# Problems of Modeling and Decision Making in Health Care

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## INTRODUCTION

The present process of health care development has been characterized by several features, one of which is the increase in the amount and variety of needed personnel, beds and other resources. Because of this, more and more people have become involved in the decision making process in the various levels of the health care system.

In order to deal with this increasing number of decision makers, it is necessary to review their functions and problems, and to develop new technologies for the decision making process. Models are one of the prime means for aiding the decision maker in the management process and if properly applied can be of great benefit in the solution of many of the problems that arise today in health care systems. [1]

## THE DECISION MAKER: HIS PROBLEMS AND MEANS FOR SOLUTIONS

A health manager faces many different problems. These can be combined into several general types as shown in Figure 1. All of these problems in turn consist of different subproblems and tasks such as those listed below.

Operational problems:

- estimation of the health status of the population
- estimation of the environmental condition
- estimation of resources and their utilization
- estimation of the relation between health, resources, and environment
- comparative analysis

Tactical problems:

- short-term forecasting of health indices, environmental

parameters, resource demands
- construction of health care establishments

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

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; on the national level the decision maker deals with tactical and strategic problems. He faces 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. Many times he consults other decision makers in order to obtain expert advice. He also uses information acquired from routine "statistics", special studies or

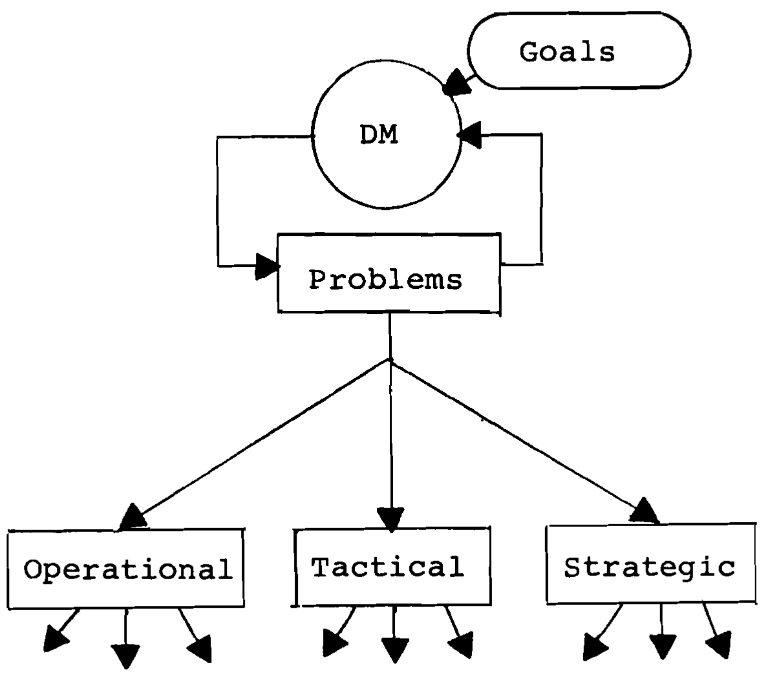


Figure 1: Different general problems faced by the health manager.

surveys, and natural experiments. For many problems routine information concerning individual health, medical procedures and administrative policy is enough to make a decision. For other problems, special comprehensive studies of health care or natural experiments with real medical procedures are needed. In all these cases the decision maker builds in his own imagination the method of decision and/or solution of management problems by means of acquired information and his own experience (his mental model).

Another method of analyzing a problem which is open to the decision maker is the mathematical computer model. This method, however, is not as commonly used because only a limited number of models exist that are applicable to present health management problems. It is also true that the decision maker has a certain mistrust of mathematical models because these models have been built according to the model builder's own point of view of the health care system and its problems.

Most decision makers believe in the importance of mathematical and computer modeling but the main difficulties at present are to find a way for combining the computer model with their mental model.

The first step to the successful resolution of this task is a detailed analysis of the individual decision maker's problems and their classification as to importance and complexity. Such a classificiation will permit the model builder to distribute more rationally his time and the time of his colleagues and allow him to concentrate his attention only on the more important problems.

The work of classifying problems may be done by a group of experts working independently with the aid of the following table (Table 1). In this table all problems are rated at specified levels which are scaled according to their importance and complexity.

The second step deals with the organization of special timing procedures.

| Problems of lower level \ Problems of lower level | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Importance Scale |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | + | | | + | | + | | 3 |
| 2 | | | + | | + | | | + | + | | 4 |
| 3 | + | | | | | | | | | | 1 |
| 4 | | + | + | | | + | | + | | + | 5 |
| 5 | | | | + | | | | | | | 1 |
| 6 | | | + | | | | | + | | + | 3 |
| 7 | + | | + | | + | | | | + | | 4 |
| 8 | | | | | + | | + | | + | | 3 |
| 9 | | | | + | | | + | | | | 2 |
| 10 | | + | | | | + | | | + | | 3 |
| Complexity Scale | 2 | 2 | 4 | 3 | 3 | 2 | 3 | 3 | 5 | 2 | |

Table 1: Definition of the Complexity and Importance of the Problems of the Lower Level.

## THE INTERACTION BETWEEN DECISION MAKERS AND MODEL BUILDERS AS A BASIS FOR MODEL DEVELOPMENT

When developing a computer model for a complex system, the modeler often meets with incomprehension on the part of the decision maker. This incomprehension exists because of the different perspectives from which the modeler and the customer view the system. The decision maker concentrates on experience and intuition to form his mental, nonformal model which he consciously or subconsciously used to make his decision. The computer model suggested by the modeler must correspond to the decision maker's intuitive conceptions of the problems and their solution. The correspondence of the model to these intuitive conceptions may be set by special procedures in the model's "tuning" in order to gain the decision maker's confidence in the model's performance (Figure 2).

