with a number of quantitative and qualitative criteria and with incomplete and indirect observations. At present problems in such systems are solved by decision makers on the basis of their personal experience. We believe that HCS modeling activity will not only assist in the present decision process but also will help to improve methods of long-term planning.

OUR APPROACH

Figure 3 depicts our general approach to model building. We have divided this scheme into the creation and the use of models to emphasize the importance of each step in the work. In general, our modeling activity lies on the right side of this scheme, but this does not prevent us from creating and using models in different ways in different situations.

Figure 4 summarizes the outcome of this process: a conceptual model that shows how the HCS and its subsystems work and that provides a basis for discussion between scientist and nonscientist. It represents one part of the larger system shown in Figure 1: namely, the processes by which people fall ill and by which health resources are provided and used for their treatment. This model also summarizes the system of submodels constructed by the IIASA HCS Modeling Task up to 1978. There are five groups of submodels. *Population* projections are used by *morbidity* models to predict true health needs. These estimated needs can be used to estimate *resource requirements* at a certain normative level, or they can be partially satisfied according to a *resource allocation* model, which has some inputs from a *resource supply* model. The decision maker can choose his policies, standards, and performance indicators. Beyond the HCS boundary are the external systems of environment and economy.

Figure 4 shows how the existing submodels are logically related, and

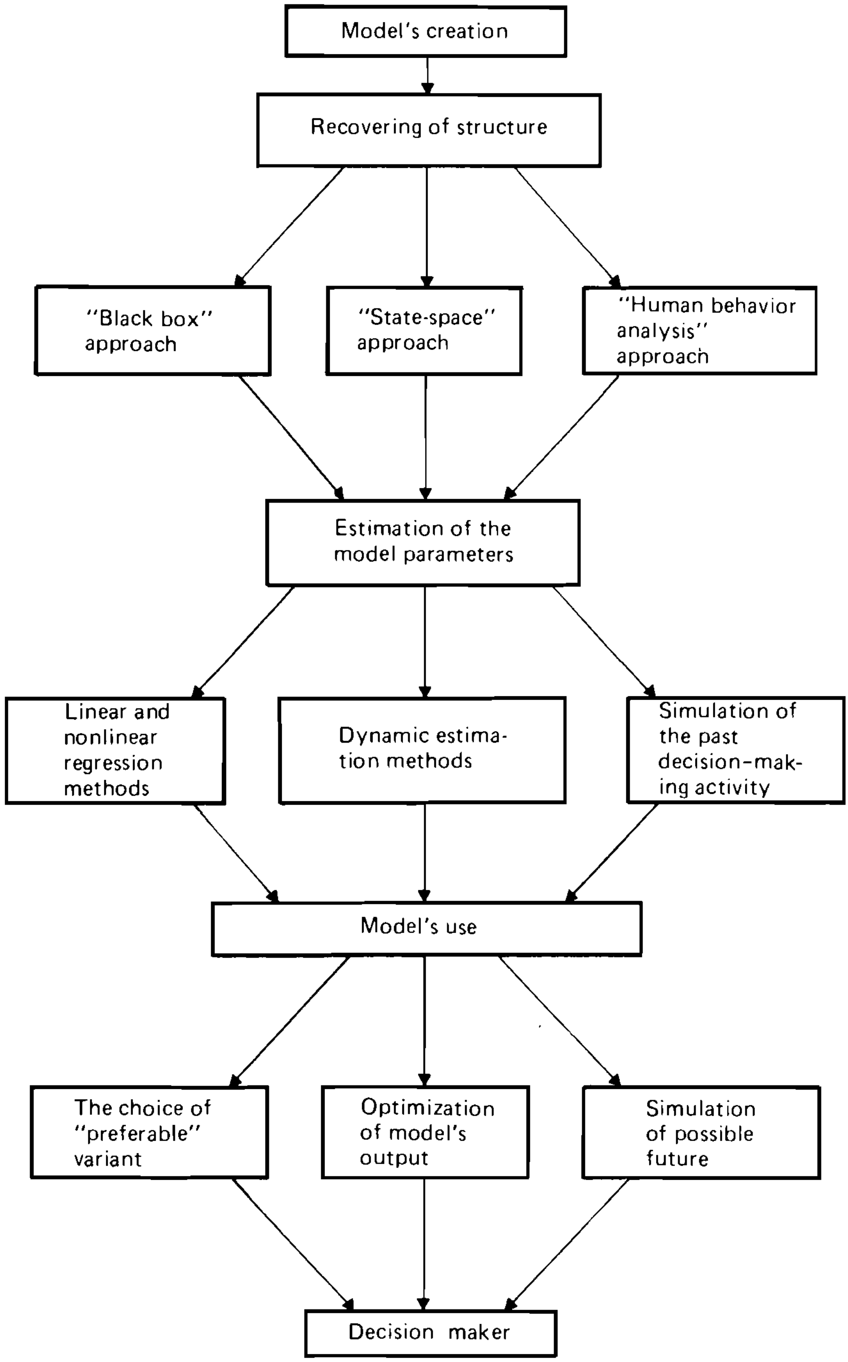

FIGURE 3 Different stages of modeling.

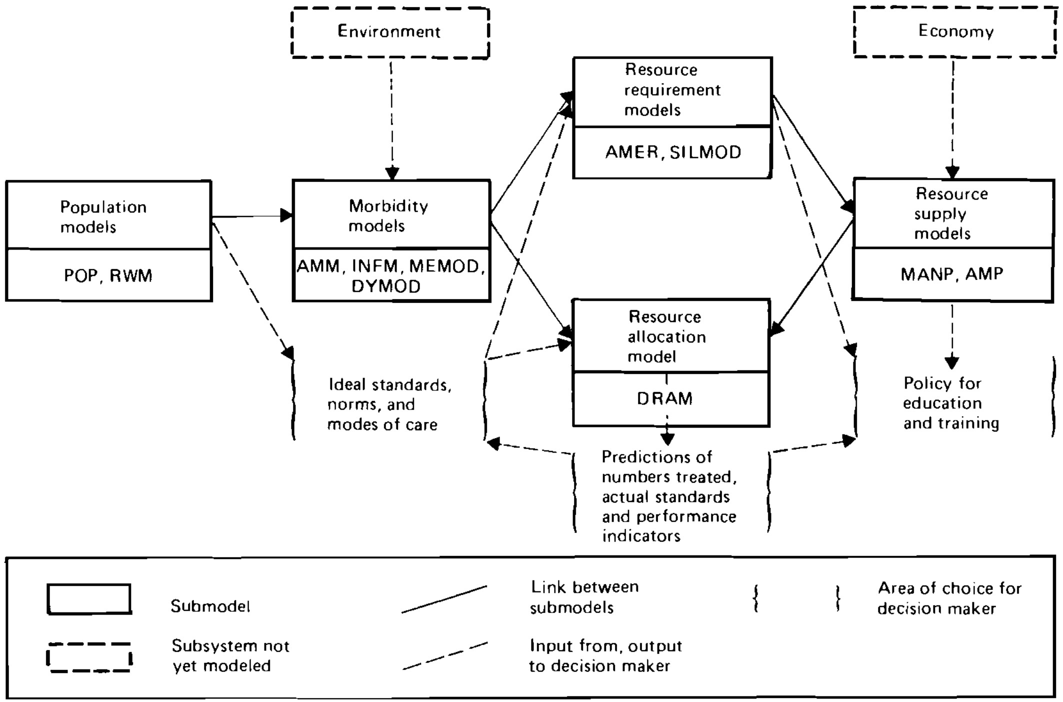

FIGURE 4 Family of HCS submodels constructed at IIASA. Specification of submodels: POP, population model (RM-76-36); RWM, Rogers-Willekens model for demographic analysis (RM-76-58); AMM, aggregate morbidity model (RM-78-21); INFM, infection morbidity model (RM-78-10); MEMOD, morbidity estimation models (RM-77-40); DYMOD, dynamic approach to the estimation of morbidity; AMER, aggregate model for estimating resource requirements (RM-78-21); SILMOD, sick leave model (Fleissner, 1978); DRAM, disaggregated resource allocation model (RR-78-7, RM-78-50, RM-78-67); MANP, manpower supply model (RM-78-20); AMP, manpower migration model (Yashin, 1978). (A full list of Research Reports, Research Memoranda, and Collaborative Publications by the Health Care Systems Modeling Task is given in Appendix C.)

it suggests new areas for modeling adjacent to these. The submodels, however, are not conceptual but *actual*, with precise assumptions and mathematics, usually available as computer programs. Today, the conceptual framework implies a logical order or methodology for applying the submodels: in the future, it will guide any plans to link the submodels more permanently.

Admitting that we cannot model the whole of the HCS at a stroke, it is reasonable to ask why we have chosen to model those parts that we have. The first reason is that these are the parts of the HCS that are easiest to parameterize. The mechanisms by which doctors are trained are easier to identify and depict than those by which the environment influences health. Second, these are the areas of the HCS for which data are most readily available. Every country has statistics of mortality and of resource supply and use that are broadly comparable. Third, it is these parts of the HCS that generate many of the important medium-term problems – problems with horizons of 5 to 15 years. One of the reasons we have not yet modeled the influence of treatment upon mortality is that the influence is likely to be a long-term one. On the other hand, many countries are now finding it necessary to draw up medium-term policy plans for health care that are linked with plans for welfare and social services.

It is also reasonable to ask who will use these models. We have designed them for *use* by scientists at IIASA and in different countries with whom we are collaborating. On the other hand, we hope that the models will be *useful* for decision makers at the higher levels of the HCS. This distinction is important. Unfortunately, it is difficult and expensive for a small IIASA HCS modeling team to establish active links with decision makers in every country around the world. Where this is impossible, it is appropriate for scientists already in a country to develop their own links with such decision makers, with the additional professional support that IIASA can provide. Two institutions* have already sent scientists to IIASA to contribute their own expertise to IIASA's work and to bring back the results of IIASA's research to their own institutions. Our models are designed for use by scientists to help decision makers in national health authorities or officers of the World Health Organization.

A third natural question is to ask what mathematical models already exist within our area of interest. In 1976–1977, Fleissner and Klementiev (1977) carried out a review of 38 HCS models, reporting on the status, goals, and methods used by each group of workers; they also presented

*Operational Research Services, Department of Health and Social Security, London; and the Institute of Control Sciences of the USSR Academy of Sciences, Moscow.

three examples in more detail. They found that some of the models were aimed at specific local, national, or medical sector problems and that many of the models had not proceeded beyond academic discussions. These findings further tend to support the research emphasis outlined above: that of developing submodels of the whole HCS and of applying them to real problems.

A MIXED MODELING STRATEGY

Our 1977 review of mathematical models distinguished between models according to their modeling technique: macroeconomic, systems dynamic, or optimization. Since the time of the review, however, mathematical models have become more sophisticated, and the value of such a classification has decreased. From our point of view, it is more useful to distinguish among models according to the aim of the modeling or the type of use. Figure 5 shows the aims of modeling in each of the five boxes in Figure 4. These aims are diverse and cannot be attained via a single model or technique (Yashin and Shigan, 1978).

As an example, in the creation of any optimization model, before using the special optimization technique, it is necessary to have the *model of the system*, to *estimate its parameters*, and to carry out *sensitivity analyses*, i.e., to build a simulation model. On the other hand, in some simulation models it is necessary to simulate human behavior, and here it is natural to use the *utility function* and some *optimization technique* to recover the input–output interrelation of the system.

Figure 6 illustrates this mix of approaches in the IIASA HCS models. Our morbidity estimation models are state-space-structured simulation models, but they incorporate no element of human behavior and no optimization technique. The resource requirement models also do not use any optimization technique, but these simulation models permit the choice of the "most preferable" resource allocation. Our resource allocation model is also a simulation model, but in order to simulate some element of human behavior, it assumes that the human agents in the system act as if they were maximizing a utility function. Finally, the manpower education and training model is an optimization-type model, although application of the dynamic linear programming technique presupposes a successful simulation using the state-space approach.

