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MODELING OF PUBLIC HEALTH: CALL FOR INTERDISCIPLINARY ACTIONS

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PREFACE

Under the auspices of the project, Adaptive Resource Policies, IIASA personnel carried out a number of exploratory workshops that translated policy concerns and the expertise of a client group into a preliminary microcomputer simulation model. These models served several purposes:

They helped the clients identify and agree upon the most essential parts of their problem. They provided a tool for communicating the problem to others. They became the basis for additional workshops and subsequent research activities. In several cases the ARP models were extended and refined until they became credible instruments for scenario development and even policy assessment.

In March 1982 the Slovakian Deputy Minister of Health requested that an ARP team work with a group of Czech medical specialists on a preliminary assessment of health problems related to the environment. The workshop took place in April 1983 in the Bratislava Research Institute of Medical Bionics, which has subsequently collaborated with IIASA on an extension of the work.

Out of that meeting came a preliminary model that quantifies preliminary theories about the relationships between environmental factors and the incidence of hypertension and diabetes. This paper first provides a general summary of historical trends that lay behind the concerns which engendered the workshop. It describes the model, provides an equation listing, and shows a variety of illustrative runs.

Dennis Meadows
Integrative & Special Studies Project

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ABSTRACT

Health care systems today confront a range of diseases for which preventive measures lie outside traditional therapeutic medicine. The variety and multicausality of illness forms are closely related to the differences among people, especially social, economical and other conditions of their lives. The activities of many institutions which are not directly involved in health regulation, influence public health today. These facts apply also to the scale of possible control actions.

Joint effects of population heterogeneity and the hierarchical nature of public health regulation seem to have led naturally to the current mix of problems and also seem to indicate that only more holistic approaches will improve the situation.

One of the problems, how to overcome interdisciplinary barriers and organize effective preventive measures, may be solved only by joined efforts of social and economical institutions directly or indirectly responsible for the modern pattern of diseases. Workshops with computer modeling seem to be an appropriate instrument for developing interdisciplinary collaboration. The results of an experiment with the Slovakian Ministry of Health suggest that intensive modeling workshops involving health care planners, physicians, and other experts lead to better problem formulation and policy analysis.

CONTENTS

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INTRODUCTION

Health care planning over the next few decades will encounter a new set of complex problems. Improvements in sanitation and hygiene as well as advancements in modern therapeutic medicine have produced impressive results in reducing human mortality rates. However, some new problems cloud the horizon. In the U.S., for example, health care costs are escalating rapidly. Some experts attribute these accelerating costs to technological innovations requiring more and more costly machinery (e.g. Rifkin 1979). Despite these therapeutic innovations, physicians now must deal with an increasing array of diseases that have complex origins that are largely outside the domain of traditional medical practice. Faced with these problems, those agencies or individuals charged with regulation or planning of public health programs must contend with the basic sources of uncertainty. How to improve public health when the combined effects of existing medical programs, socio-economic influences, and environmental pollution are poorly understood is a dilemma faced in all industrialized nations and a growing one in the less developed regions of the world.

What is clear about current and future public health planning is that explicit recognition of the hierarchical and multicausal nature of the problem is required. Groups of individuals have varied susceptibility to a wide range of risk factors, and medico-demographic analysis of them must recognize this heterogeneity if it is to provide a reasonable guide for intervention. Implementation of public health policies occurs in a hierarchical health delivery system. Success of any policy may well depend upon where and how it is introduced in this hierarchy. Finally, public health management is itself embedded in a larger environmental and socio-economic milieu. Many possible public health interventions may, in fact, lie in this domain, and thus interdisciplinary or interjurisdictional collaboration will be required.

In this paper, we give our interpretation of some of the problems confronting public health care managers. We then summarize our experience with a possible approach to aiding this decision making process. Finally, we examine priorities for future work.

CHANGES IN PUBLIC HEALTH: FAILURE OF GERONTOLOGICAL SUCCESSES

Demographic consequences have been the main criteria of success of public health programs. The steady increase in life span over the past 150 years is certainly a good example. Average life span in the world as a whole has about doubled in this period, and is continuing to increase in many countries (Figure 1). While many experts believe that the ability to increase longevity is far from exhausted, there are signs that life spans, particularly in industrialized countries, began to peak in the 1950's (Rifkin 1979).