Gaining this confidence may be achieved by two means. The first and traditional way, consists of testing the model, and adopting identification procedures based on retrospective statistical data. [2] This is the most appropriate way for countries

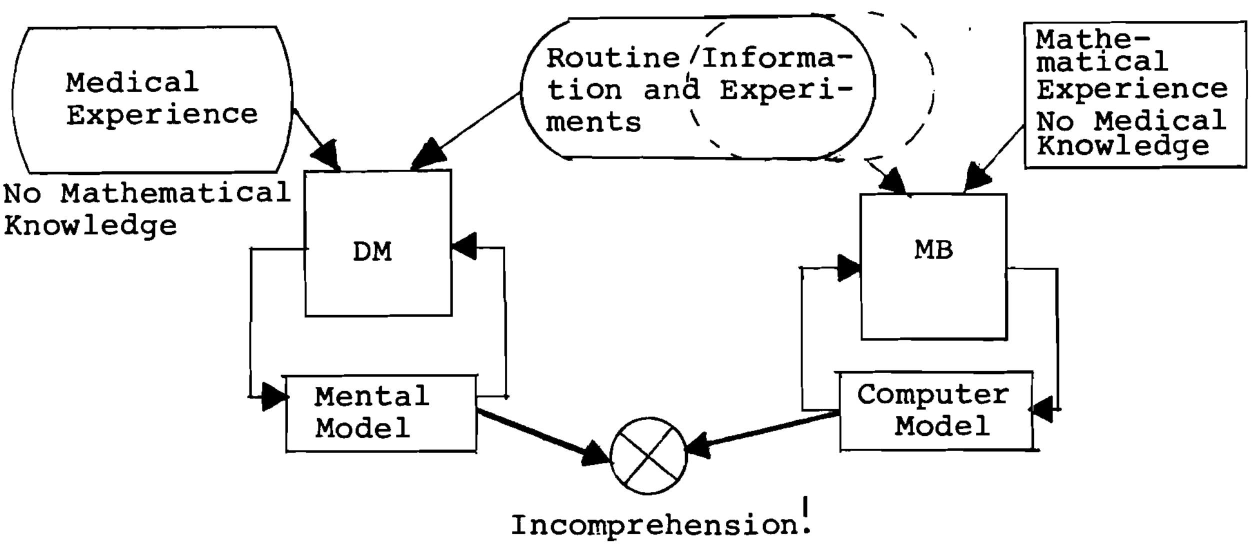


Figure 2: The necessity of interaction between mental and computer models.

with developed information services. The second and non-traditional way, consists of using the experience and intuition of the manager. Both approaches should be applied, starting with the identification methods which use formal criteria and retrospective data to implement the preliminary model tuning and ending with the fine tuning with the decision maker (Figures 3 and 4).

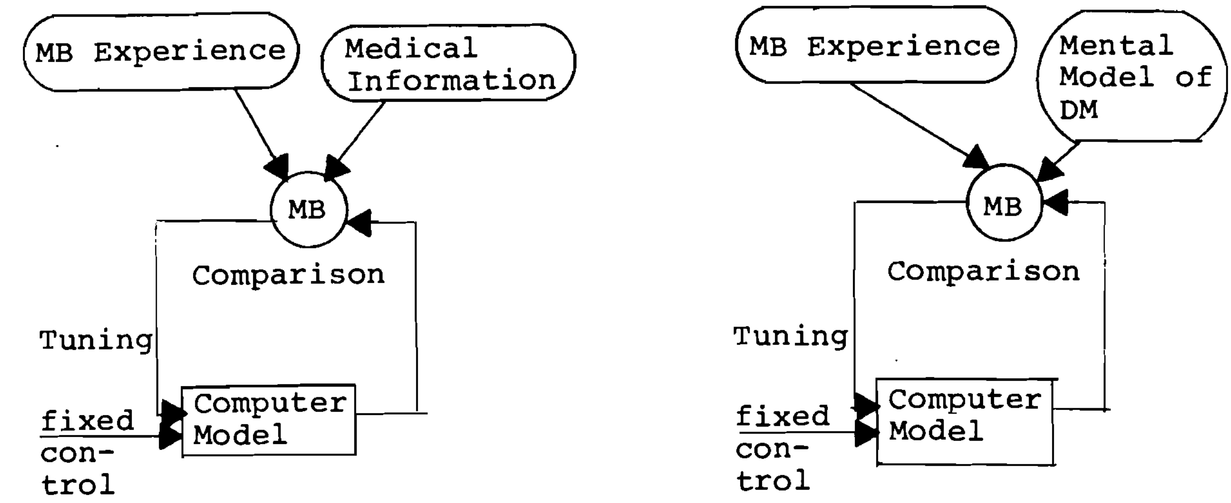


Figure 3: Two ways of tuning the model.