In summary, then, some parts of the HCS (e.g., resource allocation) depend significantly upon human behavior and the appropriate models probably need to reflect this. Gibbs (1977), for example, concluded that

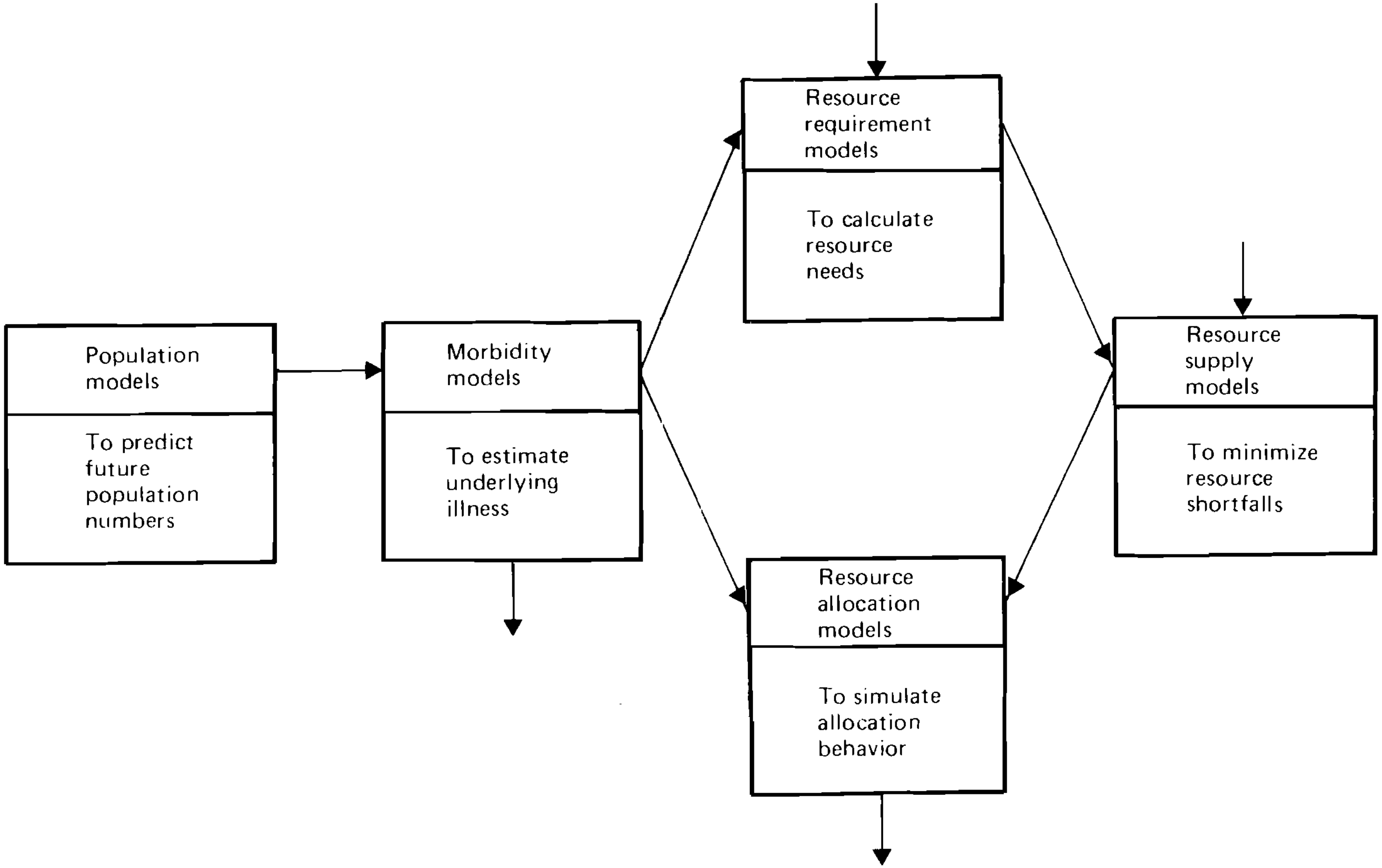

FIGURE 5 Classification of models by purpose.

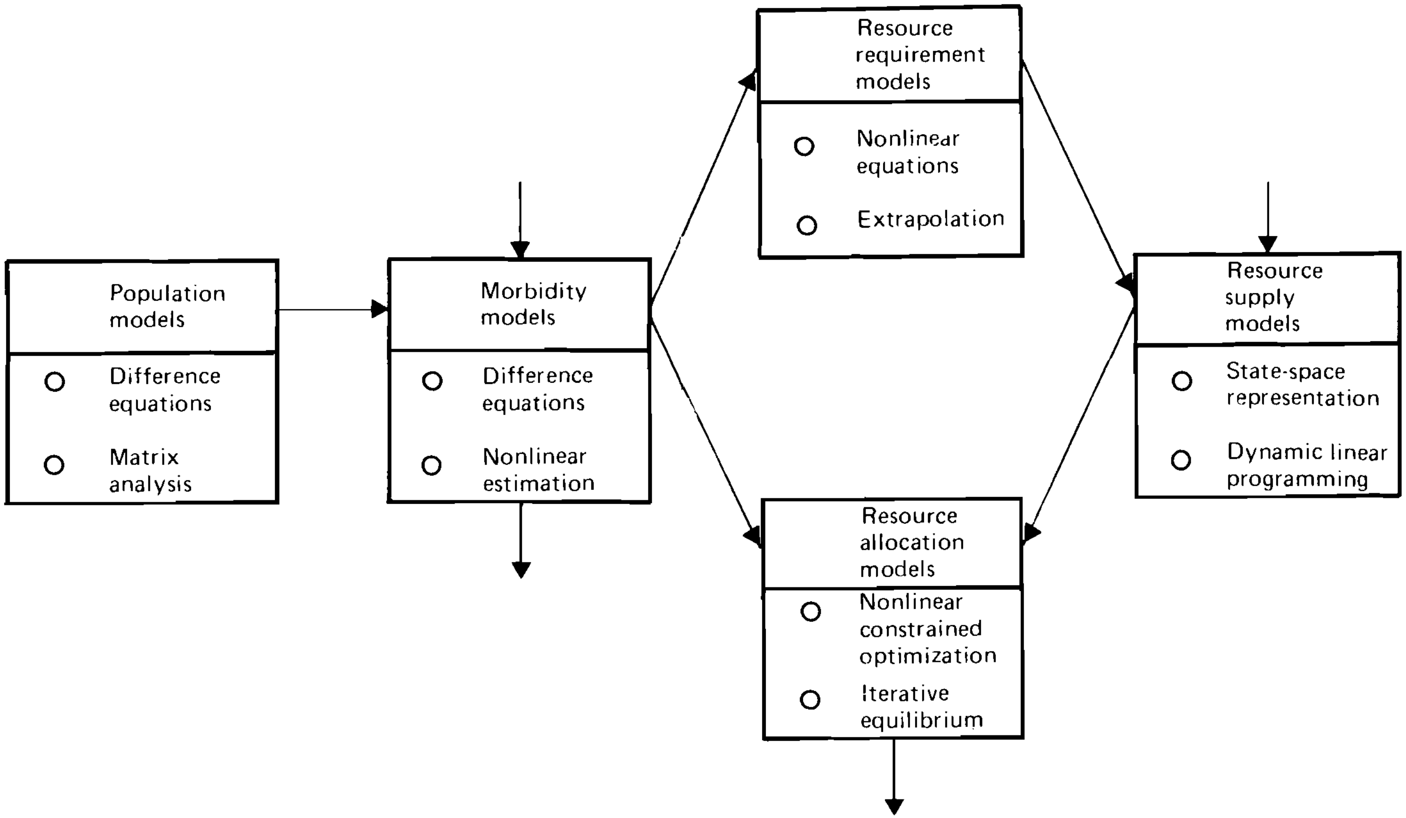

FIGURE 6 Mathematical techniques used in IIASA health care system modeling.

a resource allocation model should adopt the behavior simulation approach. In other parts of the HCS (e.g., morbidity prediction), this influence is less important. In some parts of the HCS (education and training of manpower, for example), it is more natural to formulate a control model; in other parts of the HCS (e.g., resource requirements), it is often more interesting to simulate behavior. Such are the differences that have so far prevented modelers from producing any monolithic, successful model of the HCS. Our view is that we must use a mixed modeling strategy in which different mathematical tools designed for different tasks are developed within a single conceptual framework.

MODELING AIMS

We conclude this chapter by mentioning the common features of the model descriptions that follow in Chapter 3. This will also summarize our *modeling aims.*

First, our models are compact. We believe that large models are hard to comprehend and difficult to use. It is always tempting to include as much structure as one can identify; usually, however, this leads to models with many more parameters than can be sensibly estimated. Second, we have tried to design our models for use with existing data. Such models are more useful than models that cannot be used without a special survey. Nevertheless, if data from special surveys are available, then our models are designed to allow incorporation of such data within the same structure. Finally, however, model-building is not the only aim of this work. Although we want models that will represent the main components of the HCS mathematically, we want also to use them to help decision makers at different levels of health care system management.

Chapter 3

PROGRESS TO DATE

The first five sections of this chapter describe in more detail the submodels depicted in the five blocks of Figure 4. The last section of the chapter mentions some application experiments common to all our work.

MODELS FOR DEMOGRAPHIC PROJECTION

It is obvious that the dynamics of morbidity rates and, hence, mortality rates themselves are correlated with the dynamics of the demographic age pyramid and that this correlation is different for different countries. In developed countries the age-specific registered morbidity rate (shown in Figure 7 for the UK) is changing very slowly over time by comparison with the dynamics of age structure. Evidently, therefore, models for morbidity prediction must be age-specific, and, indeed, all of our submodels need information about population.

For some applications it is possible to use population projections provided by national agencies; for other applications we have two separately developed models. Both models use the initial population age–sex structure; the fertility rate for the initial year and specified by age per 1,000 female population and the death rate given for the initial year and specified by age and sex per 1,000 population. Both models assume without loss of generality that all rates are constant over time. They can also be used to reflect any scenario of changing future mortality and fertility rates.

The first model is the model of Willekens and Rogers (1976), which uses spatial demographic data and can be used not only on the regional

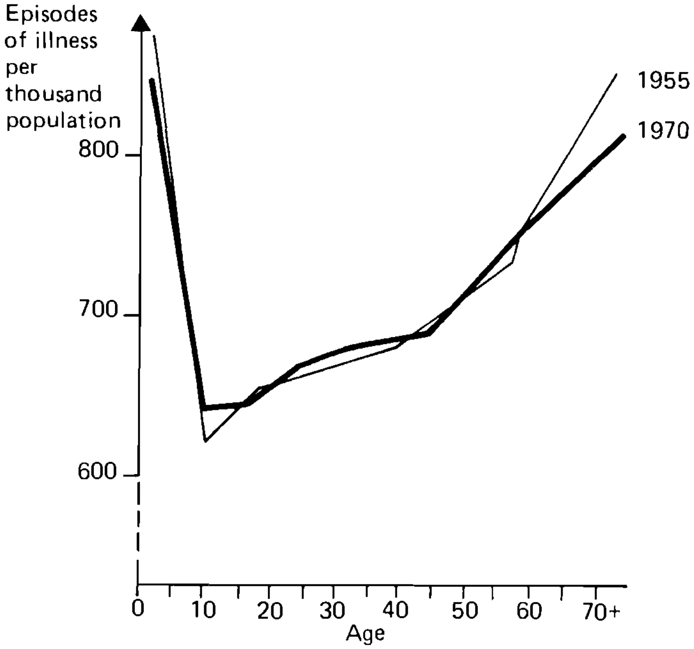

FIGURE 7 Age distributions of morbidity rate in the UK, 1955–1970. Data from Hicks (1976), Table 85, p. 142, and Table 121, p. 176.

(multiregional) or national level but also for more precise projections of population because it uses more detailed information about fertility and mortality rates in the different regions and includes multiregional migrations. This model uses the age–sex-specific migration rates between regions to give forecasts of a spatially distributed population's age–sex structure. The second model is for projecting a national population structure. The development of this type of model was begun in the framework of the Institute of Control Sciences' HCS modeling activity, and the model was installed and tested at IIASA by Klementiev (1976). This model omits a spatial distribution analysis but includes features such as the separating-out of the perinatal death rate, division into strata that take into account the structure of existing health care statistics, and the updating of strata according to specific indicators for death rate and according to transition coefficients. Such a model can then include the influence of the HCS on the population age–sex structure. These peculiarities necessitate a somewhat special structure for this model. But such a structure is more convenient for the model's inclusion in a family of HCS models.

Both population models have been programmed and tested on the demographic statistics of several countries. Some examples of the results for Yugoslavia are shown in Figure 8. The population forecasts were used in the Aggregate Model for Estimating HCS Resource Requirements (AMER) (Klementiev and Shigan, 1978) and in other IIASA HCS models. The estimation of the trends in morbidity, and hence mortality, on the basis of different medical statistics may also be useful for future development of the demographic models.

