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HEALTH CARE SYSTEMS MODELLING AT IIASA: A STATUS REPORT

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Preface

The focus of the Human Settlements and Services Area at 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 the Fall of 1978 by the Health Care Systems 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 decisionmakers be aware of changing demands and needs for health resources and services. In the light of this, the HCS Modeling Task has set a goal of creating a model that will assist national decisionmakers in their policy formation. 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 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
Human Settlements
and Services Area

Acknowledgement

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 1. 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.

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HEALTH CARE SYSTEMS MODELLING AT IIASA: A STATUS REPORT

1. INTRODUCTION

1.1 History of the Task

"Biological and Medical Systems" was one of IIASA's eleven first research projects, and the IIASA Planning Conference which took place in August 1973 identified a large number of possible research topics within the context of this theme (Bio-medical Project, 1973). One year later Dr. Dimitri Venedictov (USSR), the Deputy Minister of Health of the Soviet Union, was appointed the leader of the Bio-medical Project. Because of his responsibilities in Moscow, Dr. Venedictov was represented in Laxenburg by his deputy, Dr. Alexander Kiselev (USSR) who, following the recommendations of the 1973 planning conference, formulated a research program to develop a methodology for the dynamic modelling of national health care systems, as well as to complete those research topics begun previously.

In 1974 a second Bio-medical conference was held, the proceedings of which were published as a book, (Bailey and Thompson, 1975), and in December 1975 it was concluded at a third conference that IIASA should concentrate on the development of universal models of national health care systems (Venedictov, 1977). In 1976 the old Bio-medical project was merged with the Urban project to form the Human Settlements and Services Area, and became the Health Care Systems (HCS) Modelling Task within that Area. Since then, two IIASA workshops held in March 1977 (Shigan and Gibbs, 1977) and November 1977 have reaffirmed the aim of developing universal models of national health care systems.

Since November 1976, the leader of the Task at IIASA has been Dr. Evgenii Shigan (USSR), and scientists from Austria, Japan, UK, and USSR have served as research scholars. Particularly close links were established between IIASA, the Institute of Control Sciences in Moscow, and 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.

1.2 Problems in Health Care Systems

The starting point of the HCS Modelling 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).

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 decisionmakers in different countries who face similar problems of health care. What are these problems? Here are some examples.

Operational Problems include the:
- estimation of health status indices, environmental parameters, resource demands and utilization,
- control of costs of medical services,
- efficient satisfaction of emergency and non-emergency demands.

Tactical Problems cover the:
- 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 the:
- long-term forecasting of health, environmental, and resource demand indices,
- reorganization of the health care system,
- development of new scientific directions.

In addition to the problems themselves, the mix of operational, tactical, and strategic problems facing the decisionmaker 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 decisionmaker deals mainly with tactical and strategic problems. Both face many different problems that must be classified as 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 decisionmakers 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 make a decision. For other problems, comprehensive studies of health care or natural experiments on real objects are conducted (e.g. on health centres, hospitals, ambulance services, etc.). Such experiments are, however, very expensive and take much time, and they cannot be used to test many alternatives for a planning policy.

The situation is much more difficult for health managers of 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 also becomes complicated by the strong dependence of the health care system on socioeconomic, environmental, and other external systems. As to conducting any natural experiments on health systems at the highest level (global, regional, national), they are practically impossible.

Finally there is the problem that the HCS is not independent of other systems. A group of USSR scientists from different research centres (medical, mathematical, economical, environmental, etc.) have designed, under the guidance of Dr. Venedictov, the functional description of a public health system shown in Figure 1. We see that both internal and external systems may be divided into subsystems and that the connections between

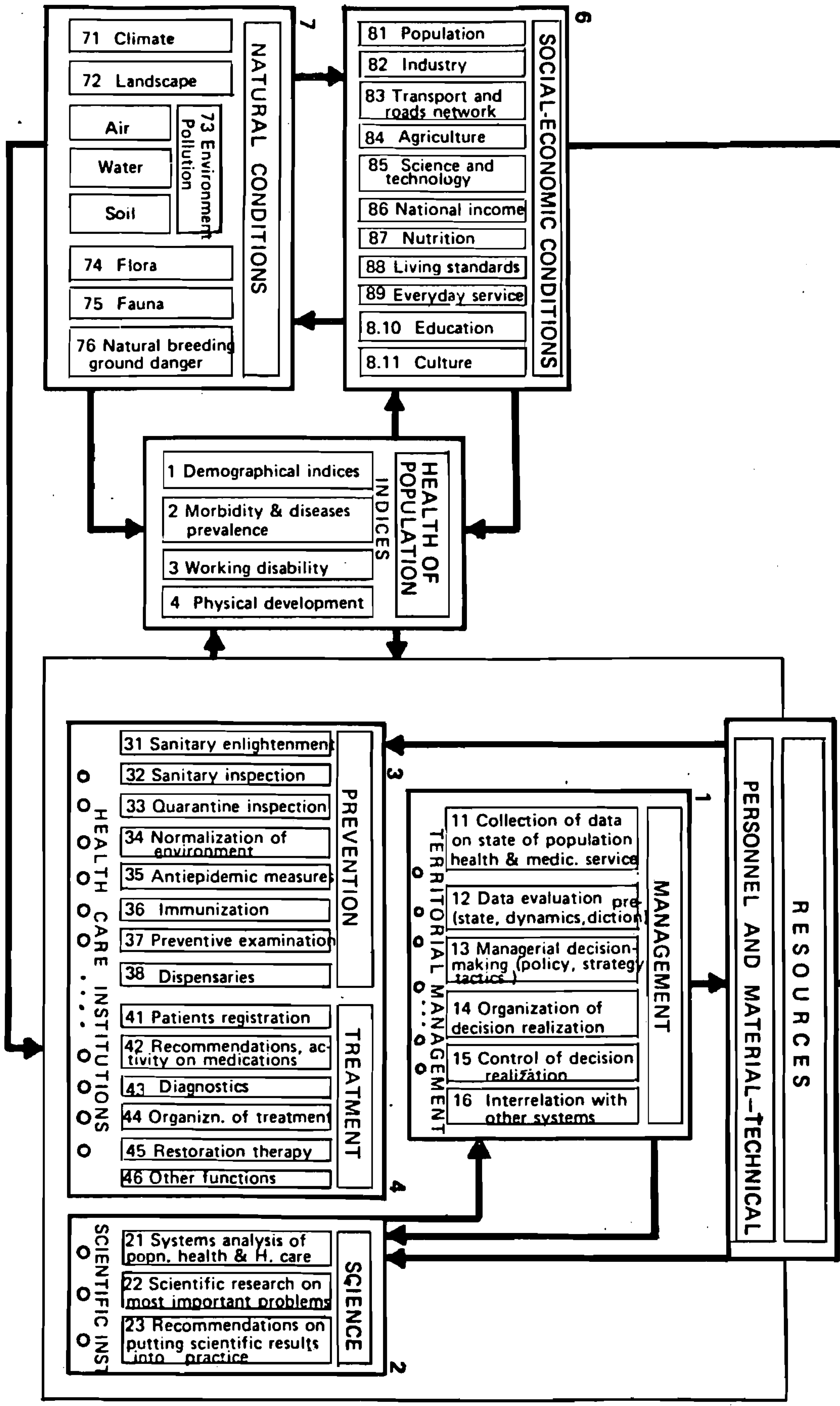


Figure 1. Functional chart of a public health system.

Source: Venedictov (1977).

subsystems and their parameters could be direct or indirect, continuous or discrete, strong or weak, changeable in time or practically constant. It is clear that it is very difficult for a manager to estimate all the possible consequences of his decisions using only his own experience. He also needs special means to estimate the behaviour of internal and external subsystems, their trends, etc. That is why in order to test different health care strategy alternatives, the decisionmaker responsible for the highest levels of the health care system needs a health care system model.

1.3 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. This main goal can be divided into certain *subgoals*, several of the most important of which are presented in Figure 2. Some 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 towards 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 distant from our main goal. These results include:

1) the estimation of unobservable statistics from observable ones, e.g., morbidity from mortality,
2) the evaluation of the consequences of certain plans and policies, e.g., for resource allocation,
3) the derivation of optimal policies to achieve certain aims, e.g., for manpower training,
4) the analysis of relationships between decisionmakers in the health care system and modellers 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.