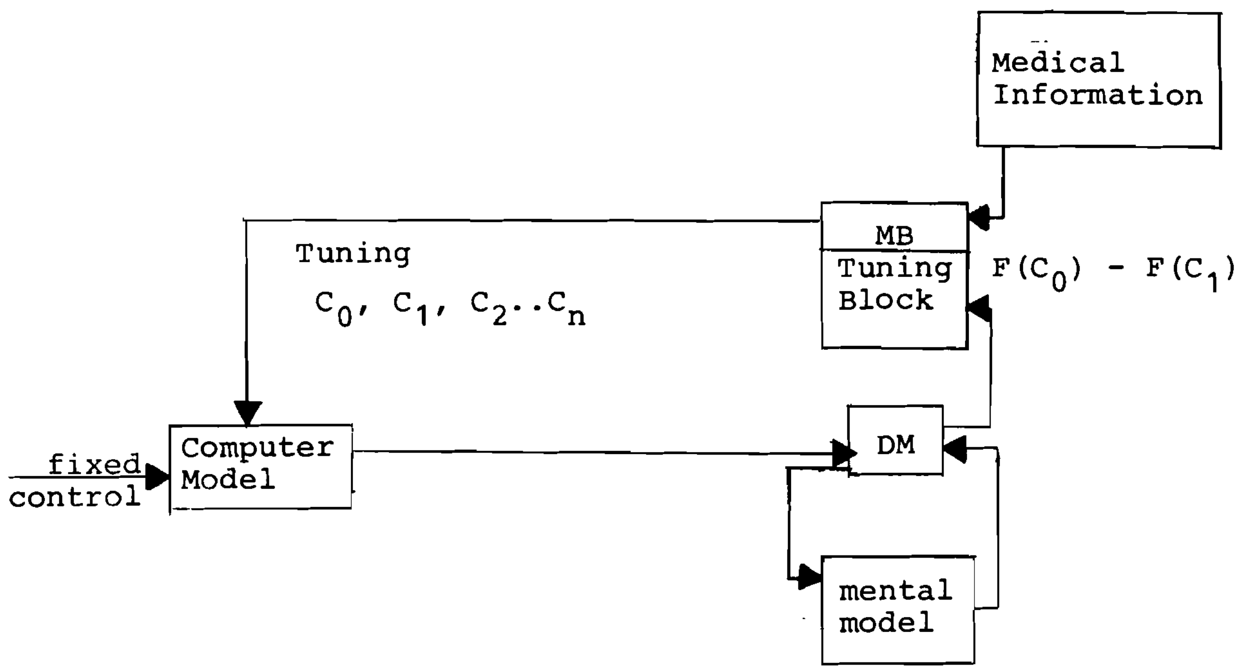


Figure 4: Combined way of tuning the model.

## MODELING

### Basic Principles

When developing a set of models for a manager, a model builder may use the basic principles followed by the decision maker as a guide for the model. These principles include:

a) the manager's tasks and objectives;
b) the manager's possibility to influence the system, i.e. the control possibilities;
c) knowledge of the system, its structure, peculiarities, laws of functioning; and
d) the technical possibilites of modeling.

The implementation of these basic principles is not a formal process, but one based on the experience and intuition of the modeler. The decision maker's objectives are formulated in quantitative terms, thus making it possible to define a set of variables for the model's output. The set of input and control variables is determined by the many possibilites the decision maker has to manage the system.

Because of the existence of statistical data on the system's inputs and outputs it is possible to use the simplest methods of cybernetics (black box techniques) to build regression models (Figure 5). If the model built in such a way satisfies the manager in the sense that it achieves the objectives and solves the tasks, then the process of tuning the model may be terminated. If subsequent model-tuning is needed in order to fulfill requirements of the man-machine procedure, no change in the structure of the model is necessary.

If the model of the black box type does not satisfy the manager, then the modeler is required to rebuild a model bearing in mind all available information concerning variables and links in the system. In this case the black box becomes transparent. The consideration of the system's links and exogeneous influences leads to the necessity of introducing new variables describing both internal parameters and characteristics of the system and

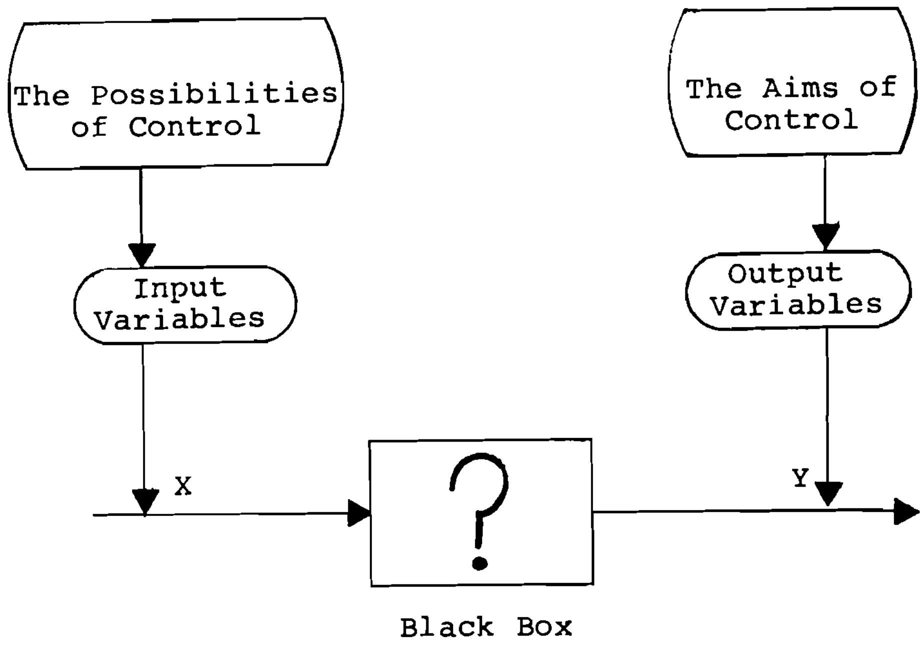


Figure 5: Black Box technique in modeling.

external subsystems. This leads to the creation of the so-called "system models". One may arrange the models in sets of classes. Each class differs in the complexity of its structure. The most complex class of models is defined by the boundaries of knowledge about the system or the technical possibilites of the modeling. The models within each class also may be arranged systematically.

Traditional Methods of Identification

When implementing traditional approaches to tune health care system and subsystem models the following mathematical difficulties occur:

a) the need to develop special methods to identify non-linear systems, and
b) the need to develop special methods to identify the systems that are described by jumplike processes.