MORBIDITY MODELS

The Need for Mathematical Models

The problem of estimating trends in health indices is a serious problem in all countries, and much attention has been given to it by WHO. WHO and others have used a number of indices, all of them roughly divided into groups – demographics, morbidity, physical development, and so on. Demographics, for example, includes mortality rates, nationality rates, and expected lifespan. Morbidity indices are those rates that reflect deviations in physiological conditions. Physical development indices describe the physical condition of individuals and groups of population. These indices taken independently could estimate health status only partially – the combination of these rates reflects more accurately the health status of the population.

Unfortunately, the problems of identifying and collecting medical information about individuals in order to plan and operate social services have not been solved anywhere, and in developed countries dynamic computer registers are being created only for small localities or to cover only parts of the population. Because all these experiments are proceeding according to very limited aims and have only just started, the main sources of complete information about the health of the population in many developed countries are special comprehensive studies in a sample locality (or localities) during a fixed period of time. These comprehensive studies include the following:

- Census of a sample population
- Testing of individual physical development
- Investigation of all individual out-patient visits to out-patient departments, polyclinics, medical and health centers

year 1961 / year 1966

	population				population		
age	total	slovenia	r.yugos.	age	total	slovenia	r.yugos.
0	915700.	67800.	847900.	0	967579.	69924.	897655.
5	979300.	74100.	905200.	5	865621.	66731.	798890.
10	878800.	70700.	808100.	10	976572.	73995.	902577.
15	677500.	60100.	617400.	15	875950.	71060.	804890.
20	788400.	62900.	725500.	20	674103.	60534.	613569.
25	840500.	66500.	774000.	25	783110.	63284.	719826.
30	795500.	67100.	728400.	30	833790.	66331.	767460.
35	696200.	62900.	633300.	35	788196.	66848.	721349.
40	431900.	39500.	392400.	40	687934.	62615.	625319.
45	485000.	47900.	437100.	45	424793.	39079.	385715.
50	505100.	51300.	453800.	50	472913.	46957.	425956.
55	435400.	46100.	389300.	55	485716.	49841.	435875.
60	365400.	39600.	325800.	60	408341.	43969.	364372.
65	260100.	29500.	230600.	65	327792.	36090.	291702.
70	201700.	21700.	180000.	70	216213.	24653.	191560.
75	135300.	14400.	120900.	75	150262.	16054.	134208.
80	68300.	7100.	61200.	80	86006.	8557.	77450.
85	42900.	3600.	39300.	85	65870.	4435.	61435.
tot	9503000.	832800.	8670200.	tot	10090763.	870955.	9219808.

year 1971 / year 1976

	population				population		
age	total	slovenia	r.yugos.	age	total	slovenia	r.yugos.
0	988585.	71442.	917143.	0	1049627.	74584.	975043.
5	914592.	68846.	845746.	5	934448.	70341.	864107.
10	863211.	66624.	796588.	10	912044.	68752.	843292.
15	973399.	74488.	898911.	15	860408.	67035.	793374.
20	871544.	71869.	799676.	20	968495.	75553.	892941.
25	669603.	60604.	608999.	25	865705.	72203.	793501.
30	776864.	63087.	713777.	30	664288.	60247.	604042.
35	826119.	66149.	759971.	35	769722.	62891.	706831.
40	778819.	66593.	712225.	40	816273.	65944.	750329.
45	676613.	61949.	614664.	45	765989.	65918.	700072.
50	414197.	38325.	375871.	50	659734.	60757.	598977.
55	454757.	45630.	409127.	55	398276.	37265.	361012.
60	455509.	47551.	407958.	60	426462.	43543.	382919.
65	366309.	40073.	326236.	65	408603.	43349.	365254.
70	272478.	30165.	242313.	70	304495.	33496.	270999.
75	161067.	18235.	142833.	75	202986.	22314.	180672.
80	95514.	9539.	85975.	80	102335.	10831.	91504.
85	83092.	5347.	77746.	85	92264.	5960.	86304.
tot	10642274.	906515.	9735759.	tot	11202155.	940982.	10261173.

FIGURE 8 Dynamics of the Yugoslavian population: age-spatial distribution. (r.yugos. = rest of Yugoslavia.) Source: Willekens and Rogers (1976), pp. 46–49.

- Study of all in-patients during a certain period
- Screening of a sample population, together with complete examination by a team of different specialists

Such comprehensive studies, repeated over several years, allow us to estimate trends in health indices for different groups of the population.

In some countries where the confidentiality of personal medical information is weighed very heavily, the results of such a study are practically unavailable or can be used only by limited groups of specialists (e.g., those involved in insurance systems). In other countries all this information is available for various scientific purposes, including the modeling of health care systems. At IIASA, where scientists from different countries are working, the lack of information in one country can be compensated for by information taken from other countries.

Comprehensive studies with complete information about health also enable us to estimate the completeness of existing sources of official "routine" information. This is depicted in Figure 9, where all the completeness coefficients K_i could be studied according to different diseases, age, sex, residence, or other parameters. If there were a number of such periodic comprehensive studies, it would be possible to estimate all of these coefficients through time.

Because there are many sources of morbidity data in each country, differing in coverage and accuracy, the procedure of estimating morbidity rates becomes more difficult and mathematical description is required. The development of such mathematical models would have the following effects:

- In countries where there has been difficulty in obtaining personal medical information, the need for this would be reduced.
- In other countries, the application of these mathematical methods would bring about a decrease in the number of expensive comprehensive studies.
- For all countries, these models would help in forecasting health status and medical resource requirements on the basis of a common methodology.

Types of Models

Shigan (1977) described different alternatives for estimating morbidity rates using the information available in different countries. Such models

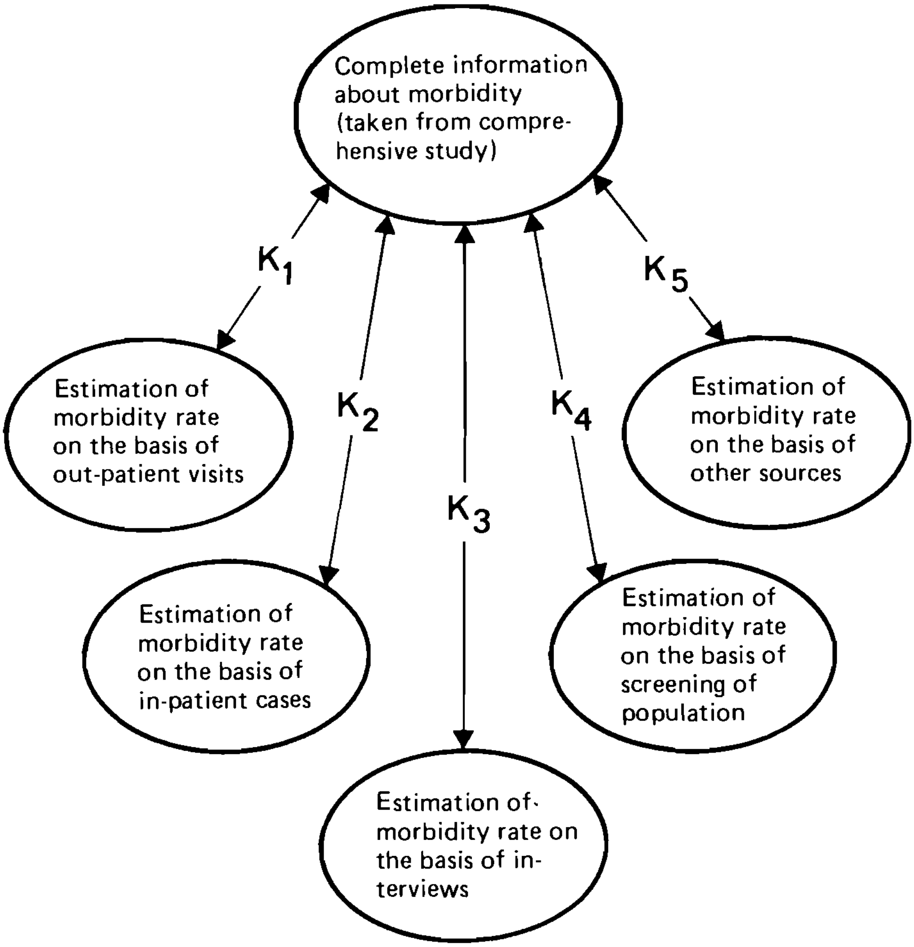

FIGURE 9 Comparative analysis of completeness of different sources of medical information about morbidity.

can be classified by degree of detail into the following types:

1. Aggregative morbidity models, which estimate and forecast "crude" general morbidity rates without specifying particular diseases or groups of diseases
2. Group morbidity models, which model groups of diseases, e.g., the classes in the International Classification of Diseases (ICD), or the groups used in several IIASA publications (degenerative diseases, infections, accidents, and so on)

3. Specific morbidity models, which consider specific diseases (e.g., cancer, cholera, tuberculosis)
4. Stage-of-disease models, which look not only at a specific disease but also at the different stages of its development and at risk-group estimation and classification

When the results are to be used to estimate medical resource requirements, it is much better to use morbidity models specified according to disease or type of diseases (2–4 above). But to do this we need information about the frequency of disease in the population and the numbers of consultations, beds, laboratory tests, and so on required for each disease. Unfortunately, such information is not available in most countries and may be found only by special comprehensive studies. Moreover, each country uses its own classification of hospital department, laboratory techniques, medical specialties, and so on (the ICD is the only good example of international agreement on medical terminology). Because of these difficulties, however, mathematical models developed on the basis of information taken from several countries will be very useful to WHO and other organizations in comparing different countries according to the same principles.

Together with a number of national centers, we have designed and constructed several computer models using the statistics of WHO:

AMM:	for estimation of aggregative morbidity rates
INFM:	for estimation of morbidity rates for infectious diseases
MEMOD:	for estimation of morbidity rates for terminal degenerative diseases
DYMOD:	for estimation of morbidity rates in the case of unstable and unstationary populations

AGGREGATIVE MORBIDITY MODEL (AMM)

As mentioned above, data about morbidity and its trends can, with a certain amount of difficulty, be taken from real comprehensive studies, conducted periodically in some developed countries. However, because there are only slight variances among aggregate morbidity rates, aggregate mortality rates, and the ratios between them (risk ratios) over time, it is possible to estimate aggregate morbidity data roughly using mortality data from official vital statistics and the risk ratios from such studies. The AMM uses as input the age-specific mortality rate, a forecast of the population age structure, and the age-specific risk ratio. The central assumption of the model is that risk ratios are constant over time. As output, the model forecasts age-specific morbidity. This model was used as an auxiliary morbidity submodel in the AMER model described by Klementiev and Shigan (1978) and treated briefly below.

A MORBIDITY SUBMODEL OF INFECTIOUS DISEASES (INFM)

This model was designed by Fujimasa *et al.* (1978). The aim of INFM is the estimation of age-specific prevalence and death rates per total population for two groups of diseases: infective and parasitic diseases (ICD A1–A44) and diseases of the respiratory system (ICD A89–A96).* On the basis of some standard rates that one can easily obtain from domestic health statistics, it is possible to estimate the prevalence rate, disease-specific death rates per capita, and mean length of hospital stay, under the assumptions that mean length of stay is less than 1 year and prevalence is constant over time. In accordance with the model's first assumption, the aging of sick individuals during the duration of the disease is not taken into account. On the other hand, the second assumption implies that prevalence does not oscillate during this time. It means that the model itself is static and its technique is static analysis, but that the output of the model can be dynamic if one of the model's inputs – for example, population structure – is changing over time.

To test the validity of the model, we applied it to the data of Japan and compared the results with data from Finland, Austria, Sweden, England and Wales, Japan, and France. The calculations were performed separately for epidemics and infectious diseases of the respiratory system, and the results were then combined to obtain an estimate of prevalence for all infectious diseases. The disease-specific death rates per capita thus obtained were compared with those from WHO statistics. Table 1 gives sample results.

In this study, the prevalence rate and the mean length of stay are mainly based on the data for Japan for 1974. The prevalence rate of infectious diseases was obtained from the national health survey of Japan (Ministry of Health and Welfare of Japan, 1977) and the mean length of stay was obtained from the patient survey statistics of Japanese hospitals

*International Classification of Diseases (ICD) numbers.