Underlying the increase in longevity over the past 50 years has been a shift in the relative importance of various disease categories (see Table 1). In the beginning of our century approximately one third of all deaths were caused by infectious diseases. Currently only about 5% belong to that category and the majority are of acute respiratory tract type (World

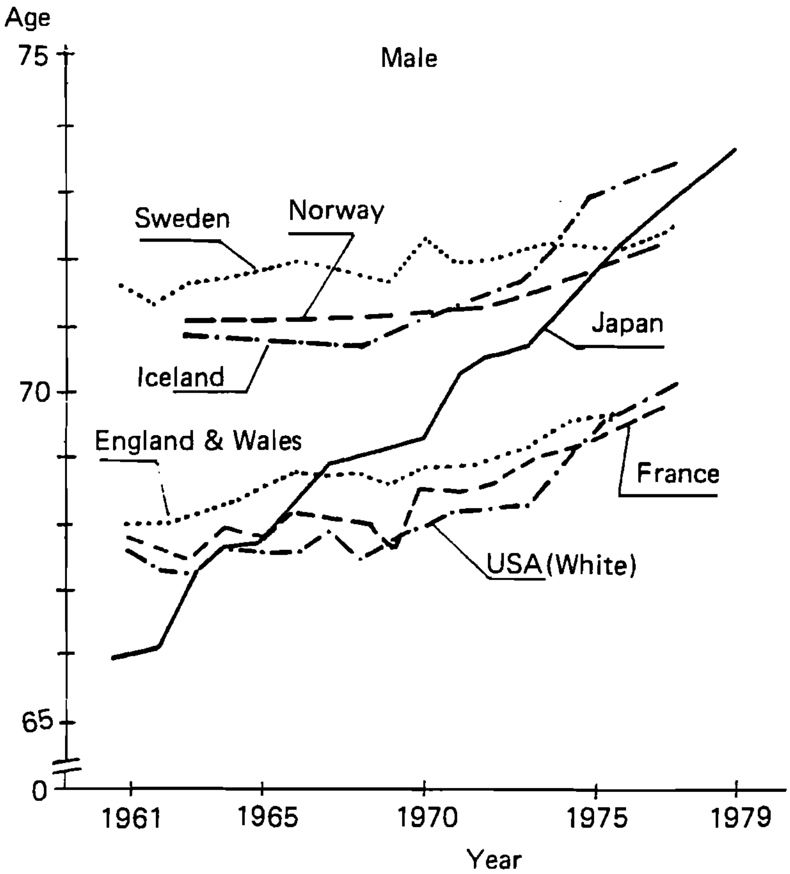

Figure 1. Life expectancy continues to rise. (Source: UN Demographic Yearbook. 1980. New York: UN Office of Publications.

Health Statistics Annual 1981).

The spectrum of patients dying from such infectious causes has been shifted to the groups of elderly people and premature births. There is no longer the threat of fatal dissemination of tuberculosis in young people, nor the threat of widespread epidemics of typhoid, measles or plagues. The main action taken to get these diseases under control was to improve living and working conditions of a wide range of inhabitants. See Table 2.

This has been confirmed by several authors (Dubos 1965; McKeown 1965; McKeown 1971; Shryock 1969; Miller 1981; Podluzhnaya and Shilova 1982; Breslow 1982). Introduction of sanitation methods as well as regular quality checking of food and water, have resulted in relieving many epidemics. But impairment of hygiene standards during the First and

Table 1. Death Rates for Leading Causes of Death in Death Registration States, United States, 1900 and 1950.*

1900**		1950***	
Cause of Death	Rates per 100,000	Cause of Death	Rates per 100,000
All Causes (total)	1719	All Causes (total)	964
Pneumonia, influenza	202	Diseases of the heart	356
Tuberculosis	194	Malignant Neoplasms	140
Diarrhea, enteritis	143	Vascular lesions affecting central nervous system	104
Disease of the heart	137	Accidents	61

*The Death Registration Area did not include all states until 1933.
**First Revision, ISC, 1900.
***Sixth Revision, ISC, 1948.

Source: National Office of Vital Statistics. 1950. Vital Statistics of the United States. Vol.1,8:403. P.209.