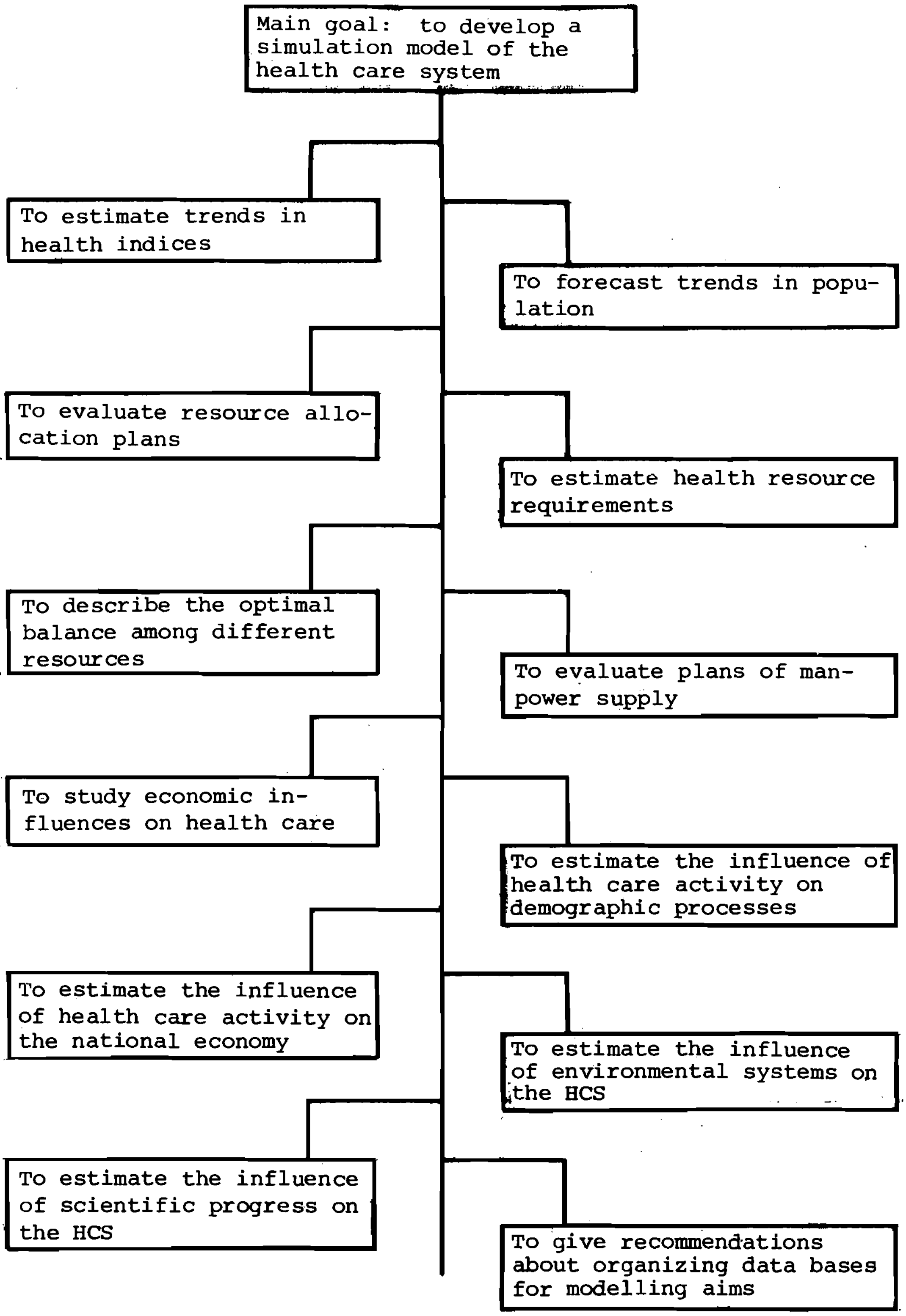


Figure 2. Tree of goals and subgoals of the IIASA Health Care Systems Modelling Task.

This is one of the important *objectives* set out in our IIASA Research Plan (1978-79). We 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 having interests in health care system modelling (see Appendix 2), and our models are also very useful for the decisionmaker at the international level (e.g., World Health Organization), because international comparison of health care systems is more useful than that of separate static indices. Finally, we are in contact with decisionmakers themselves from some of the health ministries of the IIASA national member countries.

1.4 The Position Today

Where does the HCS Modelling Task stand today (Fall, 1978)? First, we have developed views about how to go about modelling mathematically a complex human activity system such as the HCS. These are summarized in Section 2 of the report. Section 3 summarizes our progress along these lines, and gives some details of the various submodels which we have constructed. More information about each submodel is given in other IIASA publications, and a full list of publications within the Task is included in Appendix 3. Finally, Section 4 gives our plans for future work, both to apply the existing ones to real problems and to develop new models. For the second purpose, we offer in this report a catalogue of mathematical tools to help decisionmakers in health care systems.

2. MODELLING APPROACH

2.1 Health Care Systems

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

What is special about health care systems?

- The health care system is a social system. Its behaviour reflects the participation of individuals such as patients, doctors, health managers, and their interrelations with external systems.
- The HCS is often organised *hierarchically*. Not only are the sytems in particular regions often managed separately, but there is usually some specialization according to the the severity of disease.
- The HCS is *dynamic*. The number of doctors available today depends upon the training policy of five to six years ago, and society's health today may depend upon the activity of the HCS during the last half century.
- The main result of HCS activity--the health status of population--can only be estimated by a set of interrelated quantitative and qualitative indices.
- Almost nothing in the HCS blocks can be subjected to experiments, even at local levels.
- There are some specific communication problems between the decisionmaker and the model builder, caused by different educations, experiences and approaches to the solution of real health care problems.
- Existing medical data bases are adapted mainly to classical medical statistical aims but not to forecasting or estimating the consequences of different policies in health care systems management.

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

2.2 Our Approach

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

Figure 4 summarizes the outcome of this process: a conceptual model which shows how the HCS or its subsystems work, and which provides a basis for discussion between scientist and/or non-scientist. 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 Modelling Task up to 1978. There are five groups of submodels. *Population* projections are used by *morbidity* models to predict true health needs. Such estimation of needs can be used either 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 areas of choice for the decisionmaker include 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 it suggests new areas for modelling adjacent to these. The submodels, however, are not conceptual but *actual*

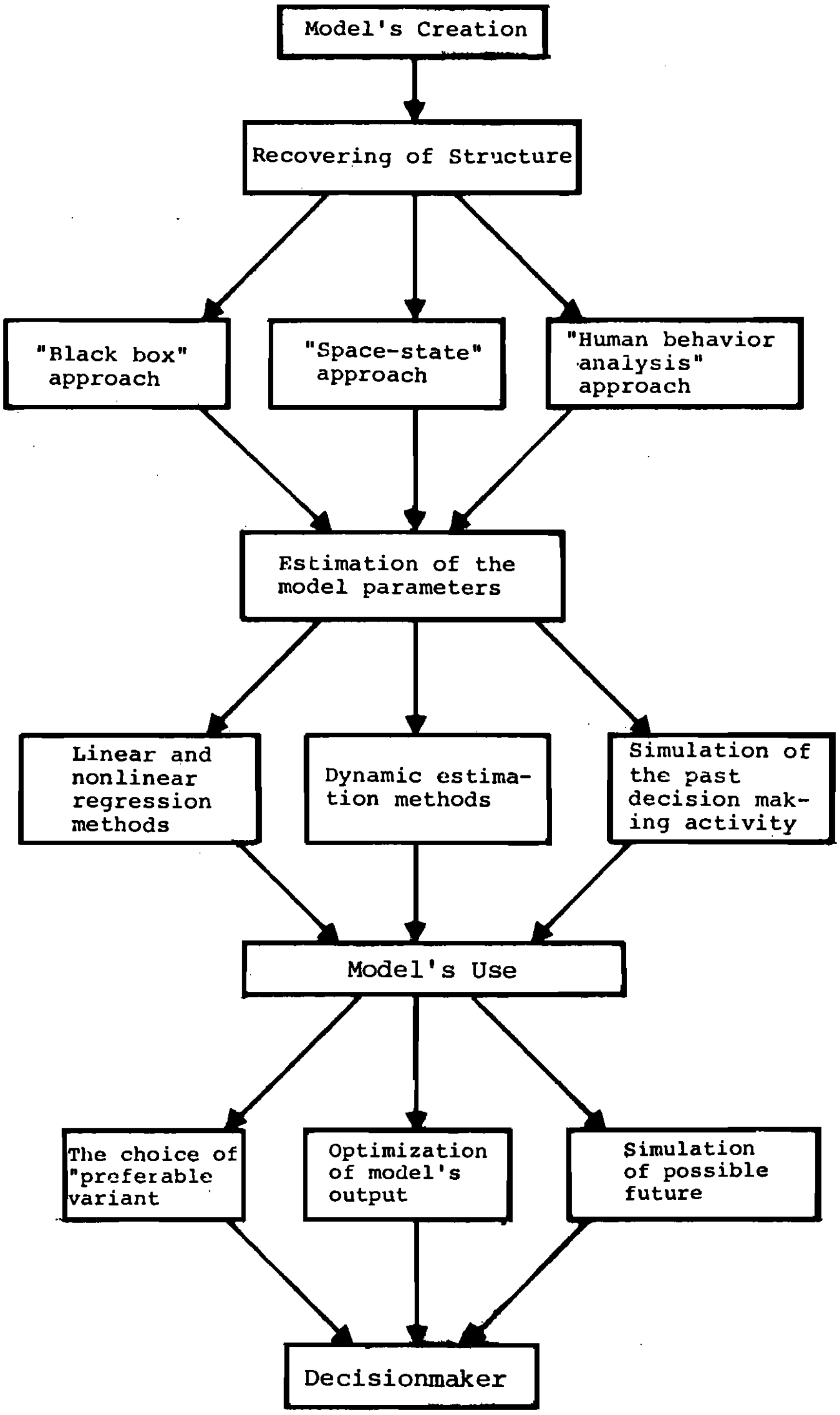
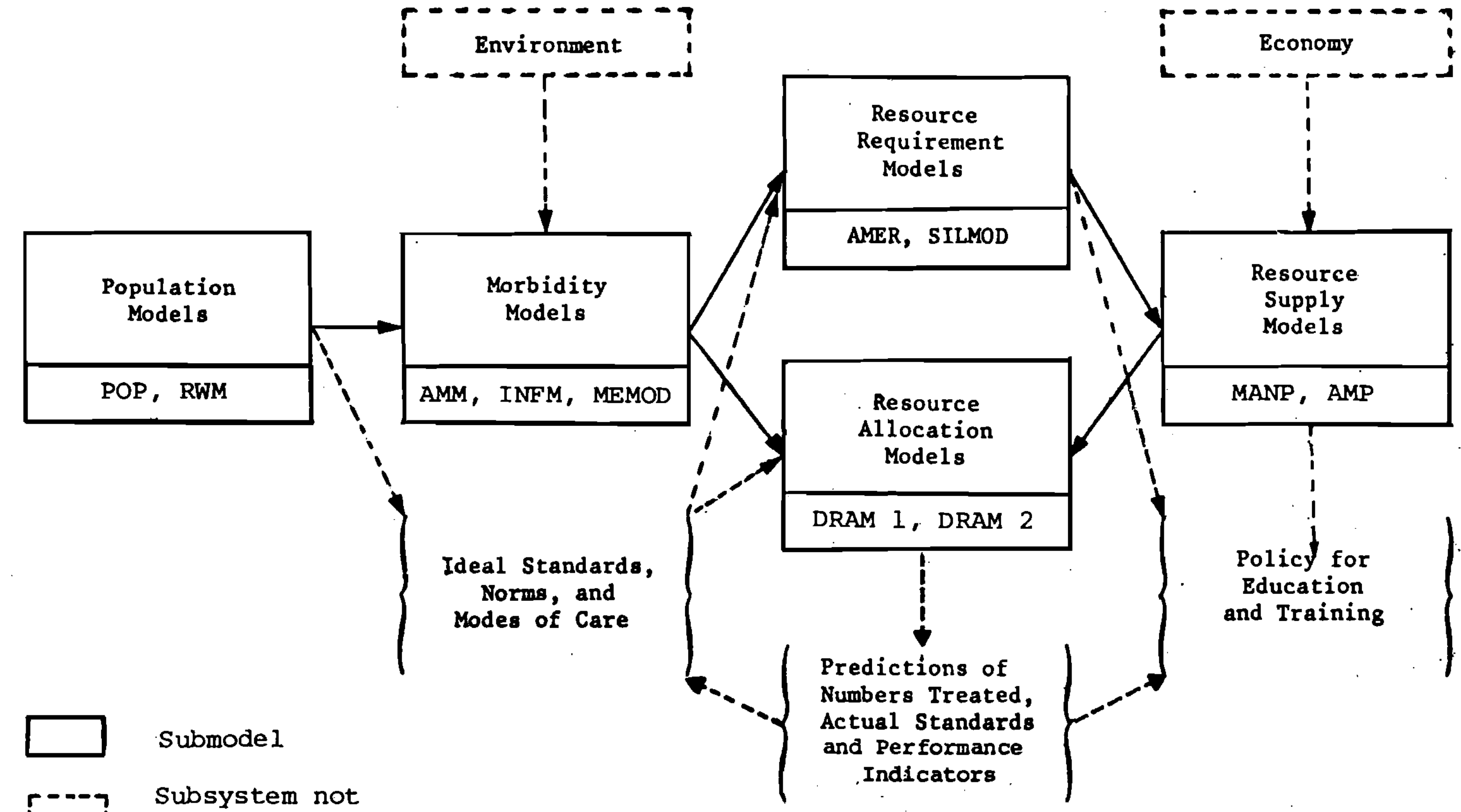
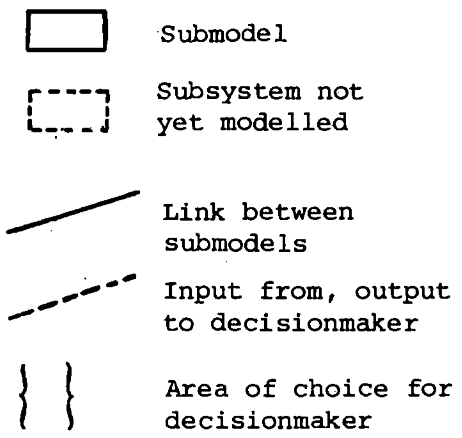