TABLE 1 The three standard rates (MR, RECOV, DR) of the infectious disease morbidity model and the validation of the model against disease specific death rates per capita.[a]

	ICD A1–A44 (Infective and Parasitic Diseases)						ICD A89–A96 (Diseases of the Respiratory System)					
				DRPN						DRPN		
Age	MR	RECOV	DR	Computed from PN	Japan 1974	Austria 1974	MR	RECOV	DR	Computed from PN	Japan 1974	Austria 1974
0	1,400	0.2	4	95	98	244	10	0.14	125	32	62	24
1–4	1,400	0.2	0.4	10	13	12	10	0.14	12.5	3	8	5
5–14	300	0.25	2	7	4	3	6	0.16	6.25	1	1	1
15–24	200	0.2	2	6	3	5	1.5	0.2	25	1	2	1
25–34	170	0.17	2	6	4	3	2	0.16	37.5	2	4	2
35–44	250	0.17	2	8	7	8	2.5	0.14	70	5	11	8
45–54	250	0.125	3	21	15	18	3	0.125	125	11	21	10
55–64	200	0.1	8	57	50	60	3	0.1	250	27	42	26
65–74	100	0.05	30	213	215	221	2.5	0.08	500	54	99	56
75+	100	0.03	100	1,141	911	957	2.5	0.065	1,000	122	228	91

[a]Standard rates in the model: MR, morbidity rate (per 100,000 healthy persons); RECOV, recovery rate (per sick person); DR, death rate (per 100,000 sick persons). Input: PN, population of Japan 1970. Output: DRPN, death rate per population (per 100,000 population in the age group).

SOURCE: Adapted from Fujimasa *et al.* (1978), p. 11.

(WHO, 1974). The standard model's coefficients, morbidity, recovery, and death rates obtained from these statistics are shown in Figure 10.

These results show that the model can predict the fundamental part of infectious diseases, and that this type of approach is feasible in health planning. However, we cannot estimate the prevalence rates in developing countries with this morbidity model, because these essential rates of infectious diseases are correlated with other socioeconomic factors such as net income, food supply, education, hygiene, and preventive medicine. The correlation of these factors with infectious diseases will involve further development of INFM.

MORBIDITY MODELS OF DEGENERATIVE DISEASES

Degenerative diseases are inherent in human beings. They are caused by the aging process, and the morbidity rate in these diseases usually increases with age. In our work, we have defined three groups of diseases as degenerative: cardiovascular disease (ICD A80–A88), malignant neoplasms (ICD A45–A60), senile deaths and deaths from unknown causes (ICD A136–A137).

Unfortunately, the routine morbidity statistics in all countries record only some of the cases of degenerative diseases, and it is necessary to estimate the true number of cases on the basis of other indirect statistics – in particular, mortality data. The dynamics of degenerative diseases are slower than those of infectious diseases, however, so we must take into account not only the population structure and its changes, but also the individual dynamic property of each specific disease.

In the IIASA morbidity models for degenerative diseases, different assumptions and techniques are used. Nevertheless, we shall try to describe these problems in a unified form. For this, we shall indicate the data that we can use to estimate the morbidity of degenerative diseases on the basis of mortality statistics:

- The age distribution of specific mortality rates and their dynamics over time
- The age distribution of general mortality rates and their dynamics over time
- Survival characteristics that describe in some sense the dynamics of disease, e.g., the proportion of individuals who were afflicted with a given disease at a certain time and age, and who did not die within a certain time
- The population's age structure and its dynamics

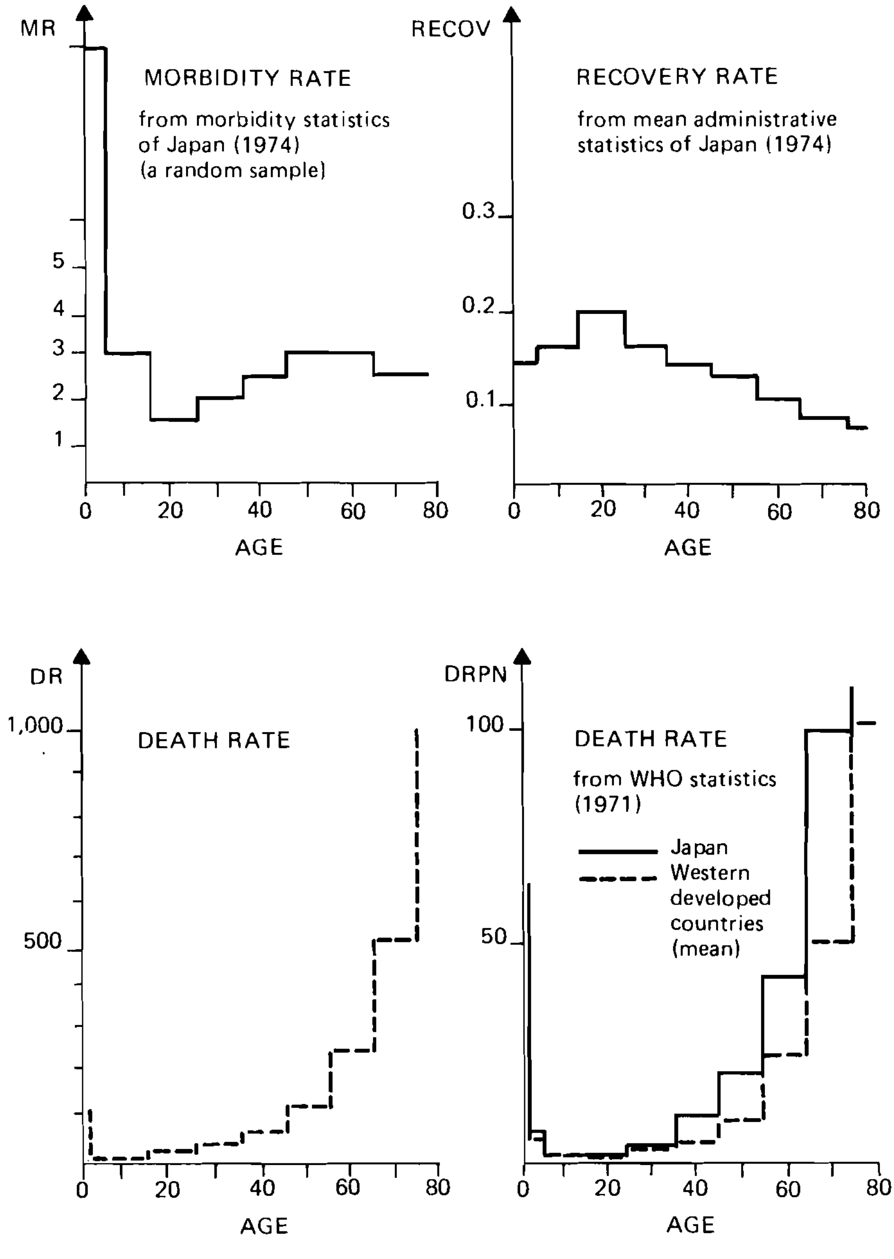

FIGURE 10 Rates used in the morbidity model of infectious diseases (ICD A1–A44). (MR, RECOV, DR, and DRPN are defined in Table 1.) Source: Fujimasa *et al.* (1978), p. 9.

It is possible to describe mathematically the dynamics of the process "health → sickness → death" by integral equations that link the statistical data listed above with morbidity rates and prevalence distributed by age. Many morbidity estimation problems can be formulated in these terms, but the HCS modeling activity in this field is focused on one particular problem: how to estimate prevalence distributions and morbidity rates from general and specific mortality data, survival probabilities, and population age structure.

First Model. Because the quality of data is not the same in all countries, different assumptions about survival were used in the IIASA morbidity models. In the first IIASA model of this type (Kaihara *et al.*, 1977), the following assumptions were used:

- All variables are independent of time.
- People suffering from degenerative diseases are considered sick for the rest of their lives.
- Persons who become ill will inevitably die at a certain definite time after contracting the disease. The duration of illness (T) is dependent only on the type of disease.

In accordance with these assumptions, the model uses as input the population age structure, the durations of illness, and the death rate according to cause specified by age; it gives as output the age-specific morbidity rate and the age-specific prevalence rate.

To test the validity of the model, it was applied to various countries, using data from the Philippines, Mexico, Japan, England and Wales, and Sweden. In the calculations, a population structure of 5-year age intervals was used. It was then further divided into 1-year intervals, and the variables for outputs were calculated separately for cardiovascular and malignant diseases. Some of the results for Japan are shown in Figure 11. Although this model covers only degenerative diseases, some interesting results have already been obtained.

The first area of application will be an international or regional comparison of the death rates for degenerative diseases or the number of patients suffering from such diseases. If statistics for patients with degenerative diseases are available, it will be of interest to compare them with the results obtained from the model. A difference between the two figures would imply the existence of "latent" patients who could seek medical care.

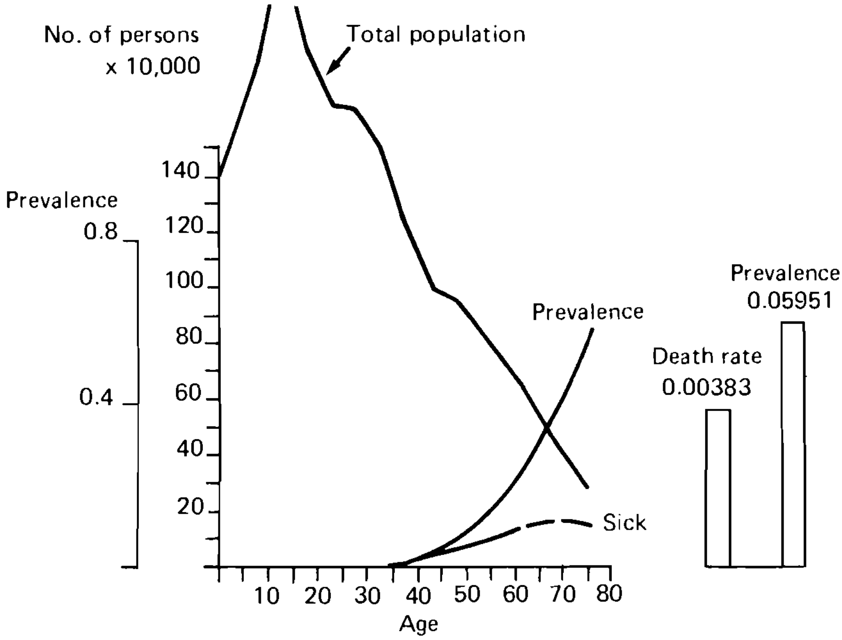

FIGURE 11 Number of sick, prevalence, and death rates of cardiovascular diseases as predicted by model (in Japan in 1960). Source: Kaihara *et al.* (1977), p. 27.

The second application of the model will be to the projection of trends in degenerative disease. Models for estimating future population structure have been described above. Because the morbidity model is dependent only on the age structure of the population, population and morbidity models can be combined, and future trends in degenerative diseases can easily be calculated. Some preliminary calculations along these lines suggest that the prevalence of degenerative diseases in England and Wales is decreasing gradually, while in Japan it is sharply increasing toward the year 2000.

The third application of the model may be in the evaluation of treatment for degenerative diseases. When such treatments are proposed, the model may be useful for predicting the likely impact.

Second Model (MEMOD). In the second IIASA degenerate morbidity model developed within the HCS Task (Klementiev, 1977) the last assumption on page 28 is changed so that persons who become ill at time t can die at time τ with probability $P(t,\tau) = P(t - \tau)$, and the possibility of death from other causes is not equal to zero. This model needs some inputs beyond those of the first model. These inputs are death rates specified by age, for all causes, and the survival probabilities $S(t-\tau) = 1 - P(t-\tau)$ obtained from clinical experience. This new assumption is more realistic than the assumption in the first model, but it complicates the model's structure. Nevertheless, the estimate of prevalence and morbidity rates can be obtained as the solution of a sequence of systems of linear equations.

Estimation of malignant neoplasm prevalence was carried out for Austria, Bulgaria, and France, using data from WHO (1971) and Emmanuel and Evseenko (1970). The results of the calculations are presented in Table 2. To simplify the comparison of the number of deaths with the prevalence figures for the same age group, these figures are presented in a double column.

Future Development

Further development of the morbidity models is directed toward reducing the restrictions on the dynamics of population structure and disease. For example, the present assumption that population structure is stable and stationary implies that these models can be applied only to populations with a monotonic-like age structure. In addition, it is necessary to adapt these models to use comprehensive health study data about a specific region, in order to avoid extending clinical survival data to the latent sick individuals.