Second World Wars was immediately accompanied by new epidemics. Tuberculosis and scarlet fever withdrew together with the improvement of quantity and quality of food and housing and the introduction of immunization methods and isolation of people sick long before chemotherapy and antibiotic therapy was developed. The widespread use of antibiotics has led to a significant decrease of mortality and incidence of complications of rheumatoid fever. Prevalence of this sickness is shifted now to the group of elderly people, born in the first decade of our century.

Chronic diseases have become the main medical problem for citizens of developed countries. In the year 1967 in about 50 countries of the world, cardiovascular diseases caused an average of 37% of all deaths, a higher incidence than deaths caused by cancer, accidents or infectious diseases (World Health Organization 1967). This trend can be seen in Figure 2.

Table 2. A Strategy for Improvement of Health.

Health Problem	Medical Care Measures	Environmental Measures	Behavioral Measures
Trauma from automobile accidents	Ambulance and first aid service Emergency medical service Definitive medical care and rehabilitation	Construction of streets and highways Design and construction of automobiles Road signs and obstacles • Regular • Special circumstances	Driver training in vehicle manipulation Avoidance of alcohol and other drugs before driving Avoidance of driving during adverse psychologic states, e.g., fatigue
Dental caries	Dental care	Fluoridation Reduce production and promotion of refined carbohydrates	Prudent diet Brush teeth
Myocardial infarction	Screen for and treat risk factors Ambulance service Coronary care units	Alter food supply to reduce intake of foods that raise blood-cholesterol level	Exercise Prudent diet Stop cigarette smoking
Lung cancer	Detect and treat disease early	Reduce occupational exposures that cause lung cancer Reduce production and promotion of cigarettes	Stop cigarette smoking
Infant deaths	Routine pediatric care	Maintain hygiene in home Assure safe water supply	Good diet Proper mothering

Source: Breslow, L. 1973. A Research Strategy for Health. International Journal of Health Services 3:7-16.

The differences between chronic debilitating diseases and infectious sicknesses is not in etiology alone but in therapy and preventive methods as well. The characteristic feature of these diseases (i.e., inception hidden in maturation, manifestations occurring in middle age, and significant health impairment in the elderly) leads to an interaction with the process of aging. This constitutes a paradox situation: the average life expectancy is increasing, but the prevalence of disease and the risk of getting sick is growing as well. This produces the increase in numbers of long time hospitalizations, demand for nursing homes and rehabilitation, and, in the majority of cases, retirement from employment. The