Figure 3. Different stages of modelling.





Specification of Submodels elaborated at IIASA

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-77-40)
MEMOD	Morbidity Estimation Models (RM-77-43, RM-78-10)
AMER	Aggregate Model for Estimating Resource Requirements (RM-78-21)
SILMOD	Sick-Leave Model (Fleissner, 1978)
DRAM	Disaggregated Resource Allocation Model (RR-78-07, RM-78-50)
MANP	Manpower Supply Model (RM-78-20)
AMP	Manpower Migration Model (Yashin, 1978)

(A full list of Research Report, Research Memoranda, and Collaborative Publications by the Health Care Systems Modelling Task is given in Appendix 3.)

Figure 4. Family of HCS submodels constructed at IIASA.

with precise assumptions and mathematics, usually available as computer programs. Today the conceptual framework implies a logical order or methodology for apply the submodels. In the future it will guide any plans to link the submodels more permanently.

Given that we cannot model the whole of the HCS at a stroke, it is reasonable to ask why we have chosen those parts to model that we have. The first reason is that these are the parts of the HCS which 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. Secondly, these are the areas of the HCS for which data are most readily available. Every country has statistics of mortality, and resource supply and use which are broadly comparable. Thirdly, it is these parts of the HCS which generate many of the important medium-term problems with horizons of 5 to 15 years. One of the reasons why we have not yet modelled the influence of treatment upon mortality is because 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 other plans for welfare and social services.

A second reasonable question is: 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 decisionmakers at the higher levels of the HCS. This distinction is important. Unfortunately, it is difficult and expensive for a small IIASA HCS modelling team to establish active links with decisionmakers across the world. Where this is impossible it is more appropriate for scientists already in these countries to develop their own links with the additional professional support that the IIASA task can provide. Two such institutions* have exchanged scientific

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

personnel and research in this way, and similar institutions in other countries are also involved. Our models are designed for use by these scientists to help decisionmakers of national health authorities or officers in the WHO.

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

2.3 A Mixed Modelling Strategy

Our 1977 review of mathematical models distinguished between models according to their modelling technique: macroeconomic, systems dynamic or optimisation. But mathematical models have since become more sophisticated, and such a classification is less useful. From our point of view, it is more useful to distinguish models according to the aim of the modelling or the type of use. Accordingly, we can divide HCS models into two groups; simulation models and optimisation models.

As Yashin and Shigan (1978) and Figure 3 indicate, there are different stages of modelling for both of these approaches: recovering of structure, estimation of the model parameters, and model use. Moreover, one can use different mathematical methods in either type of model. As an example, in the creation of any optimisation model, before using the special optimisation 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 behaviour, and it is natural to use for this aim the *utility function* and some *optimisation technique* to recover the input-output interrelation of the system.

We can illustrate this mix of approaches in the IIASA HCS models. Our morbidity estimation models are state-space structured simulation models but incorporate no element of human behaviour and no optimisation technique. The resource requirement models also do not use any optimisation 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 behaviour it assumes that the human agents in the system act as if they were maximising a utility function. Lastly, the manpower education and training model is an optimisation type model, although application of the dynamic linear programming technique presupposes a successful simulation using the state-space approach.

In summary, therefore, some parts of the HCS (e.g., resource allocation) depend significantly upon human behaviour and the appropriate models probably need to reflect this. Gibbs (1977), for example, concluded that a resource allocation model should adopt the behaviour simulation approach. In other parts of the HCS (e.g., morbidity prediction), this influence is less important. In some parts of the HCS (e.g., education and training of manpower), 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 behaviour. Such are the differences that have so far prevented modellers from producing any monolithic, successful model of the HCS. Our view is that we must use a mixed modelling strategy in which different mathematical tools designed for different tasks are developed within a single conceptual framework.

2.4 Modelling Aims

We conclude this chapter by mentioning the common features of the model descriptions that follow in Section 3. This will also summarize our *modelling aims*. First of all, 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 which 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. And finally, we are creating models which, *first*, will represent mathematically the main components of the HCS, and which, *second*, can be used independently by decisionmakers at different levels of health care system management.

3. PROGRESS SO FAR

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 of our work.

3.1 Models for Demographic Projection

It is obvious that the dynamics of mortality rates and, hence, morbidity rates themselves are correlated with the dynamics of morbidity rates themselves are correlated with the dynamics of the demographic age pyramid, and that this correlation is different registered morbidity rate (shown in Figure 5 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.

In some applications it is possible to use population projections provided by national agencies with specific responsibility for such work. For other applications we have two separately developed models. The first is a model for projecting a population structure on the national level. The development of this type of model was begun in the framework of the Institute of Control Sciences' HCS modelling activity, and the model was installed and tested at IIASA by Klementiev (1976). The second model is the model of Willekens and Rogers (1976). This model uses spatial demographic data and can be used, not only on the regional (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.

Both models use the initial population age-sex structure; the fertility rate for the initial year and specified by age per 1000 female population; and the death rate given for the initial year and specified by age and sex per 1000 population. Both models assume without loss of generality that all rates are constant

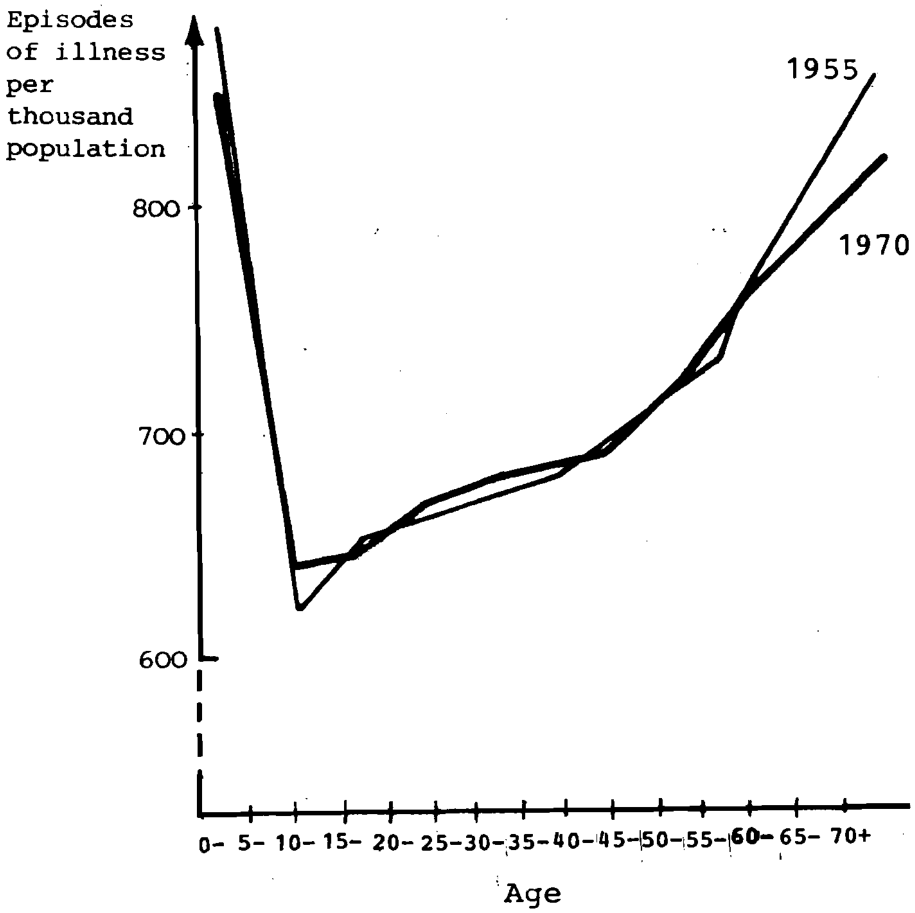

Figure 5. Age distributions of morbidity rate in the UK, 1955-1970.

Source: Hicks (1976), adopted from Table 85, p. 142 and Table 121, p. 176.

over time. They can also be used to reflect any scenario of changing future mortality and fertility rates.

Additionally, the Rogers-Willekens model uses the age-sex specific migration rates between regions to give forecasts of a spatially distributed population's age-sex structure. The other model omits the spatial distribution analysis but includes features such as the separating-out of the perinatal death rate, division into strata which take into account the structure of existing health-care statistics, and the up-dating 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 6. 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 will possibly also be useful for future development of the demographic models.