One way to overcome these difficulties is to use the state-space approach to describe disease dynamics. This approach is used in the model currently being developed for the estimation of morbidity rates in the case of unstable and unstationary population structures (DYMOD). The application of this model requires corresponding medical and demographic statistics for several consecutive years.

HEALTH RESOURCE REQUIREMENT MODELS

The Problem

One of the most serious problems in modeling health care systems is the design of models for health resource requirements. In many countries there are several different mechanisms for determining resource requirements: market, insurance, normative planning, and so on. The problem is greater in countries that use a combination of these mechanisms.

TABLE 2 Estimated prevalence and actual deaths from malignant neoplasm.

	Austria		Bulgaria		France	
Age	Estimated prevalence	Deaths[a]	Estimated prevalence	Deaths[a]	Estimated prevalence	Deaths[a]
0–4	0	0	0	6	0	19
5–14	40	10	20	12	0	64
15–24	110	22	190	32	210	121
25–34	340	78	680	104	3,210	312
35–44	1,290	332	2,210	392	12,690	2,186
45–54	3,810	950	5,380	907	38,210	6,314
55–64	10,780	2,600	10,410	2,214	81,480	14,346
65–74	18,200	5,028	15,950	2,923	153,400	23,165

[a]From Emmanuel and Evseenko (1970).

SOURCE: Klementiev (1977), p. 18.

The IIASA HCS Modeling Group is developing several models for health resource requirements using the experience of different countries in this field. Using a normative planning approach, knowledge is obtained from data about population, health status, present levels of care, and their dynamics, and about how health conditions are translated into health resources. Indices are then calculated for the number of out-patient visits per capita, the duration of one out-patient visit (in minutes), and the number of out-patient visits per patient with a specific disease, and for similar measures associated with cther forms of care. Central to the approach is the calculation of standards for these indices.

Sometimes these standards can be obtained only from the opinions of several experts. Sometimes it is possible to take standards from official "routine" statistics – e.g., hospitalization rate or average length of stay. In some countries, this set of standards is based on a comprehensive study, as mentioned earlier. In the course of such a study, old standards are revised by a team of medical specialists who observe the quality of health care received by sample patients. Such a team of experts might alter the standards, using the opinions of local specialists.

Variations in these indices indeed reflect the real situation in each country and the differences between countries. It is for this reason that we have started with commonly used indices such as average length of hospital stay, bed occupancy rate, and bed turnover interval. In some countries, these indices are published in official annual statistics on health and reflect the retrospective situation. They can be considered as constant standards and can be used for estimating the resource requirements, or they can be revised by specialists before use in the modeling process.

Structure and Assumptions

Two models have so far been developed at IIASA: AMER, Aggregate Model for Estimating Resource Requirements (Klementiev and Shigan, 1978), and SILMOD, Sick Leave Model (Fleissner, 1978). The basic structure of AMER is illustrated in Figure 12 and that of SILMOD in Figure 13. As shown in these figures, the main difference between AMER and SILMOD is in the methods of morbidity estimation and in the population groups taken into account in each model. To calculate out-patient doctor-equivalent requirements in the AMER model, the substitution effect should be taken into account: the lower the hospitalization rate and the shorter the average length of stay, the greater the number of consultations per episode. The main assumptions of AMER are linearity and stationarity of the substitution effect. In SILMOD, the substitution effect is not taken into account. However, both models assume stationary prevalence rates (or risk ratios and sick leave rates) over time.

Inputs and Outputs of Models

AMER

The inputs of the model are the planned or forecast dynamics of the standards (norms). These are summarized in the input file CTL (control variables), represented in Figure 14. Some results of the model's calculations are displayed on the terminal screen in the format shown in Figure 15. Here, the input summary appears above the line of stars, and the computation summary appears below the line of stars. The latter gives the resource requirements suggested by the model.

SILMOD

The input variables are almost complete analogues of the inputs to AMER. The output of SILMOD is divided into two parts. The first part gives detailed information on the total number of employees, cases and days of sick leave, and cases of days of hospital stays. Each of the variables is

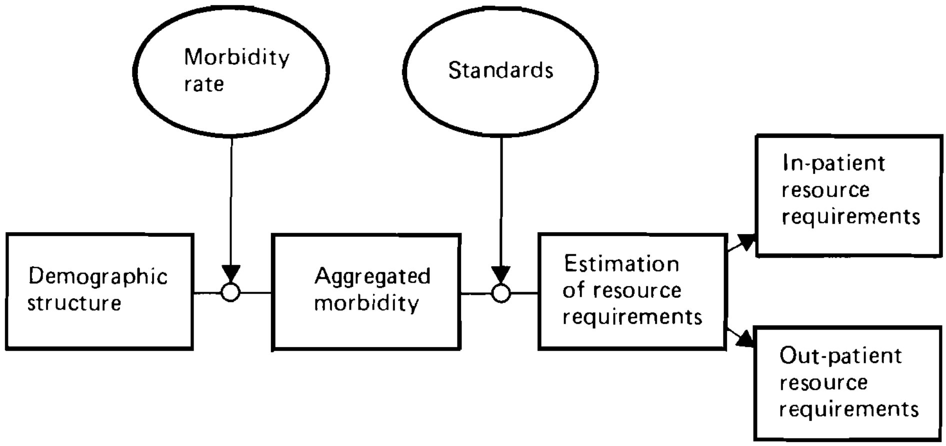

FIGURE 12 Basic structure of AMER.

divided by sex and age. The last two rows indicate sums or averages of rates for males and females, or their respective totals. The second part of the output indicates the cost factors, resources needed, and average durations of hospital stay and sick leave. The two parts of output are produced for each year for which demographic forecasts are available.

Model Use and Possible Development

The resource requirement models will help the national-level decision maker to test different policy options and to select the best among them. A model also makes it possible to forecast changes in population structure and mortality and morbidity trends, which are very important to health care. To illustrate another application, let us refer to the lowest mortality rate among a group of countries as the "ideal" mortality rate. If we replace the actual mortality of some test country with this "ideal" mortality rate, we obtain some very interesting results related to health care resources such as beds, staff, and finances.

Although these models are designed for forecasting aggregate health resources, in some cases they can be used for specific classes of disease and

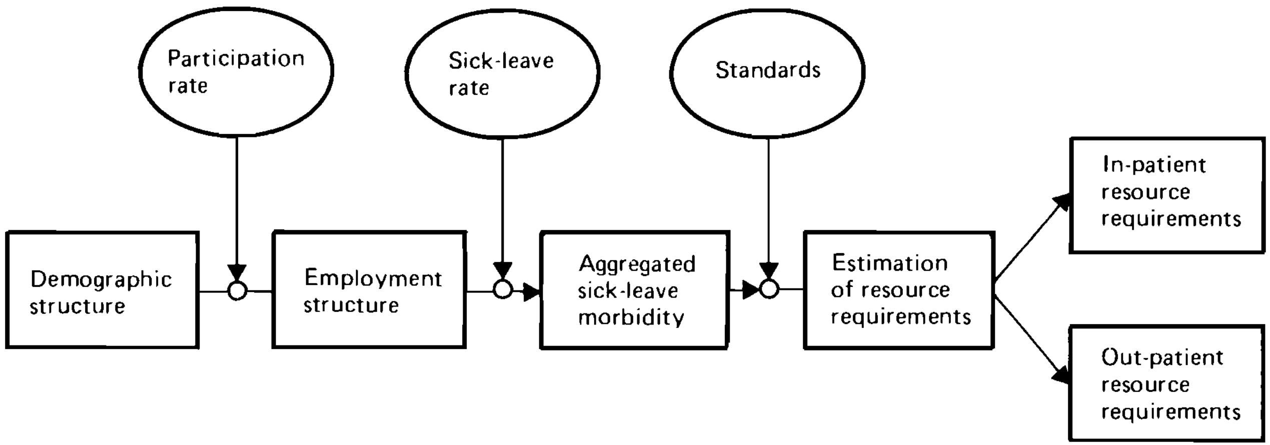

FIGURE 13 Basic structure of SILMOD.

```
                              * FILE CTL *

                   :  BASE  :   FUTURE YEARS / TRIAL FUGURES
                   :  YEAR  : YEAR 5:YEAR 10:YEAR 15:YEAR 20:IDEAL
-------------------:--------:-------:-------:-------:-------:-----
AVERG LNGTH STAY   : 33.5   : 30.0  : 28.   : 25.0  :22.0   :19.0
                   :        :       :       :       :       :
PRCNTGE HSPTLSD    : 10.53  : 10.53 : 10.   : 9.7   : 9.5   : 9.5
                   :        :       :       :       :       :
BDS/INP DOC EQVT   : 21.81  : 21.81 :21.81  : 21.81 :21.81  :17.0
                   :        :       :       :       :       :
BED TRNVR INTRV    :  4.94  : 4.7   :4.5    : 4.3   : 4.1   : 4.0
                   :        :       :       :       :       :
CNSLTS/OTPT DOC/Y:7033.0  :7033.0 :7033.0 :7033.0 :7033.0 :6000.0
                   :        :       :       :       :       :
BED'S COST/YR      :3145.0  :3300.0 :3400.0 :3500.0 :3600.0 :
                   :        :       :       :       :       :
COST/OTPT DOC/YR   :29400.0:30000.0:31000.0:32000.0:33000.0:
                   :        :       :       :       :       :
CNSLTS/EPSD        :  3.5   :
```

FIGURE 14 Input control file. Source: Klementiev and Shigan (1978), p. 9.

```
INPUT-OUTPUT SUMMARY#
                 YEAR 0  YEAR 5 YEAR 10 YEAR 15  YEAR 20   IDEAL
----------------------------------------------------------------
V LNG ST       :  33.50:  30.00:  28.00:  25.00:  22.00:  19.00:

RC HSP         :  10.53:  10.53:  10.00:   9.70:   9.50:   9.50:

DS/INP D EQV   :  21.81:  21.81:  21.81:  21.81:  21.81:  17.00:

ED TRNVR INT   :   4.94:   4.70:   4.50:   4.30:   4.10:   4.00:

NSL/OTP D/YR   :  7033.:  7033.:  7033.:  7033.:  7033.:  6000.:

ED COST/YR     :3145.00:3300.00:3400.00:3500.00:3600.00:
                         **********************************
NSLTS/EPSD     :   3.50 *   3.67:   3.99:   4.27:   4.50:
*************************
DS RQRD, TOT   :535222.:436040.:359842.:294591.:241010.:

NDS RQR, TOT   :2389.41:2121.74:1934.62:1765.30:1616.30:

OC EQVS RQR    : 48559.: 42753.: 39440.: 36452.: 33737.:
```

FIGURE 15 Format of displayed results. Source: Klementiev and Shigan (1978), p. 10.

for specific medical resources. In the resource requirement models so far, only some health care resources have been represented. However, the models can be developed to describe the use of other resources, including nurses, auxiliary personnel, facilities, and laboratories, all of which are control variables that depend on quantitative factors.

It is clear that in order to build such models it is necessary to have many kinds of medical data. Some of the data may not exist or may be difficult to obtain (e.g., substitution rates). Thus the use of such a model will create new requirements for medical information as well as suggesting new medical policy issues. The development of models and information systems in health care are closely connected.

HEALTH RESOURCE ALLOCATION MODEL

DRAM is an acronym for Disaggregated Resource Allocation Model. This model was proposed by Gibbs (1978) and subsequently developed by Hughes (1978a,b,c). In the conceptual framework shown in Figure 4, the resource allocation model lies between the estimation of morbidity and the prediction of resource supply. It seeks to represent the way in which the HCS allocates limited supplies of resources between competing demands.

Health services cannot be administered in a rigid centralized manner. In every country, doctors have clinical control over the treatment of their patients, and it is local medical workers who ultimately determine how to use the resources (e.g., hospital beds, nursing care) available to them. The specific question underlying DRAM is

> If the decision maker provides a certain mix of resources, how will the HCS allocate them to patients?

DRAM takes input data on demand and supply, uses a hypothesis about how allocation choices are made, and gives indicators of the predicted behavior of the HCS. The demand inputs are the total number of individuals who need treatment, by category (from the morbidity and population submodels); the policies for treatment (i.e., the feasible modes of treatment for each patient category – in-patient, domiciliary, and so on); and the ideal quotas of resources needed in each patient category and mode of treatment. The supply inputs are the amounts of resources available for use in the HCS and their costs (from the resource supply model). The model outputs represent the levels of demand satisfied in an HCS with limited resources. These outputs are the numbers of patients in different categories who receive treatment, the modes of treatment offered, and the quota of resources received by each patient in each mode of treatment. Inevitably, these levels fall short of the ideal demand levels. DRAM models the equilibrium that the HCS achieves in balancing supply and demand. These results can be used by health planners to explore the consequences of alternative policies for resource production, treatment, and prevention.