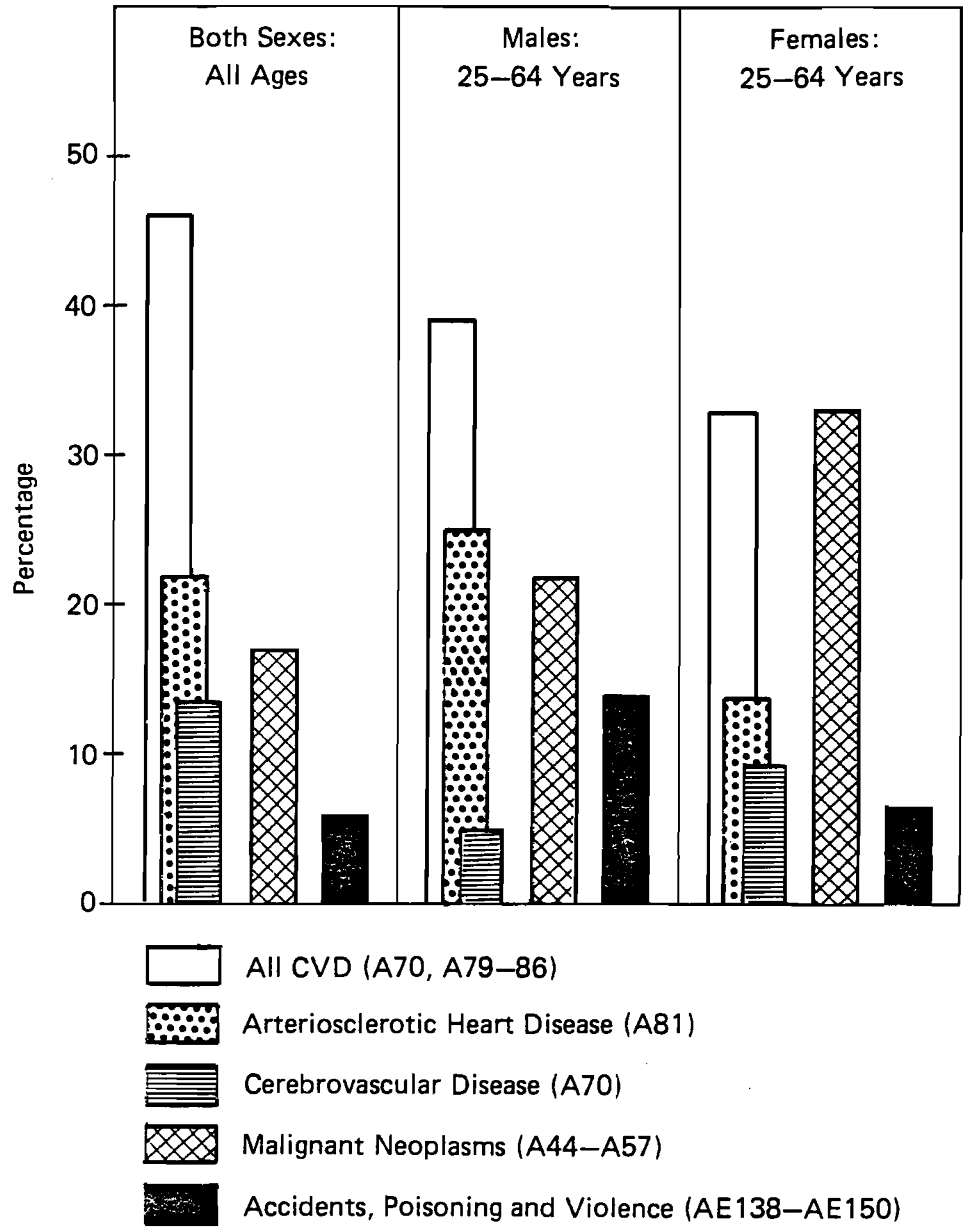

Figure 2. Major causes of death as percentages of all deaths.

most frequent of these types of diseases are nonfatal heart attacks, chronic decompensated ischaemic heart diseases, strokes, etc. The number of people with diffuse brain diseases as a result of arteriosclerosis is significantly rising, too. Patients are gradually losing their working ability and in many cases a psychiatry or neurology department is the last station. Many fatal cases of neoplasma need from months to years of treatment before death. In cases of possible successful surgical, radiotherapeutical, or chemotherapeutical treatment, people are left for long lasting sick leaves and special care (Powels 1973). Detailed analysis of cancer incidence and stage of development at the time of diagnosis indicates that the decline in death rates in middle age categories is a result of improved treatment, largely improved chemotherapy. This is in contrast to the increase in cancer mortality in older subjects. (Frei 1982).

The current mortality in people younger than 15 years has decreased to 95% of the level in 1900. The decrease was only 30% in people older than 65 years (USPHS 1979). This trend is displayed in Figure 3.

The growing percentage of older people in the population sets new demands on the whole society and especially on the health care system: for people over 65 years old, the frequency of visits payed to a physician is twice as high as for younger people. Aged people spend 3.5 times more bed-days in the hospital. On the contrary they suffer less from acute diseases compared to members of the younger generation. Nevertheless the average duration of disease is significantly longer compared to younger age categories, a situation probably caused by the longer recovery period (Harris and Cole 1980). As a result, increased hospital care for the chronically ill is a direct result of an increasing number of old people. In Sweden, for example, 50% of hospital investment goes to care for 4% of the population (Hall 1977). Unfortunately, many health care systems are not adequately prepared for the health care needs of elderly suffering from chronic diseases, and the success of eliminating acute diseases as causes of mortality has only led to new, unanticipated problems for the health care systems.