3.2 Morbidity Models

The Need for Mathematical Models

The problem of estimating trends in health indices is one of the most serious problems in all countries, and much attention has been given to it by WHO, which acts as the headquarters of the different regional offices. WHO and others have used a number of indices, all of them roughly divided into groups--demographics, morbidity, physical development, etc. Demographics includes mortality rates, natality rates, expected life times, etc. Morbidity indices comprise those rates that reflect different deviations in physiological conditions. The group of physical development indices describe the physical condition of individuals and groups of population. All these indices taken independently could estimate health status only partly. The combination of all these rates reflects much more accurately the health status of the population.

Because collection and identification of all possible individual information is desirable, many developed countries are working now to organise computer registers containing complete medical and non-medical individual information. The organization of such banks of information seriously depends on solving several problems such as the technical capacity of present and future year 1961

population

age	total	slovenia	r.yugos.
0	915700.	67800.	847900.
5	979300.	74100.	905200.
10	878800.	70700.	808100.
15	677500.	60100.	617400.
20	788400.	62900.	725500.
25	840500.	66500.	774000.
30	795500.	67100.	728400.
35	696200.	62900.	633300.
40	431900.	39500.	392400.
45	485000.	47900.	437100.
50	505100.	51300.	453800.
55	435400.	46100.	389300.
60	365400.	39600.	325800.
65	260100.	29500.	230600.
70	201700.	21700.	180000.
75	135300.	14400.	120900.
80	68300.	7100.	61200.
85	42900.	3600.	39300.
tot	9503000.	832800.	8670200.

year 1966

population

age	total	slovenia	r.yugos.
0	967579.	69924.	897655.
5	865621.	66731.	798890.
10	976572.	73995.	902577.
15	875950.	71060.	804890.
20	674103.	60534.	613569.
25	783110.	63284.	719826.
30	833790.	66331.	767460.
35	788196.	66848.	721349.
40	687934.	62615.	625319.
45	424793.	39079.	385715.
50	472913.	46957.	425956.
55	485716.	49841.	435875.
60	408341.	43969.	364372.
65	327792.	36090.	291702.
70	216213.	24653.	191560.
75	150262.	16054.	134208.
80	86006.	8557.	77450.
85	65870.	4435.	61435.
tot	10090763.	870955.	9219808.

year 1971

population

age	total	slovenia	r.yugos.
0	988585.	71442.	917143.
5	914592.	68846.	845746.
10	863211.	66624.	796588.
15	973399.	74488.	898911.
20	871544.	71869.	799676.
25	669603.	60604.	608999.
30	776864.	63087.	713777.
35	826119.	66149.	759971.
40	778819.	66593.	712225.
45	676613.	61949.	614664.
50	414197.	38325.	375871.
55	454757.	45630.	409127.
60	455509.	47551.	407958.
65	366309.	40073.	326236.
70	272478.	30165.	242313.
75	161067.	18235.	142833.
80	95514.	9539.	85975.
85	83092.	5347.	77746.
tot	10642274.	906515.	9735759.

year 1976

population

age	total	slovenia	r.yugos.
0	1049627.	74584.	975043.
5	934448.	70341.	864107.
10	912044.	68752.	843292.
15	860408.	67035.	793374.
20	968495.	75553.	892941.
25	865705.	72203.	793501.
30	664288.	60247.	604042.
35	769722.	62891.	706831.
40	816273.	65944.	750329.
45	765989.	65918.	700072.
50	659734.	60757.	598977.
55	398276.	37265.	361012.
60	426462.	43543.	382919.
65	408603.	43349.	365254.
70	304495.	33496.	270999.
75	202986.	22314.	180672.
80	102335.	10831.	91504.
85	92264.	5960.	86304.
tot	11202155.	940982.	10261173.

Figure 6. Dynamics of the Yugoslavian population: age-spatial distribution.

Source: Willekens and Rogers (1976), pp. 46-49.

computer facilities, standardisation and formalisation of all existing medical records, and confidentiality.

Unfortunately, these problems have at present not been solved anywhere, and in developed countries dynamic computer registers are being created only for small localities or to cover 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 centres, etc.;
- 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 problems of confidentiality of personal medical information are too serious, 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 different scientific purposes, including the modelling of health care systems. In the IIASA group, where scientists are working from different countries, the lack of information in one country can be compensated for by information taken from other countries.

These comprehensive studies with complete information about health also enable us to estimate the completeness of all existing

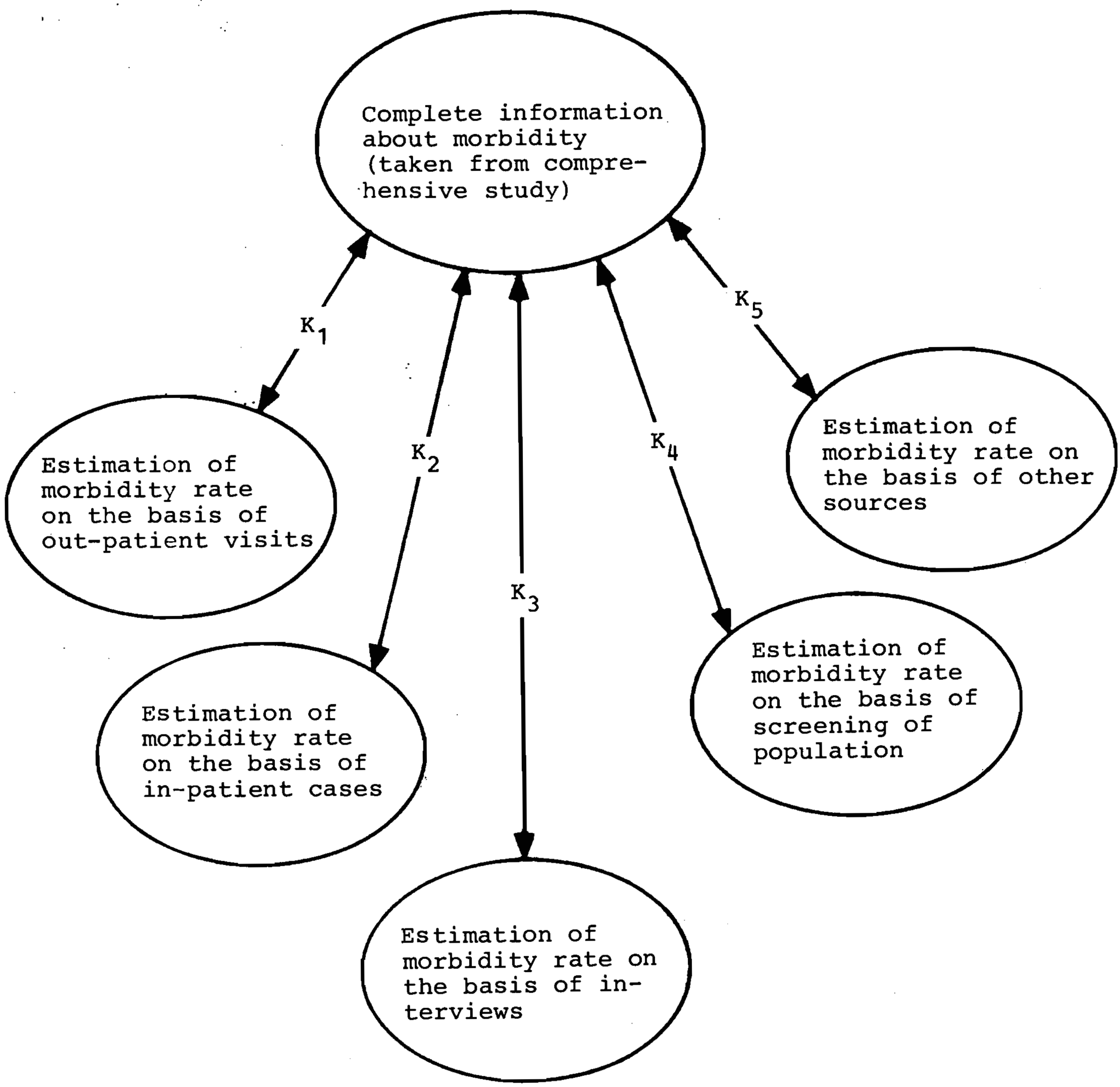

Figure 7. Comparative analysis of completeness of different sources of medical information about morbidity.

sources of official "routine" information. This is depicted in Figure 7 where all these completeness coefficients K_i could be studied according to different diseases, age, sex, residence or other parameters. If there were a number of such periodical comprehensive studies, it would be possible to estimate all of these coefficients in 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 requires mathematical description. The development of such mathematical models would have the following effects.

- In countries where there has been difficulty in obtaining and generalizing personal medical information, only simplified processes would be required and the associated problems 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 resources requirements on the basis of a universal system methodology.

Types of Models

Shigan (1977) described different alternatives for estimating morbidity rates using the information available in different countries. Such models can be divided by their degree of detail into the following types:

a. *aggregative morbidity models*, which estimate and forecast "crude" general morbidity rates without specifying specific diseases or groups of diseases;

b. *group morbidity models*, which model groups of diseases, i.e., the classes in the International Classification of Diseases (ICD), or the groups used in several IIASA publications (degenerative diseases, infections, accidents, etc.);

c. *specific morbidity models*, which consider specific diseases (e.g., cancer, cholera, tuberculosis, etc.);

d. *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 (b, c, d above). But in this case we need information about the frequency of the disease among the population, and the number and kinds of consultations, beds, laboratory tests, and the time required of the physician and specialist 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 doctor specialties, etc., and the ICD is the only good example of international agreement. But in spite of these difficulties, mathematical models developed on the basis of information taken from several countries will be very useful for WHO and other organisations in comparing different countries according to the same principles.

Together with a number of national centres, and also using the statistics of the WHO, we have designed and constructed three computer models:

1. AMM: for estimation of aggregative morbidity rates;
2. INFM: for estimation of morbidity rates for infectious diseases;
3. MEMOD: for estimation of morbidity rates for terminal degenerative diseases.

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.

But since there are only slight variances among aggregate morbidity rates, aggregate mortality rates, and the ratios between them (risk ratios) over time, it impossible to estimate roughly aggregate morbidity data using mortality data from official vital statistics and the risk ratios from such studies. The model 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 in 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 in Section 3.3 below.

A Morbidity Submodel of Infectious Diseases (INFM)

This model was designed by Fujiamsa et al. (1978). The aim of INFM is the estimation of age-specific prevalence and death rates per total population for two groups of infectious diseases: epidemic diseases (ICD A1-A44), and diseases of the respiratory system (ICD A89-A96).* On the basis of some standard rates which 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 stay in the sick state, under the assumptions that mean length of stay in the sick state is less than one year and prevalence is constant over time. In accordance with the model's first assumption, the ageing 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 this 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 for various countries:

*International Classification of Diseases (ICD) numbers.