Model Assumptions

There are two assumptions about the behavior of the HCS in the model. First, the model assumes that there is never a sufficient supply of resources to answer all the potential demands for them. This finding has frequently been noted in many areas of health care. Accordingly, the model represents the HCS as attempting to achieve an equilibrium between supply and demand. The second assumption is that the HCS allocates its resources in a way that appears to maximize a utility function whose parameters can be inferred from observations of past allocations. Such a model is of the behavior simulation kind, and, like the models of McDonald, *et al.* (1974) in the UK and Rousseau (1977) in Canada, it represents the actors in the HCS striving to attain some ideal pattern of behavior within resource constraints. If these hypotheses are sound, DRAM can not only describe past equilibria, as can classical econometric models, but it can also predict how the equilibrium is likely to change in the future as a result of changes in such factors as clinical standards, disease prevalence, and the preferences and priorities operating in the HCS.

DRAM does not, and cannot, represent every mechanism of the real process by which health care resources are allocated. Its purpose is rather to model a concept: namely, that the HCS achieves an equilibrium by balancing the desirability of treating more patients of one type against that of treating more of other types, and against that of treating each type of patient at a higher average standard. In the examples illustrating the use of DRAM, we examine how the HCS allocates beds and staff in the treatment of in-patients, but the underlying concept appears to be valid for many other HCS sectors (e.g., out-patient physicians, beds, nurses). It is therefore likely that the model could be applied quite widely.

Model Theory

Here we only summarize the model theory. Consider the problem of predicting how the HCS will use the in-patient beds available to it in order to treat acute patients. Specifically, suppose that just B bed-days are available per capita of population per year. Then the HCS must choose the admissions per capita of population per year x, and their average length of stay y, such that

$$xy = B \ .$$

This equation represents a family of hyperbolas plotted in Figure 16. If we were able to experiment with the HCS, we could change B and plot the values of x and y chosen by the HCS. Since this is not possible, we make an assumption about the shape of solution lines in the x–y space, and we estimate the parameters that define the shape using historic data from the HCS. With a model calibrated in this way, we can then simulate how the HCS would behave if it were supplied with beds at some rate chosen by the decision maker. DRAM is more complicated than this, because it can represent many patient categories and many resources that are difficult to depict graphically. Nevertheless, the underlying concept is as described above.

What assumptions do we need in order to determine the character of the model solution? We use the following assumptions.

- The utilities of treating more patients and of treating them with more resources are independent, monotonically increasing, and additive across patient categories and resource types.
- When all demands are met, the marginal utilities of increasing the numbers treated or their resource quotas equal the corresponding marginal resource costs. In this situation, extra resources are useful only as assets and not for treating patients.
- Percentage increases in x and y give rise to proportional percentage decreases in marginal utility at all levels of x and y. In other words, utility returns diminish as x and y increase.

It is important to understand that the utility function used in DRAM does not represent a quantity that anyone in the HCS is consciously, or even subconsciously, trying to maximize. Instead, it represents a hypothesis about the aggregated behavior of the HCS, in which the parameters represent the priorities implicit in the choices that are made. DRAM is a *simulation* model. We do *not* seek to optimize behavior in the HCS.

A second question is: How do we estimate the parameters of DRAM? We have two ways to do this. The first approach is to use information about the elasticities of supply to demand. A cross-sectional analysis of

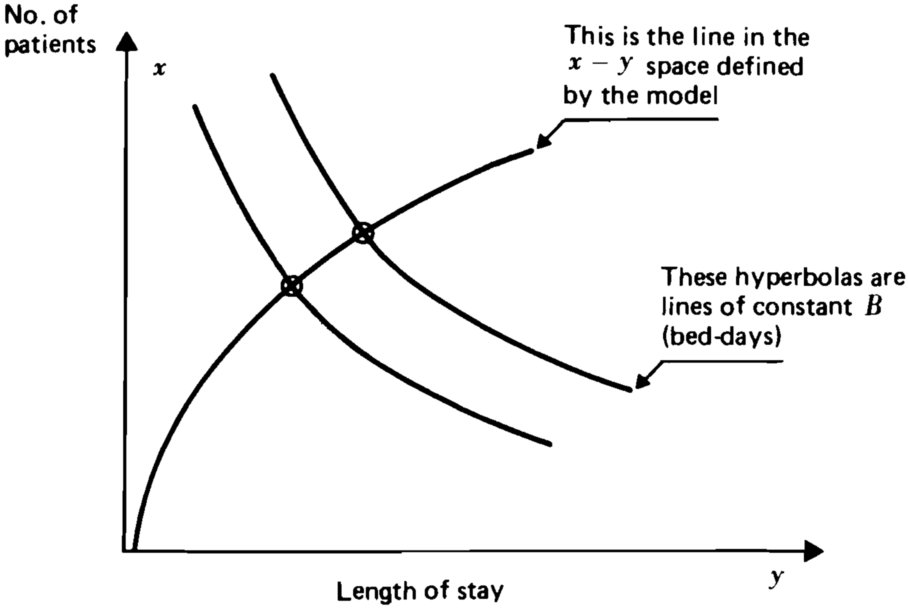

FIGURE 16 DRAM chooses solution points on the line of constant resources.

hospitals such as that of Feldstein (1967), can show, for example, how much more elastic to bed supply is the number of bronchitis admissions than the number of appendicitis admissions. Versions of DRAM that are calibrated on such data reflect the same priorities. The second approach to parameter estimation uses historic data about actual allocations. In Figure 16 historical allocations are represented by points in the x–y space that should be on the solution line. Moving the solution line so as to satisfy this requirement leads to another procedure for parameter estimation.

A third question is: What sort of mathematics and how large a computer are needed to solve the model equations? The problem as stated above could quite easily be formulated as a problem in mathematical programming, perhaps as a modified linear program. Our approach, however, has been to exploit to the full the analytic properties of the model. The solution is derived analytically using the method of Lagrange multipliers, and the only difficult computation involved is the solution of a small nonlinear equation of the form $f(\lambda) = 0$. It is therefore easy and inexpensive to perform many different runs of DRAM, and it is also simple to transfer the model to collaborating groups outside IIASA. The programs have been established in Berlin, London, Montreal, and Munich, and one of these groups has run DRAM with nearly 100 disease categories, reporting a very efficient solution.

Computer Program and Application

Two versions of DRAM have been programmed and tested: a Mark 1 version, which is restricted to a single resource and a single mode of care, and a Mark 2 version, which handles several resources within a single mode of care. The programs are compact and fast-running, and the Mark 1 version has already been implemented by collaborating groups in Canada and the UK.

Table 3 gives an example of the Mark 1 model that considers the allocation of in-patient bed-days among patients with six diseases assuming varying levels of available bed-days. Data drawn from the South Western Region of the UK were used in conjunction with the first estimation procedure described above to produce these results. The two runs given assume the availability of beds to be 800 bed-days per million population and 1,200 bed-days per million population, respectively. The resulting allocations differ for different ailments. In "appendicitis," for example, admissions have remained constant while length of stay in hospital has increased slightly. In contrast, for "bronchitis," admissions have increased considerably while length of stay has remained constant with increasing bed availability. Similarly, this model can be used to make allocation predictions for other levels of bed-days. We are grateful to the officers of the South Western Regional Health Authority for their assistance with this example.

Table 4 gives results from the Mark 2 model. This example shows how two resources are divided between seven disease categories. One of the principal features of DRAM Mark 2 is that it needs information about the relative costs of different resources. The figure used in this example (doctor cost = 1.57 × bed cost) follows from associating all of the hospital costs (*except* doctors' salaries) with bed costs. It is this assumption that actually *defines* the resource types modeled by DRAM.

Finally, we mention some of the ways in which we hope to extend this model. A useful development of DRAM would be a Mark 3 version that balanced the different modes of treatment (e.g., in-patient, out-patient) available in the HCS. Different modes often share the same resources, and it is not immediately obvious how the HCS will behave when resource levels are changed. A necessary development is an improved

TABLE 3 DRAM: Allocation of in-patient bed-days for six diseases (Mark 1).

	Run 1: B = 800 bed-days/ million		Run 2: B = 1,200 bed-days/ million	
Patient category (i)	Admission rate (x_i)	Avg. length of stay (days) (y_i)	Admission rate (x_i)	Avg. length of stay (days) (y_i)
Varicose veins	6.4	9.1	8.5	11.4
Hemorrhoids	4.1	9.0	5.4	10.6
Ischemic heart disease	3.6	20.7	5.4	30.9
Pneumonia	11.3	16.2	14.7	17.6
Bronchitis	8.1	32.8	12.3	33.3
Appendicitis	23.7	7.7	24.2	8.7
All categories	57.2	14.0	70.4	17.0

SOURCE: Gibbs (1978), p. 29.

procedure for parameter estimation. It may be possible to refine these methods further, possibly to include a procedure that would validate the underlying hypothesis of DRAM. A third sort of extension would be a refinement of the model to handle more specific areas of care within the HCS – for example, the care of the elderly, a problem that is common to many countries. We hope to investigate these and other issues in collaboration with other research centers that are at work in this important area of research.

HEALTH RESOURCE SUPPLY MODELS

A list of health care resources comprises many components, such as manpower, beds, buildings, facilities, and drugs. Because manpower is the most important of these components, we began our study of resource supply models by first considering HCS manpower problems. Manpower control presents three main fields of problems: (a) the definition of optimal demands for manpower resources; (b) the preparation and allocation of the corresponding specialists; and (c) the investigation and simulation of influences on the migration of manpower.

The first set of problems can be solved with the aid of HCS resource requirement models, and these were discussed earlier. The second set can

TABLE 4 DRAM: Allocation of resources for seven disease categories (Mark 2).

	B = 940.7 bed-days (1968), 104.1 doctor-days			B = 782.2 bed-days (1973), 125.9 doctor-days[c]		
Specialty	Admission rate	Avg. length of stay (days)	Doctor-days	Admission rate	Avg. length of stay (days)	Doctor-days
General surgery	19.6	9.5	1.14	17.3	8.3	1.27
General medicine	12.3	14.2	1.55	12.4	11.4	1.79
Obstetrics/gynecology[a]	33.1	7.5	0.59	35.0	6.2	0.67
Traumatic and orthopedic surgery	7.1	17.9	1.28	7.4	15.0	1.48
Ear, nose, and throat	5.8	5.2	0.74	4.1	4.3	1.22
Pediatrics[b]	15.4	9.7	1.67	19.0	7.1	1.92
Ophthalomology	2.4	10.1	1.68	1.8	8.6	3.18

[a] Population divisors exclude males.
[b] Population divisors exclude adults.
[c] Relative costs of doctors : beds assumed to be 1.57 : 1 (see text) in 1973.

SOURCE: Hughes (1978), p. 29.

be solved within the framework of education models. The solution of the third set of problems demands the preliminary investigation of the existing socioeconomic mechanisms influencing the manpower flows. We discuss our approach to these two latter sets of problems below.

Manpower Education and Retraining Models (MANP)

The training of health care personnel requires many years, and it is necessary for most medical workers to specialize. Thus the manpower education and postqualification training problems of health personnel are both large-scale and long-term in nature, and they affect many different levels of the HCS. Here we shall consider manpower supply models at the national and regional levels.

Comparative analysis of health manpower structure in different countries has shown that there is a relatively permanent composition: general practitioners, highly specialized doctors, nurses and midwives, junior medical personnel, technicians, and so on. In addition, there is much in common between training in medical schools and postgraduate training of health personnel. These are features that ease the modeling task slightly. Usually, the ultimate goal of a manpower education or postqualification training system is simpler to quantify than the goals of other branches of HCS. An enrollment plan is sought that will satisfy all the constraints of the system and be optimal in some sense – for example, the corresponding manpower plan at each step t will be as close as possible to the demand requirements for different types of specialists. This is another useful feature, and it means that the education and retraining problem is an example of an HCS subsystem in which one can apply some optimization technique, such as dynamic linear programming (Propoi, 1978).