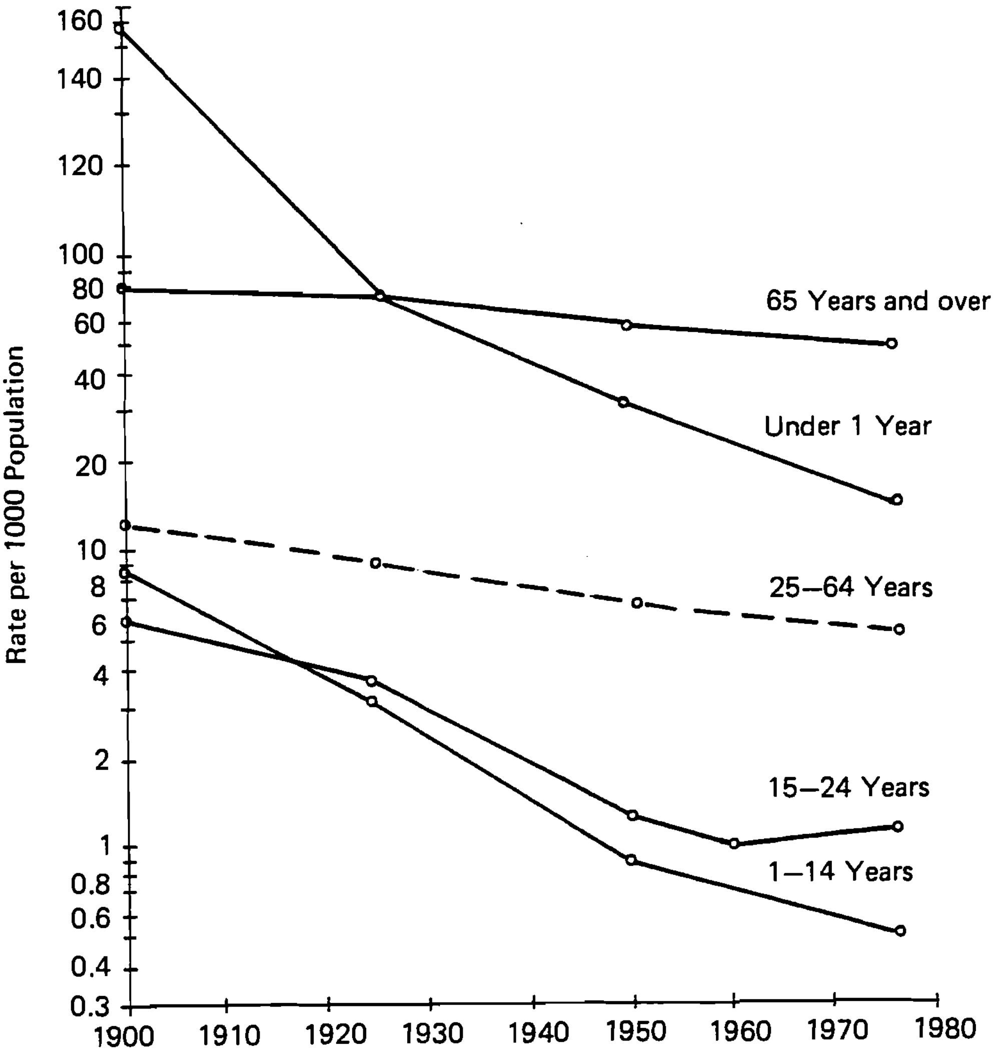

Figure 3. Death rates by age: United States, selected years 1900-1977.

CHRONIC DISEASES: SIDE EFFECT OF DEVELOPMENT?

Origins of chronic diseases are poorly understood. Life style, nutrition, housing, employment, environmental pollution, and stress are some of the factors thought to influence the onset of chronic disease. Association between economic fluctuations and life stress have been identified in Great Britain as possible causes of fluctuations in mortality rates (Brenner 1979). Not only is identification of cause of disease difficult, but these same factors may be associated with different diseases.

In fact, it is not uncommon for elderly individuals to suffer from more than one chronic, degenerative disease. Realizing that most contributing factors to onset of chronic disease lie outside therapeutic medicine means accepting the inability of most health care systems to provide major preventive measures against most modern diseases. Simply decreasing mortality only leads to increasing the prevalence of chronic diseases and creates additional problems for health care institutions. It would seem that the only way out of this cycle would be to view public health regulation in a wider context and stress interdisciplinary solutions to new problems.

Etiology of chronic diseases differs substantially from etiology of communicative illnesses. There is usually one main identifiable causal agent in infectious disease etiology. The other factors, such as the overall status of an organism, environmental influences, etc., play their roles in the sickness process, but the principle cause is always unique. In the case of chronic diseases several different factors were discovered affecting the development of the disease process. This so-called multiple causation incorporates a wide range of factors, neither one of them a condition *sine qua non* for manifestation of sickness. This makes the primary cause usually unidentifiable (Miller 1975).