Finland, Austria, Sweden, England, 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 example results.

In this study, the prevalence rate and the mean length of stay in the sick state are mainly based on the data of 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 in the sick state was obtained from the patient survey statistics of national Japanese hospitals (WHO, 1974). The standard model's coefficients, morbidity, recovery, and death rates obtained from these statistics are shown in Figure 8.

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 by this morbidity model, because these essential rates of infectious diseases correlate with other socio-economic factors such as net income, food supply, education, hygiene and preventive medicine. The correlation of these factors to infectious diseases will involve further development of INFM.

Morbidity Models of Degenerative Diseases (MEMOD)

Degenerative diseases are inherent to human beings. They are caused by the ageing 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 (ICS A136-A137).

Unfortunately, the routine morbidity statistics in all countries record only part of the existing cases of degenerative diseases, and it is necessary to estimate the dissemination of these

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.

Source: Fujimasa, et al. (1978), p. 11.

Age Groups	A1 - A44 Epidemic & Enteritis			DRPN			A89 - A96 Acute Respiratory Infection			DRPN		
	MR	RECOV	DR	Computed from PN	Japan 1974	Austria 1974	MR	RECOV	DR	Computed from PN	Japan 1974	Austria 1974
0	1400	0.2	4	95	98	244	10	0.14	125	32	62	24
1-4	1400	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
65-75	100	0.05	30	213	215	221	2.5	0.08	500	54	99	56
75 +	100	0.03	100	1141	911	957	2.5	0.065	1000	122	228	91

Standard Rates in the Model: MR, morbidity rate (per 100,000 healthy persons)
RECOV, recovery rate (per sick persons)
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)

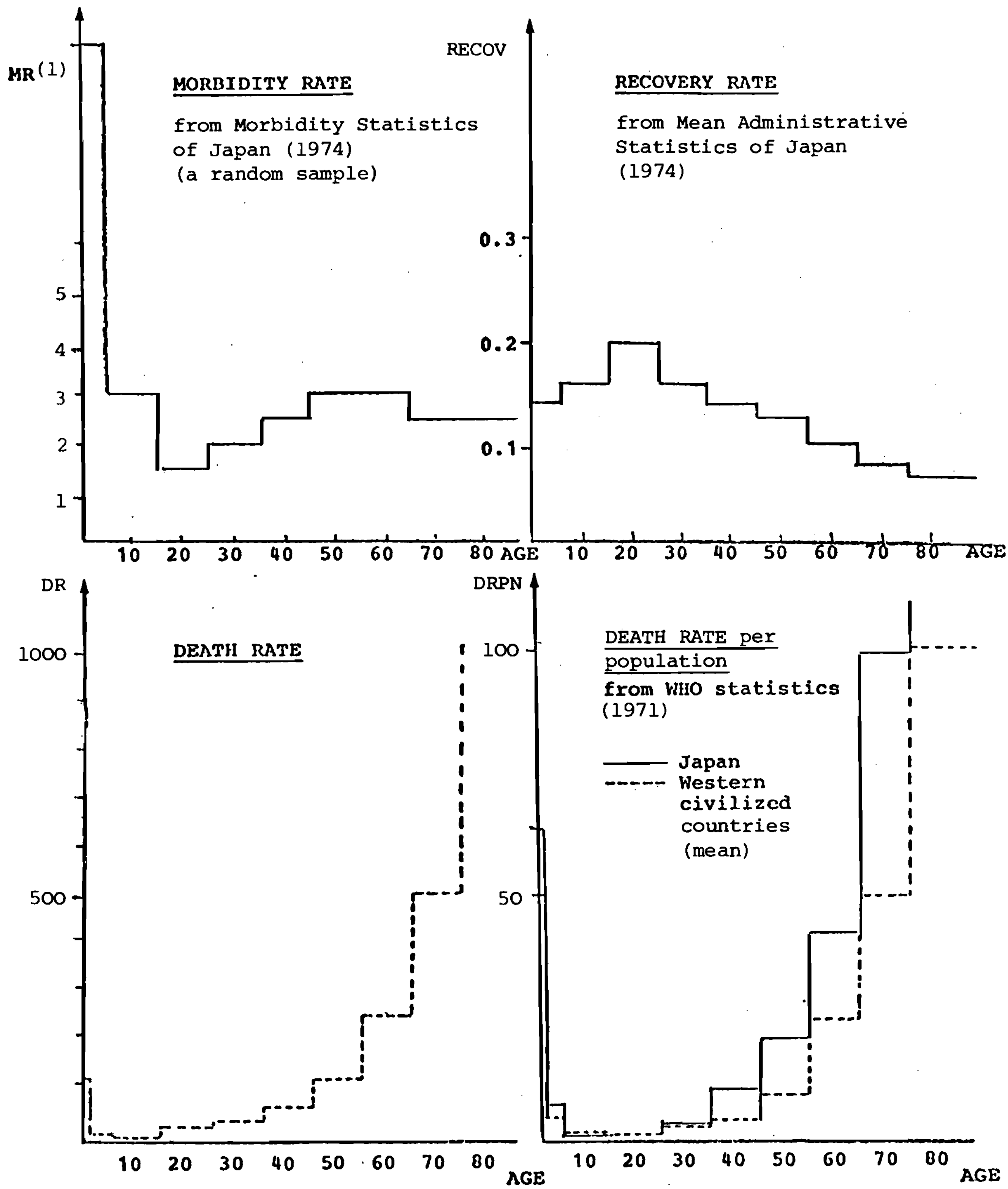

Figure 8. Rates used in the morbidity model of infectious diseases (Epidemic and Enteritis, A1 ~ A44).

(1) MR, RECOV, DR, and DRPN were defined in Table 1.

Source: Fujimasa, et al. (1978), p. 9.

diseases on the basis of other indirect statistics, in particular, mortality data. Unlike infectious diseases, however, degenerative diseases have slower dynamics, and so we must take into account not only the population structure and its changes, but also the individual dynamic property of each specific diseases.

In the two 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 main data that we can use to estimate the morbidity of degenerative diseases on the basis of mortality statistics. These data are:

a. the age distribution of *specific* mortality rates and their dynamics over time;

b. the age distribution of *general* mortality rates and their dynamics over time;

c. survival characteristics which 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 interval;

d. the population's age-structure and its dynamics.

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 modelling activitiy 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-structures?

First Model

Because the quality of data is not the same in all countries, different assumptions about survival were used in the two 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.
- Sick people suffering from degenerative diseases are considered as sick for the duration 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, to give 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 Sweden. In the calculation, a population structure of five-year age intervals was used. It was then further divided into one-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 9. Although this model covers only degenerative diseases, some interesting results can already be obtained.

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

The second application of the model is the projection of trends in degenerative disease. Models to estimate the 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

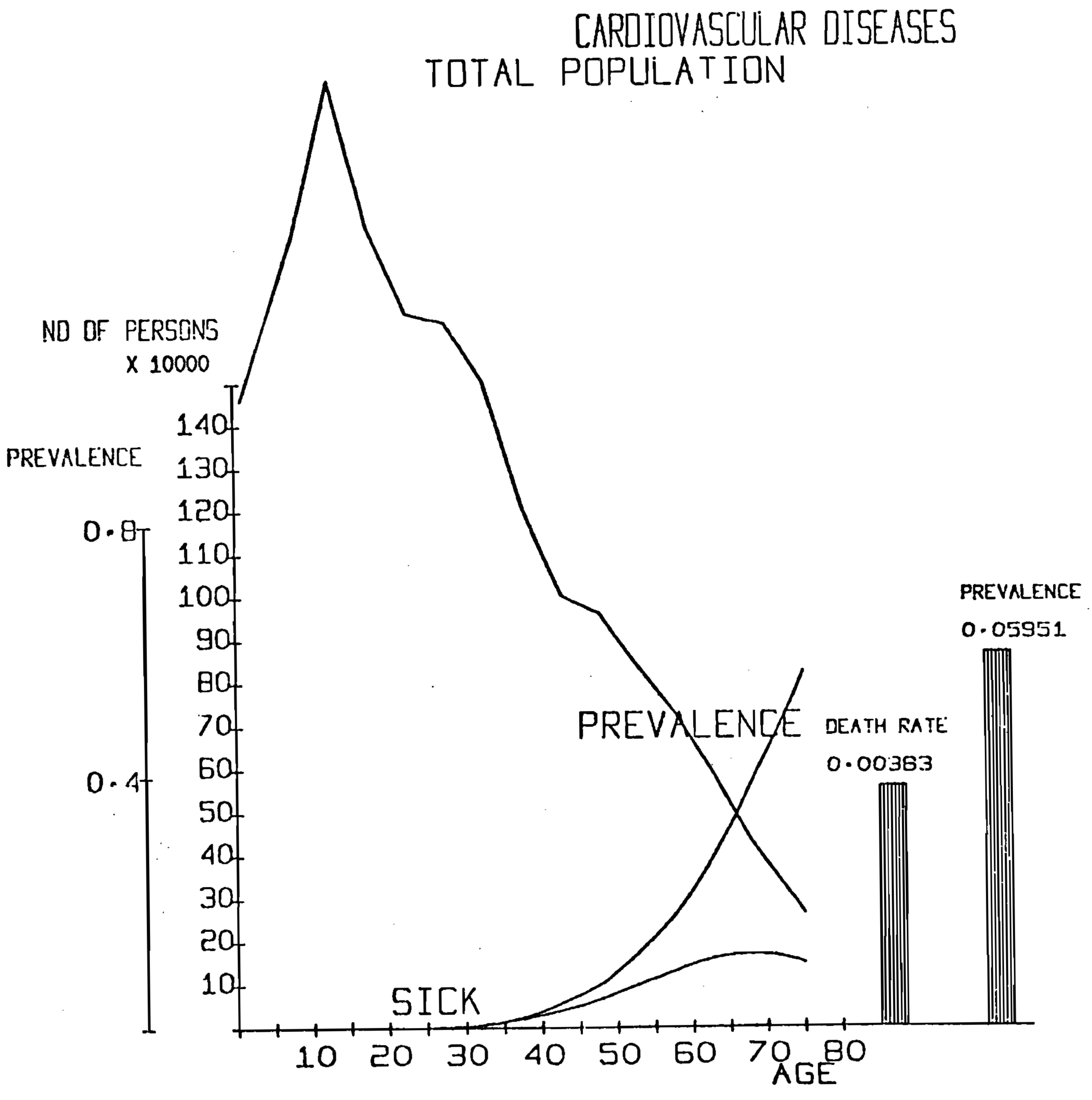

Figure 9. Number of sick, prevalence and death rates of degenerative diseases (in Japan in 1960).