These difficulties can be overcome by using the modern theory of stochastic processes and mathematical statistics including the theory of conditional Markovian processes, stochastic differential equations, and Martingale Theory. Important equations of identification can be derived by these methods. Many of these equations (specifically formulas for the estimation of jumplike processes) appear to be a new contribution to the mathematical theory of identification.

Some ideas on estimation algorithms may be given by the following example: $\Theta$ is a parameter of some queueing system that may attain one of the N possible values and then become a pseudo-Poisson jumplike process describing the input flow of demands in the system.

In this simple case the posterior probabilities of the parameter's values the $\Pi_j(t) = p(\Theta = j/\xi_0 t)$ satisfy the equations:

$$\Pi_j(t) = \int_0^t \Pi_j(\tau-) \frac{q_{\xi_T - \xi_T}(j)}{\bar{q}_{\xi_\tau - \xi_\tau}} (d_{\xi_\tau} - \bar{q}_{\xi_\tau - \xi_\tau} d\tau) + \Pi_j(0) \quad .$$

Here the stochastic integral over the process $\xi'_t$ is a Stieltjes integral at any $\omega$, $\bar{q} = M(g/\xi_0 t)$. [3]

Under some general condtions the posterior probabilities tend to the unit on the set $\{\Theta = j\}$ which warrants consistency of optimal estimates in the mean square.

Man-Machine Tuning Procedures

Tuning of the computer model is performed by means of interactive man-machine procedures based upon the method of mathematical programming. These make use of the fact that the decision maker can distinguish and compare the simulational abilities of different models in order to decide which of the models is more adequate for his needs. The existence of such a system of preferences under certain conditions is similar to the existence of a function (criterion) which generates this system of preference depending on the parameters of the model. An explicit definition of this function remains unknown, but it is not essential because only the most extreme point is of interest.

The ability of the decision maker to distinguish and compare the simulation possibilites of the model's corresponding different value parameters is equivalent in a way to his subconscious use of the certain function L(C) which possesses the following property: if from the decision maker's point of view the model with parameter $C_1$ is preferable to the model with parameter $C_0$ then $L(C_1) < L(C_0)$ and vice versa: if for certain values of parameters $C_1$ and $C_0$, $L(C_1) < L(C_0)$ then the model with parameter $C_1$ is more adequate than the model with parameter $C_0$ (Figure 6).

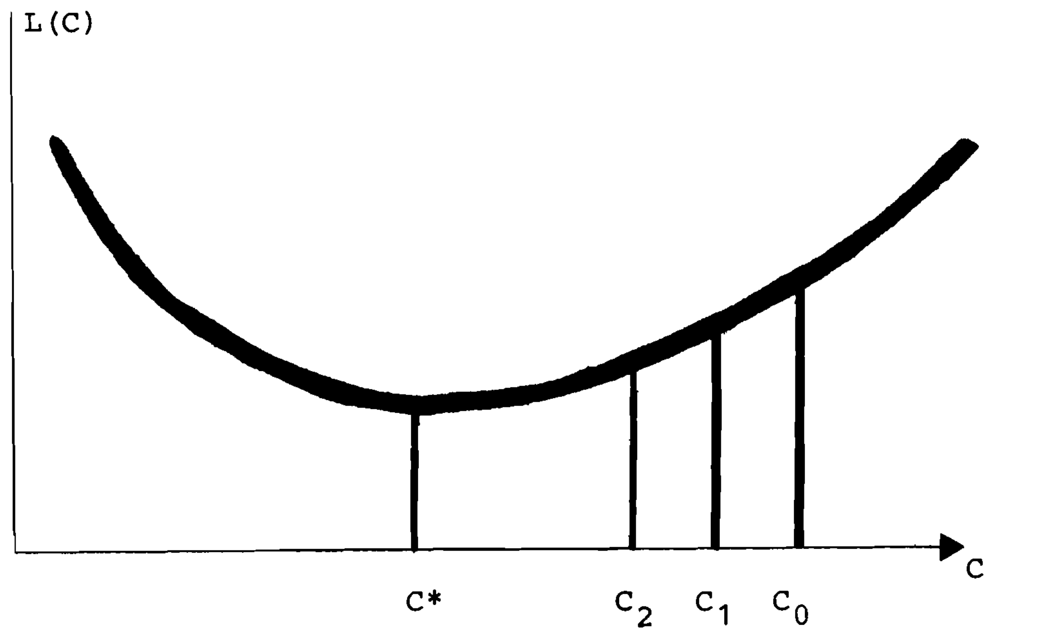


Figure 6: The tuning procedure.

Hypothesis: The system of preferences (on the set of models) is equivalent to the existence of the function L(C), where C characterizes the tuning model's parameter and C* the most preferred point.

The search for the most adequate model is focused on the problem of finding point C*, which minimizes the function L(C). The system of preference made by the decision in this man-machine procedure enables the man to find this maximum point. Thus, the decision maker becomes the person responsible for determining which of the two models is more preferable. The computational task concludes with the choice of a step's size in the parameter space which will converge into the iterational procedure at the point of optimal preference. This procedure should be continued until the simulation possibilites of the model satisfy the decision maker; or until time constraints force him to terminate the process of improving the model's quality.

<u>The Use of the Model with One Feedback Loop Control System in Decision Making</u>

The implementation of models in decision making reflects the need to compare the effects of different alternative decisions. Such comparisons are easily made if one has a single criterion for measuring the functioning of health care systems. Unfortunately, despite the multilateral efforts to introduce common indices of health state criteria, a general criterion does not exist.