MULTICAUSALITY OF CARDIOVASCULAR DISEASES

During the past decade intervention programs against cardiovascular disease in the developed countries have suddenly become popular. Breslow (1983) explained three reasons for this tendency:

- the great importance of cardiovascular disease in the mortality picture of the developed countries;
- recognition and acceptance of several factors in heart and other cardiovascular diseases against which action can be taken;

- evidence that the death rate from cardiovascular diseases is dropping in several countries (Table 3).

Epidemiological studies such as the Framingham study (USA), North Karelia study (Finland), Project Kaunas (Rotterdam), and the study in the Institute of Clinical and Experimental Medicine (Czechoslovakia), bring more light to the problem of causality by identifying risk factors of cardiovascular diseases. In 1980 an effort to compare trends of Coronary Heart Disease mortality with reference to hypertension, cigarette smoking and diet was performed in Australia, USA, England and Wales (Dwyer and Hetzel 1980). There has been a leveling off of smoking in Great Britain in middle-aged and older men (but not in women where smoking rates have increased) since 1950 when there began a progressive slight fall in overall Coronary Heart Disease mortality. (Although there is evidence of a recent rise in younger women.) With regard to improvement in mortality, changes in smoking habits appear to correlate better than decrease in hypertension. Even better correlation was found with food consumption trends; there is some support for this from dietary intervention studies as well. These studies suggest that the substantial decline in Coronary Heart Disease mortality in the USA and Australia correlates with life style changes, particularly in relation to diet and smoking. Similar conclusions have already been drawn for Great Britain (Florey, Melia and Darby 1978) and for the United States (Walker 1977).

The above mentioned Framingham study (Shurtleff 1974) has shown that patients with arterial hypertension suffered

- 2 times more from diseases of peripheral arteries
- 3 times more from ischaemic heart disease
- 4 times more from congestive heart failure
- 7 times more from stroke

than so-called healthy people.

Table 3. Mortality Rate for Coronary Heart Disease, Men Age 35-74, 1969-1977.

Country	1969 Rate	1977 Rate	% Difference
DECREASE			
United States	864.7	669.5	-22.6
Australia	843.7	683.1	-19.0
Canada	703.3	624.1	-11.3
Israel	653.3	581.0**	-11.1
Norway	582.9	537.1	-7.9
New Zealand	773.3	747.1	-3.4
Japan	126.3	102.6	-18.8
Belgium	446.1	426.8**	-4.3
Finland	893.7	878.0**	-1.8
Scotland	813.7	808.6	-0.6
Italy	313.0	309.6*	-1.1
INCREASE			
Bulgaria	299.3	423.5	+41.5
Poland	186.5	307.7	+65.0
Northern Ireland	782.4	867.1	+10.8
Romania	170.5	237.3	+39.2
Hungary	441.6	499.2	+13.0
Yugoslavia	185.0	227.6	+23.0
Sweden	523.9	560.1	+6.9
Ireland	662.2	697.7*	+5.4
German Fed. Republic	427.3	458.1	+7.2
Austria	428.3	455.3	+6.3
Switzerland	290.4	312.7	+7.7
Netherlands	478.7	500.5	+4.6
France	195.2	206.9**	+6.0
Denmark	566.1	576.3	+1.8
England and Wales	662.1	671.7	+1.4
Czechoslovakia	587.9	590.4*	+0.4

ICD 410-414, 8th Revision.

Rates, per 100,000 population are average of the rates for men age 35-44, 45-54, 55-64, 65-74.

*1975 data
**1976 data.

The epidemiological studies of Stamler (1973) showed that overweight people in the age category of 20-39 develop hypertension twice as frequently as people with normal weight, and 3 times more frequently than underweight people. In the age group of 40-46, the frequency of hypertension is 50% greater compared to the population with normal weight, and 100% greater compared to underweight people.

Because the incidence, prognosis and mortality of Ischaemic Heart Disease may have different risk factors, they were studied in the Finnish male population according to marital status and social class The highest mortality rate was found among unskilled workers, the highest incidence among widowers and those in the lower professional classes, and the lowest survival rate among divorcees, single persons, and unskilled workers. The ratio of mortality by marital status
/1.77/ was in part due to survival (ratio /1.44/) and in part due to incidence (ratio /1.32/). The ratio of mortality for professional groups /1.44/ seemed to be due more to differences in incidence (ratio /1.36/) than to differences in survival (ratio /1.18/). The distribution of conventional risk factors of Ischaemic Heart Disease by marital status and professional groups seems to explain only part of the mortality differences.