Source: Kaihara, et al. (1977), p. 27.

trends in degenerative diseases can easily be calculated. Some preliminary calculations along these lines suggest that the prevalence of degenerative diseases in England is decreasing gradually, while that of Japan is sharply increasing toward the year 2000.

The third application of the model may be the evaluation of treatments for degenerative diseases. At present, there is no effective treatment that prolongs the life of these patients. However, if such treatments are developed, the model may be useful for assessing the likely decrease of death rates or increase in the number of patients, before the treatments are actually introduced.

Second Model

In comparison with the first model, c in the second IIASA degenerate morbidity model (Klementiev, 1977) assumes 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 additional to those of the first model. They 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 assumption c in the first model but 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. The WHO (1971) and Emmanuel and Evseenko (1970) were used as sources of the initial data, and the results of the calculations are presented 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 according to disease.

The direction of the development of the morbidity models is toward reducing the number of restrictions on population structure dynamics and disease dynamics. For example, we require a

Table 2. Estimate prevalence and actual deaths from malignant neoplasm.

Source: Klementiev (1977), p. 18.

	AUSTRIA		BULGARIA		FRANCE	
Age	Estimated Prevalence	Deaths(1)	Estimated Prevalence	Deaths(1)	Estimated Prevalence	Deaths(1)
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

(1) From Emmanuel and Evseenko (1970).

morbidity model for unstable and unstationary population structures. In addition, it is necessary to adapt these models to use comprehensive health study data about a specific region, to avoid the inevitable error of extending clinical survival data to the latent sick individuals. Both those aspects are being studied at the present time.

3.3 Health Resources Requirement Models

The Problem

One of the most serious problems in modelling health care systems is the design of models for health resource requirements. In many countries there are different mechanisms for determining resource requirements; market, insurance, normative planning, etc. The problems are more in countries that use a combination of these mechanisms.

The IIASA HCS Modelling Group is developing several models for health resource requirements using the experience of different countries in this field. As a first step we have started from a normative planning approach. On the basis of this approach, knowledge is obtained from data about population, health status, present levels of care, their dynamics, and of how health conditions are converted into health resources. Standards can then be calculated for the number of out-patient visits per capita, the duration of one out-patient visit (in minutes), the number of out-patient visits per patient with a specific disease, etc., and for similar measures associated with other forms of care.

Sometimes these standards can be obtained only by generalizing the opinions of several experts. Sometimes it is possible to take standards from official "routine" statistics--e.g., hospitalization rate or average lengths of stay. In some countries, in order to get this set of standards a comprehensive study is carried out as mentioned earlier. In the course of such a study, retrospective statistical standards are revised by a team of medical specialists who keep in view the quality of health care activity applied to sample cases with different diseases. Such a team of experts might alter the standards, using the opinions of medical specialists themselves concerning the adequacy of health care for each case studied and possible changes in medical tactics.

It is clear that the quantitative level of these standards indeed reflects the real situation of each country and differs greatly from country to country. That is why we have started with commonly used standards such as average length of hospital stay, bed occupancy rate, and bed turnover interval. In some countries, these standards 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 modelling process.

Structure and Assumptions

Two models have so far been developed at IIASA: AMER, Aggregative Model for Estimating Resource Requirements (Klementiev and Shigan, 1978), and SILMOD, Sick Leave Model (Fleissner, 1978). The basic structure of AMER and SILMOD is represented in Figures 10 and 11. As shown in these figures, the main difference between AMER and SILMOD consists in the methods of morbidity estimation and in the population groups which are 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 and the shorter the average length of stay, the greater is the number of consultations per episode. The main assumptions of AMER are linearity and stationarity of the substitution effect. In the SILMOD model, 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 forecasted dynamics of the standards (norms). These are summarised in the

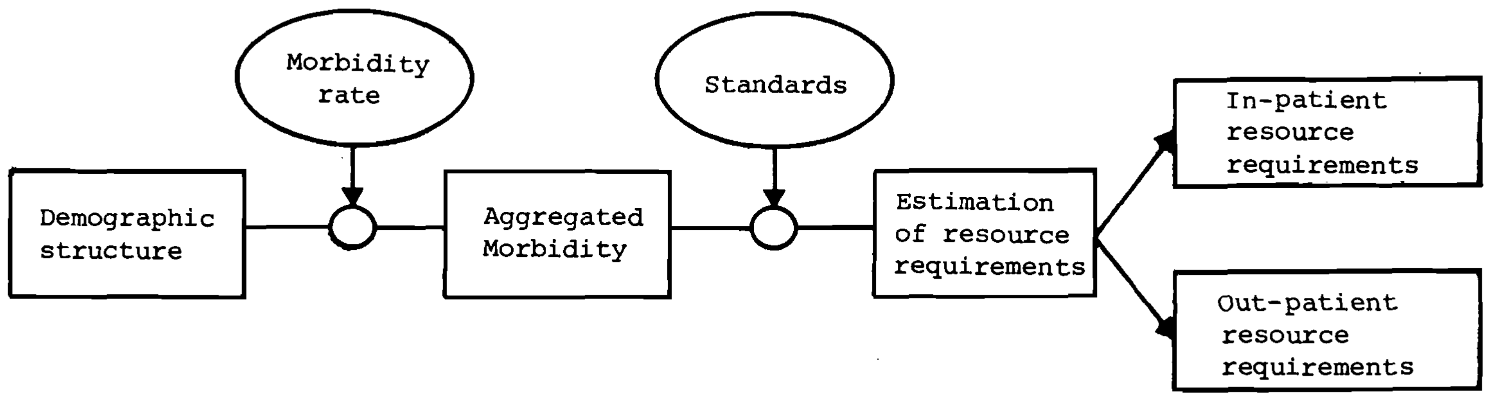

Figure 10. Basic structure of AMER.

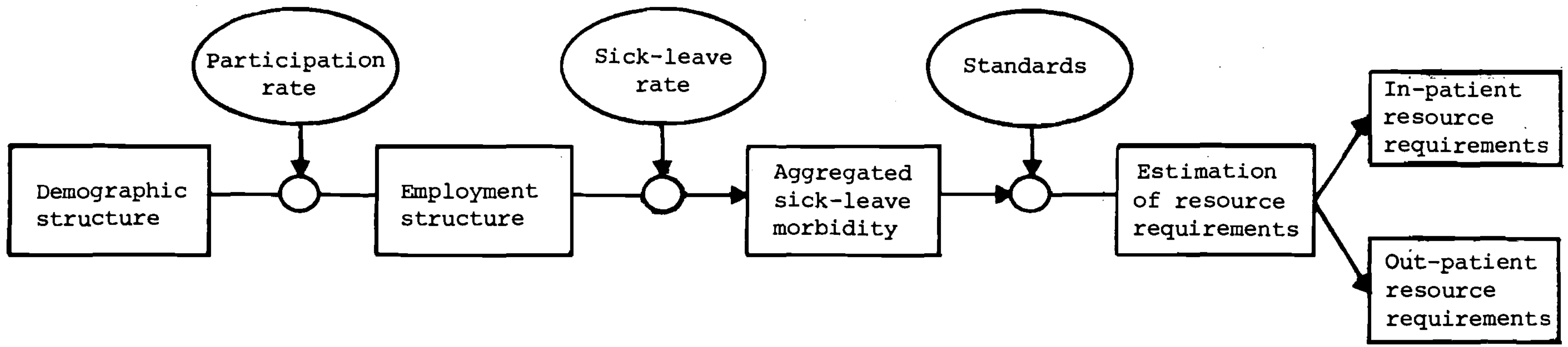

Figure 11. Basic structure of SILMOD.

input file "CTL" (control variables), represented in Figure 12. Some results of the model's calculations are displayed on the terminal screen in the format shown in Figure 13. 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 and days of hospital stays. Each of the variables is divided by sex and age. The last two rows indicate sums or averages of rates for males, 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 decisionmaker, working in an interactive regime, to test different policy options and to select the best among them. A model also makes it possible to forecast population structure changes 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 with precise medical resources. So far in the resource requirements models, only some health care resources have been represented. However, the models can be developed to describe the use of other resources including nurses, auxiliary

= file CTL =

	base year	future years / trial fugures year 5	year 10	year 15	year 20	ideal
averg lngth stay	23.8	23.0	22.	20.5	19.0	19.0
prcntge hsptlsd	10.53	10.4	10.1	9.8	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 12. Input control file.

Source: Klementiev and Shigan (1978), p. 9.

INPUT-OUTPUT SUMMARY:

	year 0	year 5	year 10	year 15	year 20	ideal
averg lngth stay	23.80	23.00	22.00	20.50	19.00	19.00
prcntge hsptlsd	10.53	10.40	10.10	9.80	9.50	9.50
bds/inp doc eqvt	21.81	21.81	21.81	21.81	21.81	17.00
bed trnvr intrv	4.94	4.70	4.50	4.30	4.10	4.00
cnslts/otp doc/yr	7033.	7033.	7033.	7033.	7033.	6000.
bed cost/yr	3145.00	3300.00	3400.00	3500.00	3600.00	
cnslts/epsd	3.50 *	3.59	3.77	3.96	4.16	
bds rqrd, total	409164.	343781.	296344.	251917.	213307.	
fnds rqrd, total	1964.65	1802.11	1676.47	1564.13	1460.81	
doc eqvts rqrd	42366.	38017.	35229.	32876.	30777.	

Figure 13. Format of displayed results.

Source: Klementiev and Shigan (1978), p. 10.

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 (routine, scientific, etc.). 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.

3.4. Health Resource Allocation Models

Introduction

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 ideal resource levels and the prediction of available resource levels. It seeks to represent how the HCS allocates limited supplies of resources between competing demands.