Figure 17 shows the flows of manpower through the training process. It indicates that the state of the system at time $t + 1$ depends upon the number of health care specialists at time t, $x(t)$, and the number of entrants to the system, $u(t)$, according to a linear matrix equation of the form:

$$x(t+1) = A(t)x(t) + B(t-\tau)u(t-\tau)\,.$$

The manpower stock attrition rate is $(I - A(t))$, $B(t)$ is the fraction of entrants who will graduate, and τ is the number of time intervals needed for each entrant to graduate. Choosing different controls (enrollment

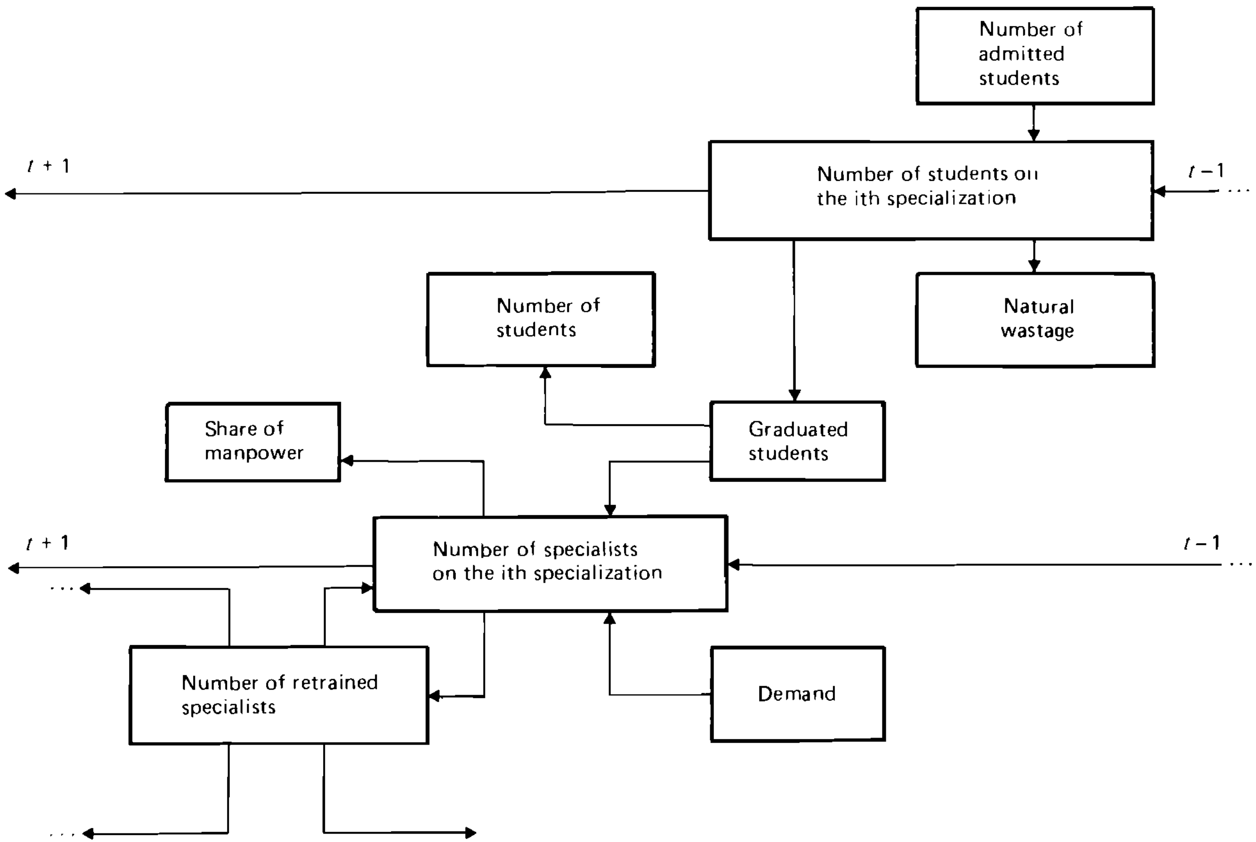

FIGURE 17 The structured scheme of the manpower planning model.

plans) u, we can define with these state equations the corresponding trajectory x (the manpower plan).

In fact, both the training process and the model are more complicated than this. First, we must disaggregate the analysis by type of specialty and type of educational institution. Secondly, we must include constraints on the model variables. There are some obvious physical constraints that require the numbers of individuals in the system to be positive. And there are resource constraints such as

$$D(t)u(t) \leqslant f(t) \ ,$$

where $f(t)$ are the resources available at time t, and $D(t)$ are the resources needed to train each entrant. In many cases it is necessary to single out the constraints on the availability of teachers or instructors of different types. These constraints and others can be written in a similar form. In simple models the numbers $f(t)$ are given as exogenous variables; in more detailed models these variables can be considered as state variables that are governed by some controllable activities – e.g., training teachers and building other educational facilities.

The ultimate goal of this manpower supply model is to meet the projected demand requirements in manpower. The projected numbers of required specialists are assumed to be known for each step of the planning period T; that is, the numbers $\bar{x}(t)$ are given for $t = 1,...,T$. The goal of control of the system is to bring the manpower stock plan $\{x(t)\}$ as close as possible, under given dynamic and static constraints, to the desired distribution of specialists $\{\bar{x}(t)\}$. In the framework of linear objective functions, this closeness can be measured by

$$J(u) = \sum_{t=1}^{T} a(t) | x(t) - \bar{x}(t) | \ ,$$

although other groups of objectives could be associated, for example, with the minimization of expenditure for education (under given demand constraints), or with the maximization of the number of eligible groups of specialists (under given resource constraints).

This completes the formulation of the model as a dynamic linear program, a technique that has been used in more sophisticated manpower education models, such as investment and vocational training submodels. All such submodels can be reduced to a single dynamic linear programming (DLP) canonical form, thus enabling us to develop unified numerical methods. It is easy to see that solution of this problem requires estimation of the attrition rates and coefficients such as b and a. This estimation problem can be solved using linear estimation techniques or by questioning experts.

So far in this work, only a single level of education has been considered, and the investments in the system are assumed to be fixed. A more detailed model could incorporate three subsystems of specialist training: nurses who graduate from nursing schools, general practitioners who graduate from medical institutes, and medical specialists of a high level who are trained in special professional courses (for example, postgraduate). Some of the second-level specialists can be teachers for the first-level educational subsystem, and all the third-level specialists can be assumed to be instructors for either the second-level or the third-level educational subsystem. However, even the simple form of the model may be useful in practice, as it takes into account in some optimal way the main features of manpower planning módels, the dynamics of the process of training specialists, and the limitations on available resources.

Manpower Migration Flow Simulation Model (AMP)

The complexity of human demands makes it necessary when planning to take into account not only the demands for manpower in different regions but also the regional conditions influencing the real supply of manpower. If one considers that a narrowly qualified specialist who spends much time on one specialty would have difficulties changing to another specialty, then it becomes clear that he will seek a region for living that will satisfy first his professional interest and second his other demands.

The specialist solves the problem of choosing his place of work by comparing conditions in the various regions with his own needs. The relative differences in these conditions serve as the background for deciding to change the place of work, and the aggregation of these differences generates the migration flows, which may result in manpower deficits in some regions. It is clear that if planning bodies could take into account the socioeconomic mechanisms influencing migration – e.g., good housing conditions, good medical care, wages, compared with those in distant regions – then they might be able to control the migration flows. These mechanisms are also essential for attracting nonqualified labor to the different regions. However, before we can model these mechanisms, it is necessary to investigate and simulate them and to describe mathematically the dynamic processes of the system. This has been the scope of our work to date on this problem.

The migration of labor in time and space may be represented by a partial differential equation characteristic of a diffusion process. It is more difficult to define the migration transition rates, but Yashin (1978) assumed that these can be expressed in terms of preference vectors characterizing each region from the point of view of young specialists. He also solved and simulated this system for an example where the diffusion equation can be solved. This example is limited to investigating the salary mechanism and tries to trace the influence of this mechanism on other socioeconomic subsystems, such as prices and quantity of goods. The activity of the planner in this simple program is to change the wages when dissatisfaction indices reach some fixed level.

The investigation of these problems reveals the close interrelation between the activities of the health care system and the functioning of some national socioeconomic mechanisms. From this point of view, HCS manpower modeling plays an important role in the national HCS model, not only as part of the health care system but also as the first "bridge" between HCS and socioeconomic systems (Venedictov, 1976; Yashin, 1977).

APPLICATION EXPERIMENTS

Application-oriented IIASA HCS modeling activity has two directions. The first is the testing of our models on the national or regional statistics of different countries – Japan, Czechoslovakia, the UK, the USSR, Bulgaria, the German Democratic Republic, the Federal Republic of Germany, France, Austria – both by the IIASA HCS team and by collaborating scientific teams in these countries. Some results of this work have been described in earlier sections.

Since IIASA HCS models are also intended for possible interactive remote use by decision makers at regional, national, or international levels, the second direction is the experimental establishment of dial-up computer links between IIASA and the offices of the decision makers. This experimental work is being carried on in close cooperation with the IIASA computer network group, who conceived the general framework for such operations (Computer Science Group, 1978). Figure 18 depicts computer links between IIASA, WHO, and national centers.

One such experimental connection was tested between IIASA and the Computer Research Center, Bratislava, several times during 1976–1977. A second link was established between IIASA and the WHO Regional Office for Europe (WHO/ROE) in Copenhagen in June 1978, during a seminar on HCS modeling attended by directors and several leaders of

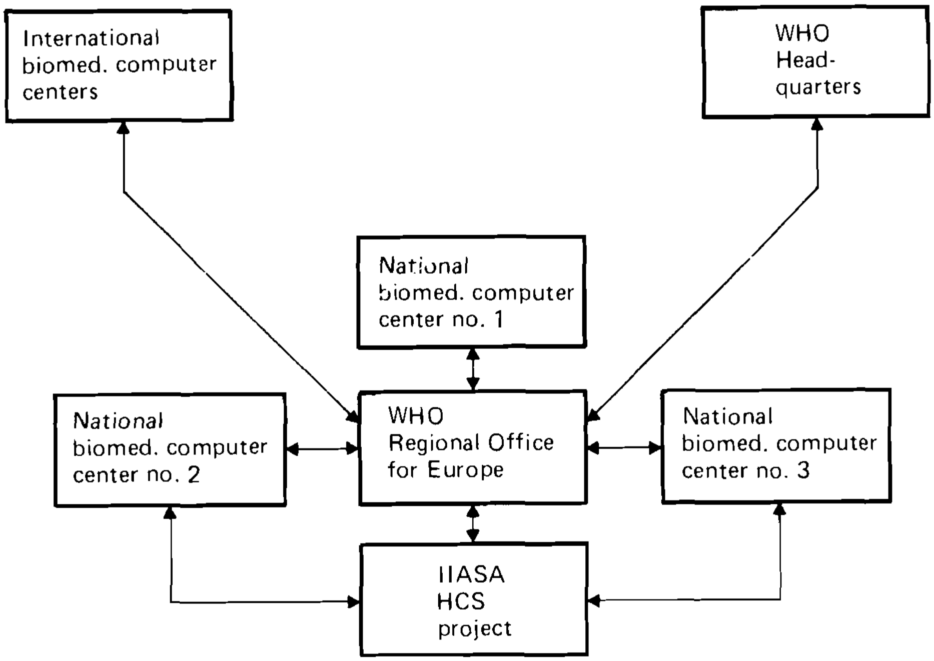

FIGURE 18 General scheme of HCS computer network development.

WHO/ROE programs. These computer links were established with the technical support and expertise of members of the IIASA computer network group. Since this demonstration, the WHO/ROE have acquired similar terminals suitable for interactive computing not only with IIASA but also with national medical computer centers. This experiment therefore has proved of great interest to the WHO, and WHO officials have expressed their readiness to support further development of HCS modeling at IIASA.

Chapter 4

FUTURE DEVELOPMENT

Our proposals for further work in health care systems modeling appear in the IIASA Research Plan for 1979–1984. The research will be divided between three activities:

- Further development of existing models
- Application of all our models in appropriate experimental applications
- Development of new models

FURTHER DEVELOPMENT OF EXISTING MODELS

Table 5 shows the completed stages of development of the HCS submodels described earlier. It includes all the models shown in Figure 4 as well as some new models (DRAM 3 and DYMOD) that were mentioned in Chapter 3 but that are not yet complete. Some other developmental work is also needed. For example, a mathematical methodology must be developed to construct morbidity data from different sources of medical information. Taking into account that all these sources, both separately and in combination, actually exist, this methodology will be very useful not only as a part of HCS modeling but also for solving other practical problems. Allied with this work is the extension of the present static models so as to include dynamic effects. When population structure is changing rapidly, it is important to recognize this fact in estimation procedures.