At the same time, the experience of managing the system allows the decision maker to appreciate and to compare different situations in health care and therefore to implement various controls in management decisions. Here also the actions of the manager may be modeled with the help of some function (F(v)), where v denotes the different versions of controls. This function helps the decision maker to compare the results of his managerial actions. Such an explicit function again is unknown.

The man-machine procedure of decision making, with the implementation of the manager's system of preference, consists of a two stage successive change. In the first stage decisions are compared and the computer is given the results. This action is undertaken by the manager. In the second stage, the computer suggests another, more preferable, variant of management decisions.

Under some conditions, these two stages give sufficient results. The need for further tuning of the model may arise when these results are applied to the problem at hand. This need, as a rule, arises after comparing the results with the real system.

This interaction between man and computer generates a series of obvious demands: for a dialogue language and for the technical equipment that is the computer. The computer should give the results in a convenient form, that is, in the form of tables, graphs, and charts. The man participating in the dialogue should use the specified computer language.

Decision Making in Multivariant Hierarchy Systems

It is believed that the use of subsystem computer models in decision making for different hierarchical levels in the health control system would improve the entire system. It is important, however, that the models and the decisions reflect the structure of the system.

Let us describe an example of this using managers from two different levels and the computer. Let us assume that the manager of the upper level applies an aggregate model to his system of control. He will apply the methods described above, check the decision, and find the preferable solution. Let us denote this decision with V*. This decision will constrain the managers on the lower level of the hierarchy $DMII_1$ and $DMII_2$. (For simplicity let us restrict ourselves to the consideration of only two decision makers on the second level of hierarchy (as shown in Figure 2).

Each $DMII_i$, $i = 1,2$, constitutes the model that may be used to analyze the consequences of decisions noted by $u^1$ and $u^2$ respectively. By using the preferable decision, the managers on the second hierarchy level work out the decisions $u_1$ and $u_2$. The indices of the second level models are accumulated in the aggregation block and are reported to the DMI.

The DMI compares the values of indices of the aggregation block's output and the aggregate model's output. The results may be different. If the indices of the aggregation block's output are not "worse" than those of the aggregated model's output, the procedure of decision making is terminated. Otherwise, an overhaul of the model structure or the coordination of the nonformal objectives of the DMII with those of the DMI must be undertaken.

First, the DMI checks the existence or nonexistence of a balance between the actual behavior of $DMII_i$ $(i = 1,2)$ and the

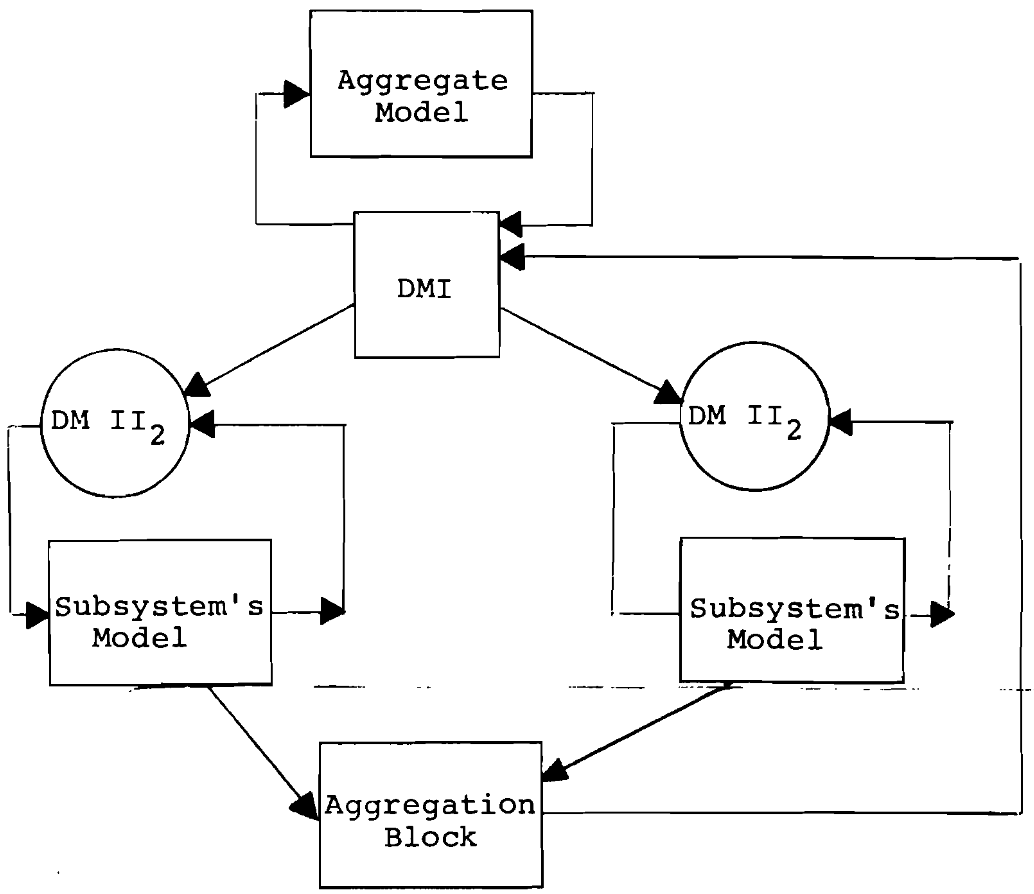


Figure 7: Decision making in multivariant hierarchy systems through the use of models.

formal objectives of behavior reflected in the aggregate model. Having cleared the causes of possible imbalance, the DMI may either alter the formal objectives according to the actual behavior of DMII or change his behavior.

It is possible that after such an exchange of opinions both the formal objectives of the $DMII_i$ $(i = 1,2)$ in the model and the nonformal objectives of the DMI are altered. After this the entire procedure is repeated and an optimal solution is sought again; this decision is reported to the $DMII_i$ $(i = 1,2)$, who in turn seeks the optimal solutions $u_1$ and $u_2$, aggregates indices, and presents them again to the DMI.