Health services cannot be administered in a rigid centralised 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) which are available to them. The specific question underlying DRAM is:

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

DRAM takes input data on demand and supply, uses an hypothesis about how allocation choices are made, and gives indicators of the predicted behaviour 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, out-patient, domiciliary, etc.), 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 production model). The model outputs represent the levels of satisfied demand in a HCS with limited resources. They are: the numbers of patients of different categories who receive treatment, modes of treatment offered, and the quotas of resources received by each patient in each mode of treatment. Inevitably these levels fall short of the ideal demand levels. DRAM models the different equilibria which the HCS must choose in order to balance 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 behaviour of the HCS in the model. First it assumes that there is never a sufficient supply of resources to saturate all the potential demands for them. This finding has been frequently 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 maximises a utility function whose parameters can be inferred from observations of past allocations. Such a model is of the behaviour 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 behaviour within resource constraints. If these hypotheses are sound, DRAM can describe not only 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 factors such as clinical standards, disease prevalence, and the preferences and priorities operating in the HCS.

DRAM cannot, and does not, 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 desirabilities of treating more patients of one type against treating more of other types, and against 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 summarise 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 head of population per year. Then the HCS must choose the admissions per head of population per year x, and their average length of stay y, such that

$$xy = B \quad .$$

This equation represents a family of hyperbolae plotted on Figure 14. 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 which 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 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 which are difficult to depict graphically. Nevertheless, the underlying concept is as described above.

What assumptions do we need to determine the character of the model solution?

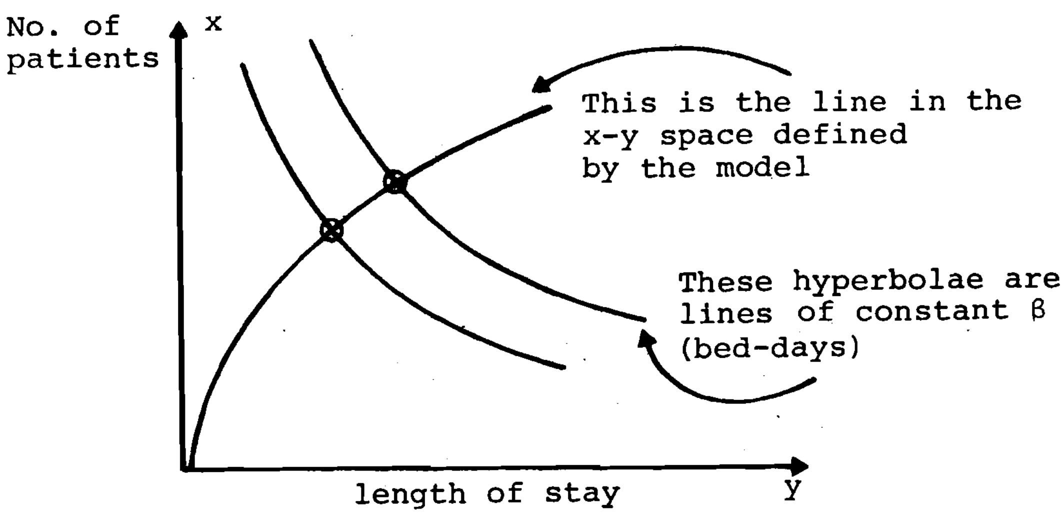

Figure 14. DRAM chooses solution points on the line of constant resources.

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 which any one in the HCS is consciously, or even subconsciously, trying to maximise. Instead, it represents an hypothesis about the aggregated behaviour of the HCS, in which the parameters represent the priorities implicit in the choices which are made. DRAM is a *simulation* model. We do not seek to optimise behaviour 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 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 which are calibrated on such data reflect the same priorities. The second approach to parameter estimation uses historic data about actual allocations. On Figure 14 we can see that historic allocations represent points in the x-y space which 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 mdoel. 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 which considers the allocation of in-patient bed-days between patients with six diseases. 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 show a significant decline in bed-numbers, which has had different results in different specialties. In "appendicitis", for example, admissions have remained constant, while length of stay in hospital has declined. However, the opposite is true in "bronchitis". These differences can be used by the model to make allocation predictions for other numbers 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 x bed cost) follows from associating all of the hospital revenue *except* doctoring with bed costs. It is this assumption which actually *defines* the resource types modelled 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 which 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 procedure for parameter estimation. It may be possible to refine these methods further, possibly to include a procedure which 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. A possible area is the care of the elderly, a problem which is common to many countries. We hope to investigate these and other issues in collaboration with other research centres who are at work in this important area of research.

Table 3. DRAM example 1.

Source: Gibbs (1978), p. 29.

Patient Category i	Run 1: B = 800 bed-days/million		Run 2: B = 1200 bed-days/million	
	Admission Rate x_i	Av. Length of Stay y_i	Admission Rate x_i	Av. Length of Stay y_i
1. Varicose Veins	6.4	9.1	8.5	11.4
2. Haemorrhoids	4.1	9.0	5.4	10.6
3. Ischaemic Heart Disease	3.6	20.7	5.4	30.9
4. Pneumonia	11.3	16.2	14.7	17.6
5. Bronchitis	8.1	32.8	12.3	33.3
6. Appendicitis	23.7	7.7	24.2	8.7
All Categories	57.2	14.0	70.4	17.0

Table 4. DRAM example 2.

Source: Hughes (1978), p. 29.

Specialty	B = 940.7 bed-days, (1968) 104.1 doctor-days			B = 782.2 bed-days (1973) 125.9 doctor-days (3)		
	Admission	Stay	Doctors	Admissions	Stay	Doctors
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
Obstet./Gynae.(1)	33.1	7.5	0.59	35.0	6.2	0.67
T&O Surgery	7.1	17.9	1.28	7.4	15.0	1.48
ENT	5.8	5.2	0.74	4.1	4.3	1.22
Paediatrics (2)	15.4	9.7	1.67	19.0	7.1	1.92
Ophthalmology	2.4	10.1	1.68	1.8	8.6	3.18

(1) Population divisors exclude males.

(2) Population divisors exclude adults.

(3) Relative costs of doctors: beds assumed to be 1.57:1 (see text) 1973.

3.5 Health Resource Supply Models

Introduction

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: (1) the definition of optimal demands for manpower resources; (2) the preparation and allocation of the corresponding specialists; and (3) 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 requirements models, and these were discussed earlier. The second set can be solved within the framework of education models. The solution of the third set of problems demands the preliminary investigation of the existing socio-economic mechanisms influencing the manpower flows. We discuss our approach to these two sets of problems below.

Manpower Education and Retraining Models

The training of health care personnel requires many years, and in addition it is necessary for most medical workers to specialise. Thus the manpower education and retraining problems of health personnel are both large-scale and long-term in nature, as well as affecting 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 specialised doctors, nurses and midwives, junior medical personnel, technicians, etc. In addition, there is much in common between training in medical schools and postgraduate training of health personnel. These are features which slightly ease the modelling task. Usually, the ultimate goal of a manpower education or retraining system is more simple to quantify than in 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 means that the education and retraining problem is an example of an HCS subsystem in which one can apply some optimisation technique, such as dynamic linear programming (Propoi, 1978).

Figure 15 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 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 which require the numbers of individuals in the system to be positive. And there are resource constraints such as

$$D(t)u(t) \leq f(t)$$

where $f(t)$ are the resource 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

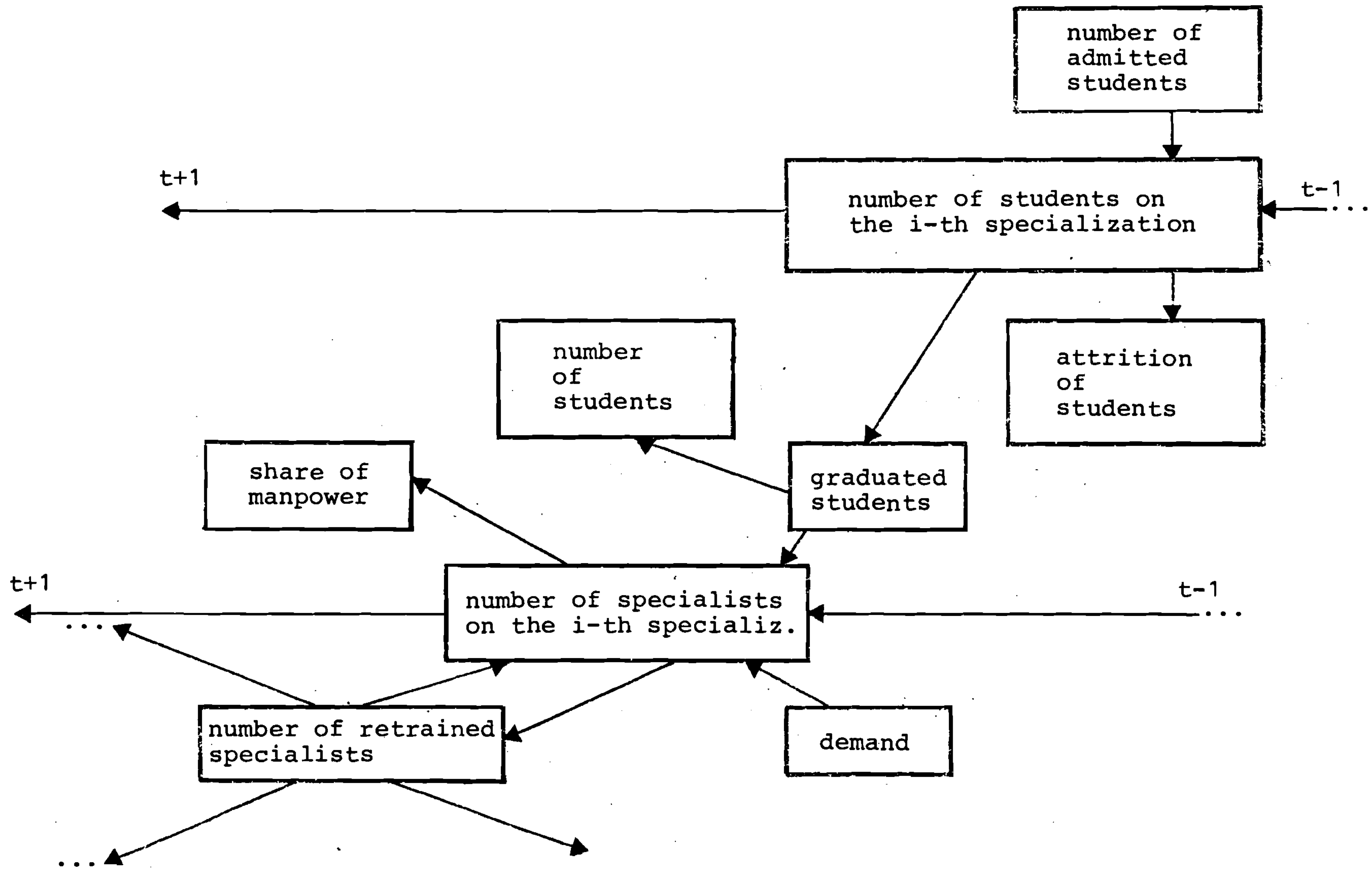

Figure 15. The structured scheme of the manpower planning model.

f(t) are given as exogenous variables. In more detailed models these variables can be considered as state variables which 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 figures of required specialists are supposed to be known for each step of the planning period T; that is, the numbers $\bar{x}(t)$ are given for $t = 1,\ldots,T$. 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

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

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

This completes the formulation of the model as a dynamic linear program, a technique which 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 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 α. This estimation problem can be solved by 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 to the system are supposed to be fixed. A more detailed model could incorporate three subsystems of specialist training: nurses who graduate from medical schools, practical physicians 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 either for the second-level or for 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 models, the dynamics of the process of training specialists and the limits of available resources.