ETIOLOGY OF CANCER

Cancer is another nightmare for human beings. Its epidemiological patterns have shown certain changes in recent years in most countries in the world. Relation of the onset of this disease to risk factors does not fully explain the mechanism of development of this illness. Nevertheless, studies of different risk factors have brought evidence that preventive actions could lead to better treatment. As an example of how the different factors affect cancer, we chose a Japanese epidemiological study done in 1979 (Hirayama 1979). A series of retrospective and prospective studies in Japan clearly showed a relationship of diet to stomach cancer: significantly higher risk in those people eating salty foods such as pickles and fish in every meal, and a significantly lower risk among those who drink two glasses of milk daily. The relative risk of stomach cancer in daily smokers compared to nonsmokers was 1.58 in males.

The 10-year follow-up results of the prospective epidemiological study for a large adult population in Japan (1965-1975) showed that the colon cancer ratio tends to be higher in those who consume a smaller amount of rice daily. However, an ongoing prospective study shows no elevated standardized mortality ratio for colon cancer in daily meat consumers. Neither smoking nor drinking is strongly associated with colon cancer.

Lung cancer mortality has been increasing rapidly in Japan and all over the world as well. Daily cigarette smoking showed up as the most important cause of lung cancer in the ongoing prospective study, the relative risk and attributable risk being 3.76 and 67.2% respectively, in males. Those who started smoking at a younger age tended to show a higher death rate for lung cancer. Lung cancer morbidity is also influenced by occupational factors, such as those experienced by metal workers.

In Finland, the leading types of cancer in males were cancer of the lung, stomach and prostate (30.9, 19.6 and 8.3% of all new cancer cases), and those in females, cancer of the breast, uterus (corpus and cervix combined) and stomach (18.8, 13.0 and 12.2% of all cases) during the years 1966-1970 (Teppo, Hakama et al. 1975).

The incidence rates of lung cancer and cancer of the larynx in males were much higher in Finland than those in Denmark, Norway and Sweden. This was also applicable to cancer of the stomach. However, the incidence rates of cancer of the breast, prostate, colon, and rectum were comparatively low in Finland. The incidence of breast cancer has increased continuously. In recent years cancer of the cervix uteri has been decreasing. The decreasing and increasing trends of various cancer types compensate each other, resulting in an almost unchanged trend in the total cancer incidence in both sexes.

Correlation analysis between the values of background variables and incidence rate showed that the degree of urbanization and the standard of living had a positive association with the risk of cancer of most primary sites. The association was strongest for cancers of the kidney, colon and breast (Teppo, Pakkala et al. 1980).

All external reasons mentioned above influence the human being together with internal biological factors (Emmanuel and Evseenko 1970). Aging processes of individuals result in the general debilitation of the human organism and increase the chances of contracting both chronic and epidemic illness. The details of interaction among all of these factors are still the subject of studies in many gerontological institutions (Chebotarev 1978).

HEALTH REGULATION: DISTRIBUTED RESPONSIBILITY

We summarize our view of the wider context of public health regulation in Figure 4, concentrating mainly on chronic diseases.

The object of attention, of course, is an individual, and within any region or nation individuals may be classified as ill or healthy from the perspective of the primary health care system. All health care systems are derived from the socio-economic systems, and thus our scheme can not be considered a correct description of the relationship between health care and social systems. Rather, our purpose is to expose different areas of responsibility as they currently exist in health care systems. Healthy individuals, i.e. those not under treatment for some disease, are on this scheme outside the health care system. Their health is a function of their life style, nutrition, employment, and other factors that are influenced by a socio-economic system. Each of these systems is in turn influenced by a more general environmental system. From an individual's perspective, however, regulation of chronic disease occurs in three distinct mechanisms: biological processes within an individual, curative and preventive in the tradition of clinical medicine, and public as represented by socio-economic influences on life style and other risk factors. Some mathematics representing the relations mentioned above may be found in Yashin, Manton and Vaupel (1983).