If the indices of the aggregation block essentially disagree with the indices of the aggregate model, the DMI may undertake once more the analysis of the structure and parameters both of his model and the subsystem, lower level models and repeat the procedure. At a certain stage, the difference between the indices of the aggregation block and the aggregate model may be attributed to the difference in the degrees of aggregating the models and the comparing procedure may be terminated.

## SOME EXAMPLES OF DECISION MAKER-MODEL INTERACTION IN THE MODELING PROCESS

As previously mentioned, the solution of management problems requires several models (Figure 8). Because it is impossible to describe all of these models in this paper we will discuss only three types: the regression model, the system model and the problem-oriented global model.

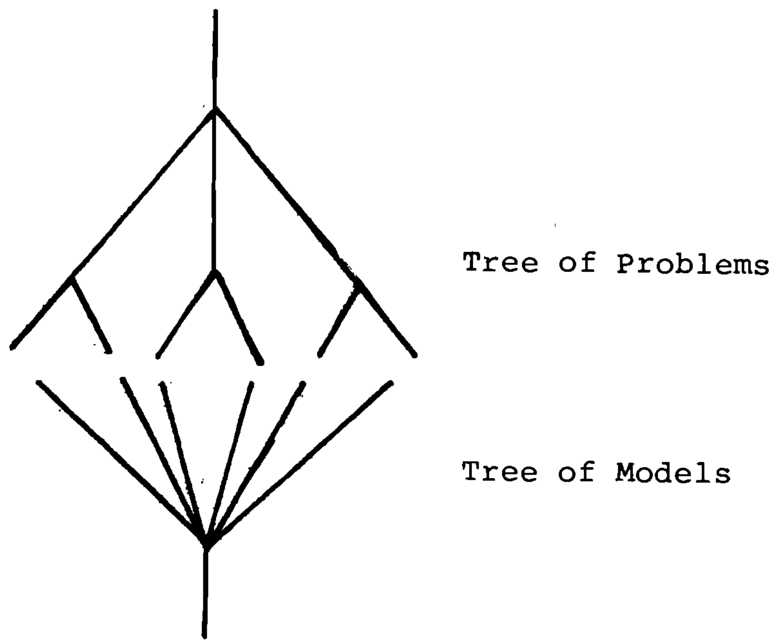


Figure 8: Tree of problems and models.

### The Regression Model

A regression model may be employed in the analysis of *short-term* forecasting of morbidity allowing for the change of environmental factors. This man-machine model is based on modified methods of regression analysis and is useful in forecasting health care indicators within a five-year period. A basic hypothesis for regressional forecasting, however, is the stability of the main structural parameters within the system.

In order to illustrate such a model, let us suppose that our objectives consist of forecasting short-term values for a number of health care system indices. A set of factors that influence the values of these indices are known. Our goal is to attain an explicit forecast for different time intervals using the statistical data of preceding years. It is necessary to stress that the modeler usually has much more information about the processes in the system than is employed in the black box approach. Also, many of the intermediate mechanisms of the processes are often known. Nevertheless, in the first stage it is more efficient to withhold some of the known information for the model building because the modeling objectives sometimes may be achieved by a rather simple model.

It would be natural to apply the methods of regression analysis to these tasks. But the classical approach leads to some difficulties. The problem is that it is not explicitly known whether all of these factors affect the indices. Using a criterion of aggreement to check an hypothesis is necessary because of the great number of factors involved and because statistical criteria are not always clearly seen by decision makers. The decision maker, as a rule, prefers to make decisions about the significance of factors himself. Therefore, the computer model must provide the manager with the opportunity of participation in the tuning process. Such an approach solves the psychological problem of allowing the decision maker to become accustomed to the model and to gain confidence in the computer model.

The linear regression approach, however, is restricted by the number of influencing factors and the quantity of the needed information for building the model.

The real links between the indices and factors may be nonlinear. The usual linear extrapolation based on previous information may lead to forecasting errors even in the presence of only small mistakes in measurements. Because of this it is advantageous to decrease the number of observation points when building the linearized model. If we have exact observations (i.e. without noise) we may build a linearized model on the basis of the measurements of only the two last time points. In practice we must use more than the last two points because the measurements derived from actual data are disturbed by noise. Therefore we need a larger number of points of observation in order to build a linearized model. The optimal number of observation points is determined by the properties of the noises and the type of nonlinearity describing the system under investigation.

In this task, the factors and type of nonlinearity are unknown beforehand. For tuning the model we suggest methods of choosing the points of observation by using retrospective data and dialogue with the manager (Figure 9). The results produced may be test forecasted, thus allowing the comparison of the model results with actual data.