Manpower Migration Flows Simulation Model

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 getting 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 of all his professional interest and second of all his other demands.

The specialist solves the problem of choosing the place for work by comparing the different conditions in the regions with his own needs. Such inconsistency vectors serve as the background for deciding to change the place of work, and the mass character of such inconsistencies generates the migration flows, which may result in deficits in the manpower of some regions. It is clear that if planning bodies could take into account the socio-economic 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 labour 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 labour 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 characterising 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 its influence on other socio-economic 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 socio-economic mechanisms. From this point of view, HCS manpower modelling 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 socio-economic systems (Venedictov, 1976; Yashin, 1977).

3.6 Application Experiments

Application-oriented IIASA HCS modelling activity has two directions. The first is the testing of our models on the national or regional statistics of different countries--Japan, CSSR, UK, USSR, Bulgaria, DGR, FGR, 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 intended also for possible interactive remote use by decisionmakers 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 decisionmakers. 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). Figure 16 depicts computer links between IIASA, WHO, and national centres.

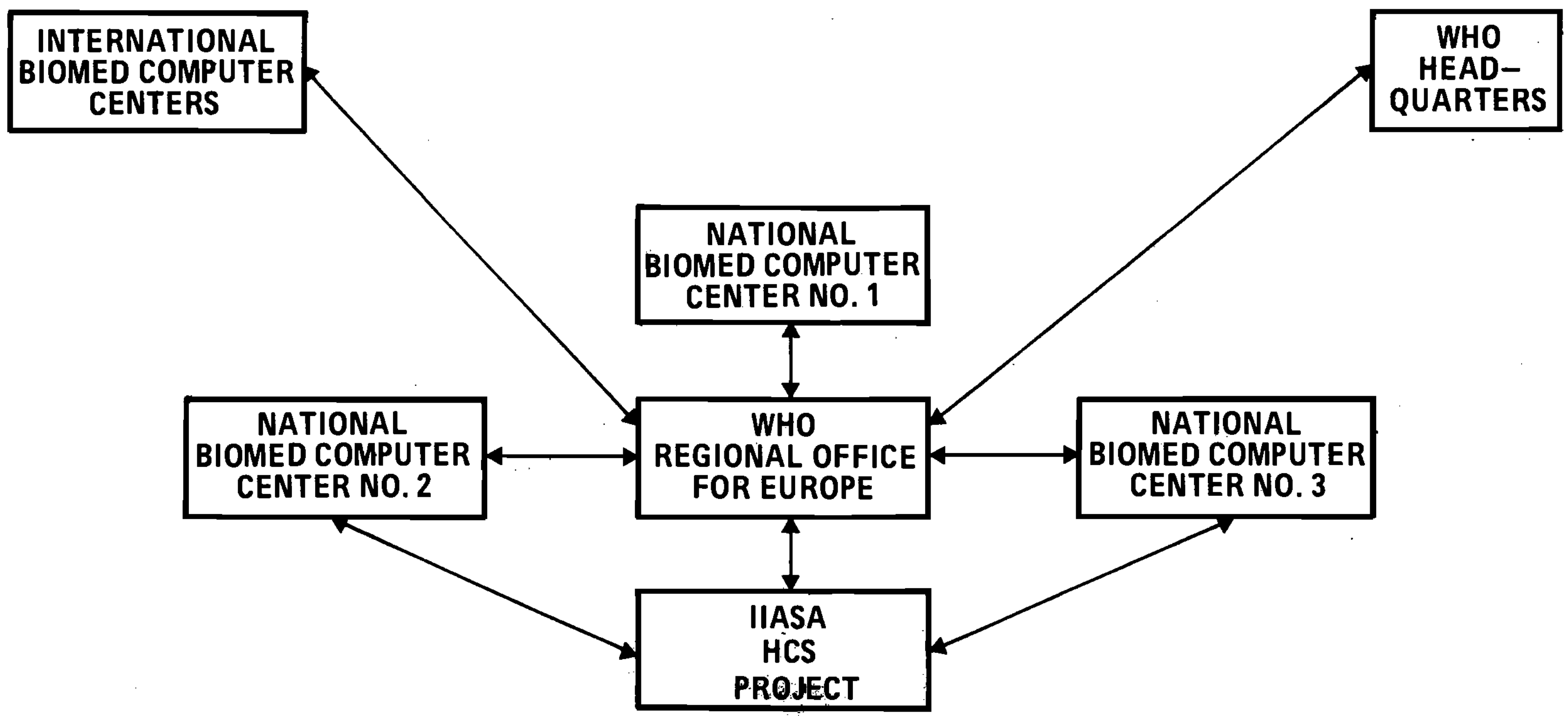

Figure 16. General scheme of biomedical computer network development.

One such experimental connection was tested between IIASA and the Computer Research Centre, Bratislava, several times during 1976-77. A second link was established between IIASA and the WHO Regional Office for Europe (ROE) in Copenhagen, Denmark, in June 1978, during a seminar on HCS modelling attended by directors and several leaders of ROE Programs. These computer links were established with the technical support and expertise of members of the IIASA Computer Network Team. Since this demonstration the WHO/ROE have acquired similar terminals suitable for interactive computing, not only with IIASA but also with national medical computer centres. This experiment therefore has proved of great interest to the WHO, and WHO officials have expressed their readiness to support further development of HCS modelling at IIASA.

4. FUTURE DEVELOPMENT

Our proposals for further work in health care systems modelling appear in the IIASA Research Plan for 1978-1983. The research will be divided between three activities:

1. further development of existing models,
2. application of all our models in appropriate experimental applications,
3. development of new models.

4.1 Further Development of Existing Models

Figure 17 shows the state 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) which were mentioned in Section 3 but which are not yet complete. Some other developmental work is needed also. For example, a first task is to

Model Group	Model Name	Defined Mathematically	Programmed and Illustrative Results Available	Tested and Applied
Demographic	POP	✓	✓	✓
	RWM	✓	✓	✓
Morbidity	AMM	✓	✓	✓
	INFM	✓	✓	✓
	MEMOD	✓	✓	✓
Resource Requirements	AMER	✓	✓	✓
	SILMOD	✓	✓	X
Resource Allocation	DRAM 1	✓	✓	✓
	DRAM 2	✓	✓	X
	DRAM 3	✓	X	X
Resource Supply	MANP	✓	X	X
	AMP	✓	✓	X

Figure 17. State of development of HCS models.

develop a mathematical methodology to reconstruct morbidity data from different sources of medical information. Taking into account that all these sources, both separately and in combination, exist in real life, this methodology will be very useful not only as a part of HCS modelling 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 recognise this fact in estimation procedures.

A second task is to develop all the models associated with health care resources. Several periodical comprehensive studies conducted in Bulgaria, USSR, UK, and other countries, present the opportunity to estimate health resource utilisation 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, nurses' and physicians' time, etc.). Health resources requirements could thus be calculated for each case, disease, and individual. This extention of "AMER" moves from disaggregative morbidity to disaggregative resources, and such a version of the model would be very useful to IIASA's NMOs. The resource allocation model "DRAM" will be extended to represent more of the choices which 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 forthcoming HSS manpower task.

4.2 Application of Models

There are a number of activities which can be labelled application, for example:

a) receiving data from NMO countries, running this data through the models at IIASA and publishing the results, perhaps with international comparisons;

b) 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;

c) visiting HCS planners in NMO countries, identifying issues of interest to them which 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;

d) offering a consultancy service to interested HCS planners in NMO countries.

To date, activities of type a) and b) 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 which will be developed next. If possible, these models will be tested not only on the state 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 d). But there are two regions (the South Western Region of the UK and the Silistra region in Bulgaria) where we hope to do some type c) applications.

Taking into account that all our models are oriented to practical application by decisionmakers, the development of communication between decisionmakers and modellers 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 model.

4.3 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 its interaction with higher and lower levels, which could be developed in possible cooperation with the IRD task and the MMT Area;
- 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 future program we should work in close contact not only with other IIASA task groups, but also with national centres and the WHO as well. The development of such collaboration is one of the most important directions of HCS modelling activity in the near future.

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APPENDIX 1: 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	GDR	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 2: COLLABORATING INSTITUTIONS

The following institutions have been actively collaborating with the Health Care Systems Modelling Task. In order to become a collaborating institution, an organisation 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 and/or processing in conjunction with IIASA;
- scientific survey in conjunction with IIASA;
- written contributions to a IIASA publication (Research Report, Collaborative Publication, book);
- model development in conjunction with IIASA:
- evaluation and/or implementation of IIASA developed or refined models:
- conducting 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
FRG	Institute for Medical Data Processing, Munich
	Industrial Enterprises, Ltd,, Munich
	Hannover Medical Center, Hannover
	The Ulm University, Ulm
GDR	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 Leyden, Leyden
UK	Operational Research Services, UK Health Ministry, London
	South Western Regional Health Authority, Bristol
USSR	Institute of Control Sciences, Moscow
	The Central Research Institute of Social Medicine and Public Health, Moscow
World Health Organization	Headquarters, Geneva
	Regional Office for Europe, Copenhagen

APPENDIX 3: IIASA PUBLICATIONS IN THE BIOMEDICAL PROJECT AND THE HEALTH CARE SYSTEMS MODELLING TASK

- The *Research Report* (RR) is IIASA's most formal vehicle for reporting Institute research, intended for broad distribution to the scientific community. RRs receive careful review, editing, typing, and printing. The RR classification is used to report final results of research, 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 organisations 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.

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