A second task is to develop all the models associated with health care resources. Several comprehensive studies conducted periodically in Bulgaria, the USSR, the UK, and other countries offer the opportunity to

TABLE 5 State of development of HCS submodels.

Model group	Model name	Defined mathematically	Programmed and illustrative results available	Tested and applied
Demographic	POP	Yes	Yes	Yes
	RWM	Yes	Yes	Yes
Morbidity	AMM	Yes	Yes	Yes
	INFM	Yes	Yes	Yes
	MEMOD	Yes	Yes	Yes
	DYMOD	Yes	No	No
Resource requirements	AMER	Yes	Yes	Yes
	SILMOD	Yes	Yes	No
Resource allocation	DRAM 1	Yes	Yes	Yes
	DRAM 2	Yes	Yes	No
	DRAM 3	Yes	No	No
Resource supply	MANP	Yes	No	No
	AMP	Yes	Yes	No

estimate health resource utilization for each disease group of the international classification of diseases (ICD) (the data include the number of out-patient visits, laboratory tests, consultations, hospital days, and nurses' and physicians' time). Health resource requirements could thus be calculated for each case, disease, and individual. This extension of AMER moves from disaggregative morbidity to disaggregative resources, and such a version of the model would be very useful to IIASA's National Member Organizations. The resource allocation model DRAM will be extended to represent more of the choices that the HCS makes in the face of limited resource supplies, and parameter estimation procedures will be further investigated. Only the first steps of programming the resource supply model have been carried out, and we hope to do some further analysis of this problem in conjunction with the planned HSS manpower task.

APPLICATION OF MODELS

There are a number of activities that can be labeled application, for example:

1. Receiving data from NMO countries, running this data through the models at IIASA, and publishing the results, perhaps with international comparisons
2. Taking the computer programs of the models to collaborating scientists in NMO countries and installing them on their computers so that they can run the models themselves to examine their own issues with their own data
3. Visiting HCS planners in NMO countries, identifying issues of interest to them that are amenable to analysis with the models, receiving data from them, running the models at IIASA, going back to the planners with the results, and finally publishing the results in the form of a case study
4. Offering a consultancy service to interested HCS planners in NMO countries

To date, activities of type 1 and 2 have been undertaken. The computer models developed at IIASA have been tested in several countries, accepted by WHO and a number of IIASA NMO countries, and used by scientists in France and Canada. This work will be continued for the old models and the new ones that will be developed next. If possible, these models will be tested not only on the national level, but also on the regional level, since all components and parameters can also be found on this hierarchical level. We do not intend in the immediate future to carry out any application activity of type 4, but there are two regions (the South Western Region of the UK and the Silistra region in Bulgaria) where we hope to do some applications of type 3.

Since all our models are designed to be of practical use to decision makers, the development of communication between decision makers and modelers has great importance. In this respect, the development of remote use of all these models will simplify their practical application. It will also help us to obtain information necessary to test the models.

DEVELOPMENT OF NEW MODELS

There are several new submodels about which we are thinking. We shall mention only a few ideas here. The HCS exists to influence health. In addition, it is itself influenced by the environment and by the economy. These three relations, and the following, may be possible areas for some new submodels:

- Models for use at the regional level of planning and for interaction with higher and lower levels, which could be developed in possible cooperation with the Regional Development Task and the Management and Technology Area at IIASA
- Models for use in developing countries, depending upon the degree of participation of developing countries at IIASA
- Models to assist in the management and planning of individual sectors of the HCS – e.g., hospitals, services for the elderly, and emergency services

It is clear that in order to carry out this program we should work in close contact not only with other IIASA groups but also with national centers and the WHO as well. The development of such collaboration is one of the most important goals of HCS modeling activity in the near future.

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4 FUTURE DEVELOPMENT

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APPENDIXES

Appendix A

THE RESEARCH STAFF*

Afifi, Abdelmonem	USA	Sept. 74–Aug. 75	HSS/SDS
Atsumi, Kazuhiko	Japan	Aug. 76–Sept. 76	HSS
Bigelow, James	USA	Sept. 74–Oct. 75	HSS/SDS
Brown, Hamilton	USA	Sept. 74–Sept. 76	HSS
Fleissner, Peter	Austria	Jan. 75–	HSS
Fujimasa, Iwao	Japan	Jul. 76–Sept. 76	HSS
Gibbs, Richard	UK	May 77–Apr. 78	HSS
Glass, Norman	UK	Jul. 74–Jun. 76	HSS
Hughes, David	UK	Apr. 78–	HSS
Kaihara, Shigekoto	Japan	Aug. 76–Oct. 76	HSS
Kiselev, Alexander	USSR	Mar. 75–May 76	HSS
Kitsul, Pavel	USSR	Jan. 78–	HSS
Klementiev, Alexandre	USSR	Feb. 76–Feb. 78	HSS
Majone, Giandomenico	Italy	Jun. 74–Jun. 75	HSS
Miller, James	USA	Jul. 73–Aug. 73 Aug. 74	HSS
Olshansky, Vladislav	USSR	Jun. 76–Aug. 76	HSS
Page, John	UK	Jan. 74–Mar. 75	HSS
Rapoport, Samuel	German Democratic Republic	Oct. 75–Dec. 75	HSS
Shigan, Evgenii	USSR	Nov. 76–	HSS
Thompson, Mark	USA	Feb. 73–Aug. 75	DIR/HSS
Umnov, Alexandre	USSR	Feb. 78–May 78	SDS/HSS
Venedictov, Dimitri	USSR	Jan. 75–Dec. 76	HSS
Zilov, Vadim	USSR	May 75–Dec. 75	HSS

*HSS, Human Settlements and Services Area; SDS, System and Decision Sciences Area; DIR, Directorate.

Appendix B

COLLABORATING INSTITUTIONS

The following institutions have been actively collaborating with the Health Care Systems Modeling Task. In order to become a collaborating institution, an organization must have at least one staff member who has worked (away from Laxenburg and without IIASA payment) on a task that is part of the IIASA Research Plan and that contributes to its successful completion in at least one of the following categories:

- Data collection or processing in conjunction with IIASA
- Scientific survey in conjunction with IIASA
- Written Contributions to an IIASA publication (Research Report, Collaborative Publication, book)
- Model development in conjunction with IIASA
- Evaluation or implementation of models developed or refined by IIASA
- Conduct of a case study in conjunction with IIASA

Austria	Institute of Socio-Economic Development Research, Vienna
Bulgaria	Central Research Institute of Public Health, Sofia
Canada	Department of Information and Operational Research, University of Montreal, Montreal
Czechoslovakia	Institute of Haematology and Blood Transfusion, Prague Institute of Medical Bionics, Bratislava Institute for Postgraduate Training of Physicians, Bratislava Institute of Social Medicine and Organization of Health Services, Prague

Finland	Ministry of Health, National Board of Health, Planning Department, Helsinki Research Institute for Social Security, Helsinki
Federal Republic of Germany	Institute for Medical Data Processing, Munich Industrial Enterprises, Ltd., Munich Hannover Medical Center, Hannover The Ulm University, Ulm
German Democratic Republic	Humboldt University, Berlin
Japan	Institute of Medical Electronics, Faculty of Medicine, University of Tokyo, Tokyo
Netherlands	Ministry of Health and Environment, The Hague University of Leiden, Leiden
Union of Soviet Socialist Republics	Institute of Control Sciences, Moscow The Central Research Institute of Social Medicine and Public Health, Moscow
United Kingdom	Operational Research Services, UK Health Ministry, London South Western Regional Health Authority, Bristol
World Health Organization	Headquarters, Geneva Regional Office for Europe, Copenhagen

Appendix C

IIASA PUBLICATIONS BY THE BIOMEDICAL PROJECT AND THE HEALTH CARE SYSTEMS MODELING TASK

- The *Research Report* (RR) is IIASA's most formal vehicle for reporting Institute research, intended for broad distribution to the scientific community. Research Reports receive careful review, editing, typing, and printing. The RR classification is used to report final results of research or interim or contributing work where the results are felt to merit broad circulation.
- The *Collaborative Publication* (CP) is used to convey results of research done jointly with other research organizations and for proceedings of conferences and workshops.
- The *Research Memorandum* (RM) is less formal than the RR classification, but still is an official Institute publication. Because of their interim nature RMs generally do not receive the careful technical reviews given RRs.
- *Working Papers* are not included in this list.

1973–1974

CP-73-5 Proceedings of IIASA Planning Conference on Medical Systems, August 6–8, 1973. Biomedical Project. (Formerly PC-73-5.)

RR-74-13 A Study of Research and Development in Environmental Engineering Using System Approach. M. Thompson.

RR-74-14 Technological Prosthetics for the Partially Sighted: A Feasibility Study. J. Page.

1975

Systems Aspects of Health Planning. Bailey, N.T.J., and M. Thompson, eds. (1975) Amsterdam: North-Holland.

RR-75-6 Economic Aspects of the Prevention of Down's Syndrome (Mongolism). N. Glass.

RR-75-7 System Analysis of the Evaluation of Bio-Medical Research. M. Thompson.

RR-75-8 On the Logic of Standard Setting in Health and Related Fields. G. Majone.

RR-75-42 An Investigation of a Hypothetical Medical Screening Program. J.H. Bigelow, H.V. Lee.

CP-75-1 Proceedings of IIASA Workshop on Road Traffic Safety in Europe. A. Afifi, coordinator.

CP-75-5 Proceedings of the Joint IIASA/WHO Workshop on Screening for Cervical Cancer. J.H. Bigelow, coordinator.

RM-75-3 Policies for the Treatment of Chronic Renal Failure: The Question of Feasibility. G. Majone.

RM-75-6 Road Safety Research in the Perspective of Policy Analysis. M. Thompson.

RM-75-21 The Anokhin Theory of the Functional System: Its Principal Proposition, Operational Architectonic and Possible Applications in Biology and Medicine. V.G. Zilov.

RM-75-23 Systems Analysis of Some Bio-Medical Problems Related to Medical Treatment Management. A.M. Petrovsky.

RM-75-31 A Systems Approach to Health Care. A. Kiselev.

RM-75-62 Factors Affecting Participation in Cervical Cancer Screening Programs. J.H. Bigelow, H.L. Brown.

RM-75-78 The Functional System Theory of an Organism and Its Application in Research into Single-Minded Behaviour in Animals. V.G. Zilov.

1976

RM-76-19 Comparing Health Care Systems by Socio-Economic Accounting. P. Fleissner.

RM-76-36 A Computer Method for Projecting a Population Sex-Age Structure. A.A. Klementiev.

RM-76-65 Mathematical Approach to Developing a Simulation Model of a Health Care System. A.A. Klementiev.

1977

CP-77-4 Health System Modeling and the Information System for the Coordination of Research in Oncology. D.D. Venedictov, editor.

CP-77-8 Modeling Health Care Systems. E.N. Shigan, R. Gibbs, editors.

RM-77-6 An Approach to Building a Universal Health Care Model: Morbidity Model of Degenerative Diseases. S. Kaihara, I. Fujimasa, K. Atsumi, A.A. Klementiev.

RM-77-40 Alternative Analysis of Different Methods for Estimating Prevalence Rate. E.N. Shigan.

RM-77-43 On the Estimation of Morbidity. A.A. Klementiev.

RM-77-49 Health Care System Models: A Review. P. Fleissner, A.A. Klementiev.

RM-77-53 Health Care Resource Allocation Models – A Critical Review. R. Gibbs.

1978

RR-78-8 The IIASA Health Care Resource Allocation Sub-Model: Mark 1. R.J. Gibbs.

RM-78-1 A Disaggregated Health Care Resource Allocation Model. R.J. Gibbs.

RM-78-3 Analysis and Future Estimation of Medical Demands Using a Health Care Simulation Model: A Case Study of Japan. S. Kaihara, N. Kawamura, K. Atsumi, I. Fujimasa.

RM-78-10 A Morbidity Submodel of Infectious Diseases. I. Fujimasa, S. Kaihara, K. Atsumi.

RM-78-20 Models for Educational and Manpower Planning: A Dynamic Linear Programming Approach. A. Propoi.

RM-78-21 Aggregate Model for Estimating Health Care System Resource Requirements (AMER). A.A. Klementiev and E.N. Shigan.

RM-78-50 The IIASA Health Care Resource Allocation Sub-Model: Mark 2 – The Allocation of Many Different Resources. D.J. Hughes.

RM-78-67 The IIASA Health Care Resource Allocation Submodel: Estimation of Parameters. D.J. Hughes.