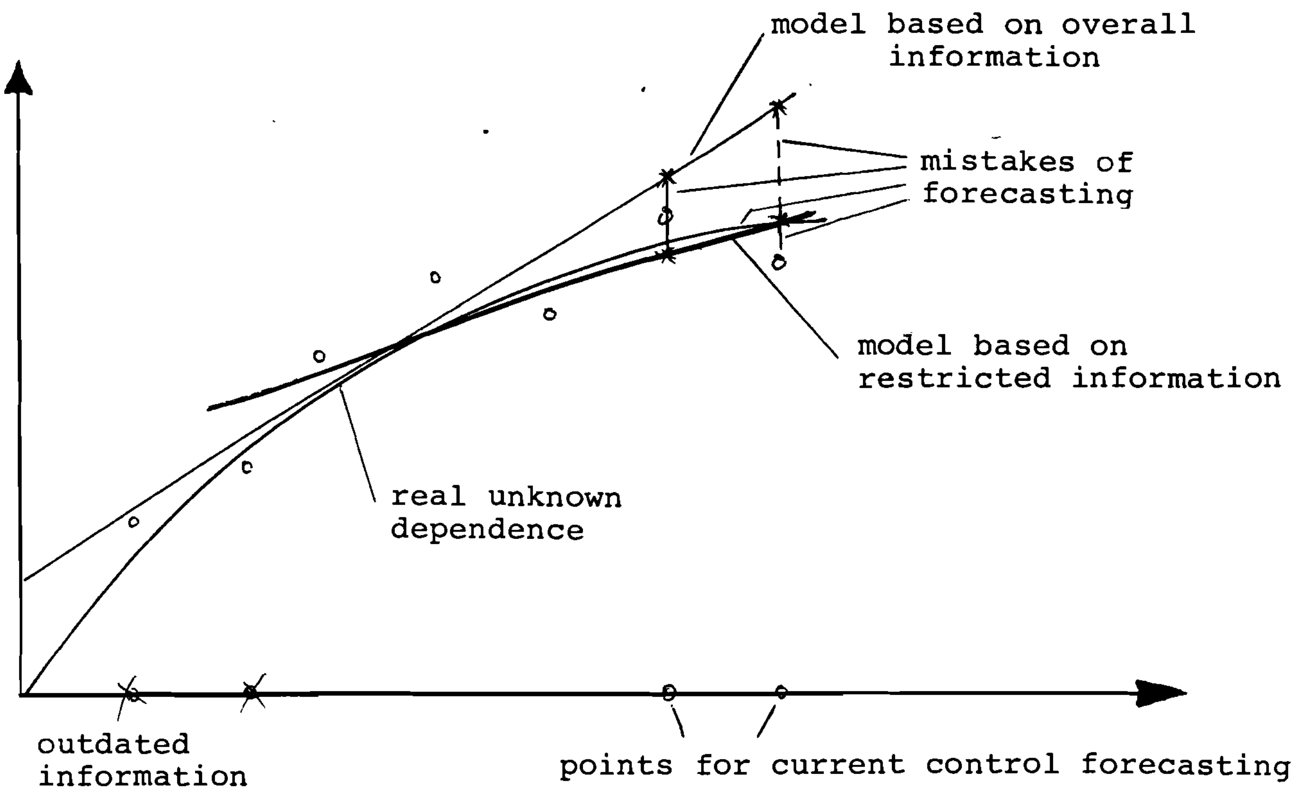


Figure 9: Short-time forecasting of non-linear dependency.

## The System Models

The second group of models is intended for *long-term* health care forecasting. For these purposes, the method of regression analysis is inapplicable because it often produces considerable divergences in long-term forecasting.

Models of this type may also be used to simulate separate diseases. They are based on the principle of dividing the population into an interacting group, corresponding to the different stages of disease and the relation to the health care system (Figure 10). For example, one model of tuberculosis epidemiology deals with a system consisting of nine population groups with functional links between them. This model enables one to make a forecast of the epidemiological tuberculosis problem while considering various preventive/curative methods. [4][5]

## The Problem-Oriented Global Models

A mathematical description of the second loop of the control system requires the use of a great quantity of information about the health of the population, the dynamics of changing factors of the environment and the influence of these factors on demographic and medical indices. [1] The use of this information in modeling health care systems is called problem-oriented modeling. The main point of this approach is to choose a more detailed description of a central problem within the model and to analyze it in detail.

We have built such a model for health care, taking into consideration the factors of technological progress and environment. We will also briefly show how the health care system influences the economics of industry and agriculture. The restricted possibilities of the health care system and the actual nonlinear feedback loops are also taken into consideration.

The indices of the performance of the health care system showing the quality of medical services are chosen. The population is divided into four groups according to its state of health:

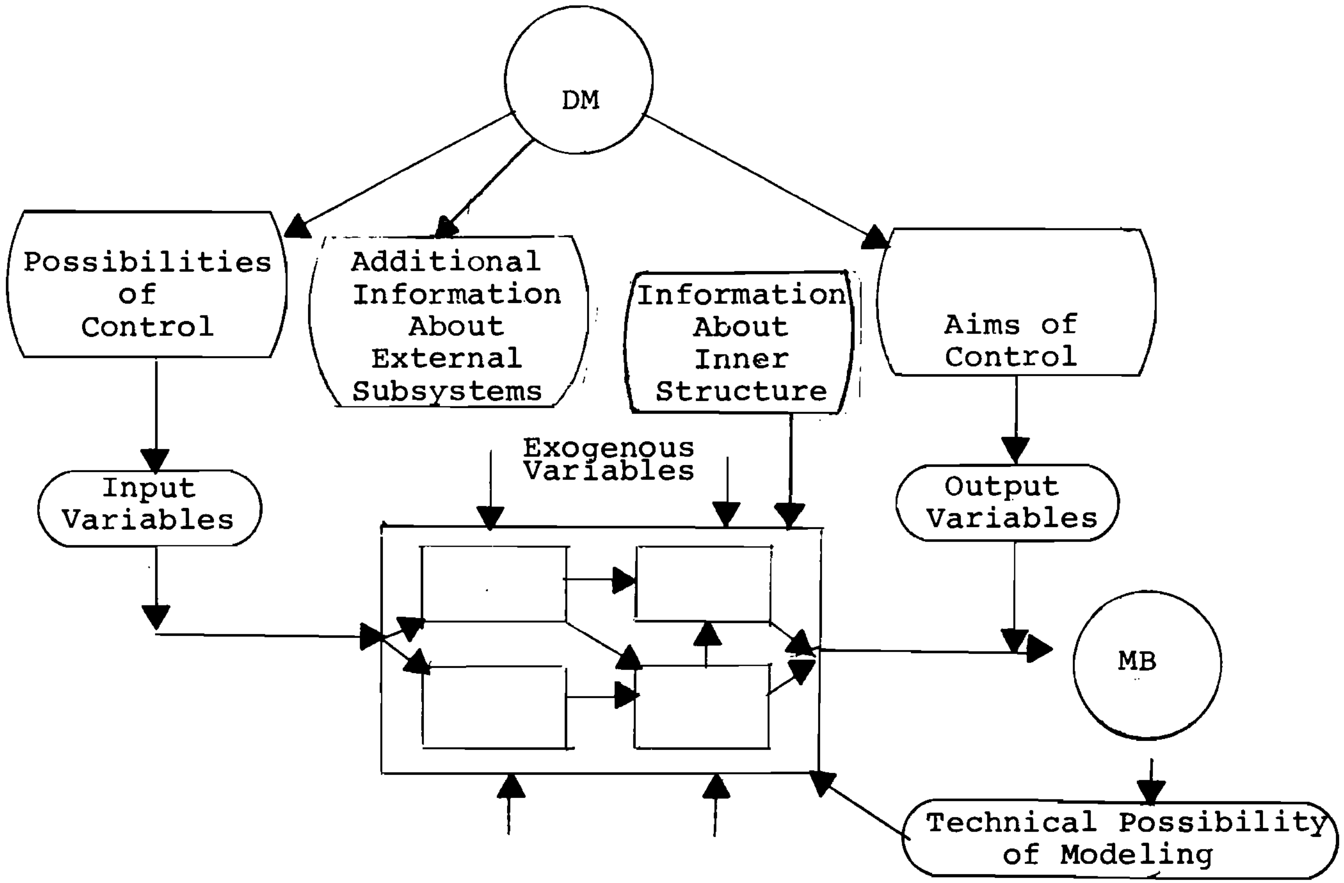


Figure 10: Problem-oriented system modeling. A calculation of exogenous variables.

- the healthy,
- the latent ill,
- the detected but treated sick, and
- the patients being treated in medical institutions.

The division of the populations by sex, age, and state of health are described in the model by the following system of partial differential equations:

$$\frac{\partial U(j,t,x)}{\partial t} = - \frac{\partial U}{\partial x} (j,t,x) \sum_{j=1}^{K} q_{ij}(x,\vec{U},\vec{Z},R)\, U(j,t,x)$$

$$U(i,x,0) = f_i(x),\ U(i,0,t) = \sum_{i=1}^{K} \int_0^{\infty} \phi_{ij}(R,x,t)\, U(i,t,x)dx$$

where $K = 4$ is the number of state-of-health categories, and $U(j,t,x)$ is the number of population in the state-of-health category in age x and at time t. $q_{ij}(x,\vec{U},\vec{Z},R)$ is the transient probability depending on the general case of the vector $\vec{U} = (U(1,x,s) \ldots U(K,x,s))$, $0 \leq X < \infty$, $s < 0 \leq t$, R are external factors and $\phi_{ij}(R,x,t)$ is the fertility function.

The influence of pollution on the environment and nutrition are considered by the coeffients $q_{ij}$. The outputs of the system, in their turn influence such external forces as labor resources and indices of social performance in health care. Labor resources are divided into industry and agriculture. The models of these subsystems are specified with Cobb-Douglas production functions. The effects of industrial activities can be related to environmental pollution and the effect of rural agriculture can be related to the supplies of nutrition to the population of the region.

## CONCLUSION

Success in the development of improved health care models depends on all of the elements involved in the modeling process (Figure 11). There are many problems linked with the participation of the decision maker in the modeling process. However, if one acknowledges that the decision maker can make good use of a set of computer models, in order to derive the appropriate models, one must first classify the decision maker according to his job description and then create a standard set of models for the management of standard problems.

The educational level of both the decision maker and the model builder is also very important and therefore it is necessary to use them both--first in system analysis methodology and, second, in understanding the health care problem. Otherwise the initial mental models of the health manager and the model builder will be quite different and their collaboration will be much less effective.

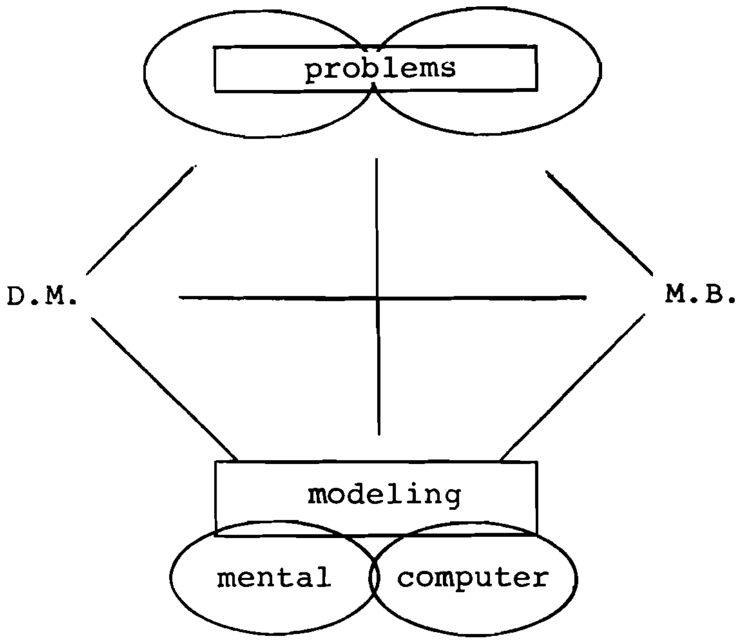


Figure 11: Elements in the modeling process.

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