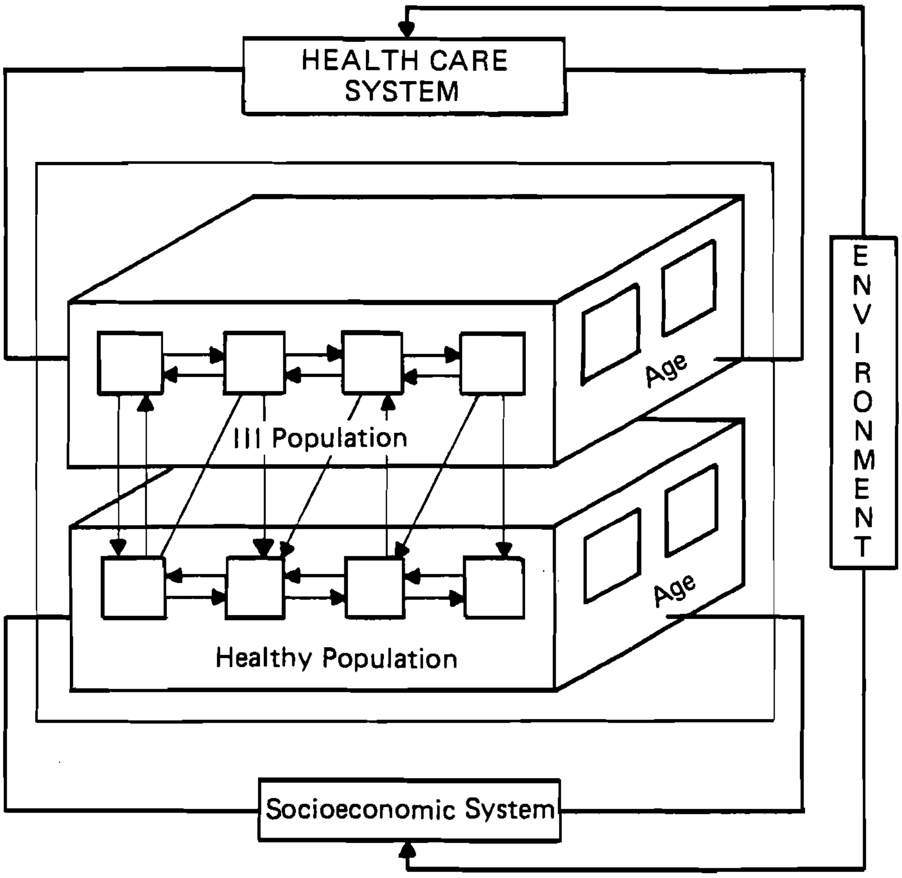

Figure 4. Mechanism of public health regulation.

These three mechanisms are, of course, hierarchical and respond to different control interventions. The low level is purely biological. Regulation is homeostatic and mediated by physiological processes. For the most part, the functioning of these control mechanisms is well understood, and this understanding forms the basis for much of therapeutic interventions by physicians. The next level in the hierarchy is the primary health care system. Its individual components are health care personnel (doctors, nurses, adminstrators, etc.). It has its own institutional structure as well, and interventions occur through training and distribution of medical manpower, production of drugs, and building of medical facilities. The objective of this level usually is restricted to treatment of disease conditions that overwhelm the lower level. The third and third and overlying level is socio-economic and cultural. It consists of the population, health care management bodies, higher governmental institutions and other systems that cannot be included in the health care systems but have an impact directly or indirectly on the health status of the population. One of the main functions of the health care management body at this level is to signal to the higher governmental institution possible consequences of unfavorable effects of life style, stress, or other factors outside control of the health care system. This is an advisory role only. In fact, at this level, responsibility for public health is distributed, often with no clear authority for intervention.

From a historical viewpoint, it is clear that these mechanisms can act in concert or in conflict. The existence of feedbacks makes this hierarchy work, and often differences in time scales of response determine the overall harmony of public health regulation. A particular disease may be attached with various control measures. For example, public immunization programs may be initiated by the health care system to prevent it. An alteration of budget for health care systems may affect the efficiency of medical services appropriate to the disease. Finally, improvement of living conditions can raise the resistance level of individual immune systems. At the same time, we emphasize that these three levels of public health regulation respond to different problems. We believe that it is this difference in "problem" perception that, in part, leads to the current dilemmas facing public health regulation.

Difference in problem perception also implies difference in tolerance of risk. A more general socio-economic system, for example, cues on very general measures of population health and causes of mortality. Recognition of a problem and reaction to it may require a period of many years. Risk perception at this level is influenced to a great degree by informal social and psychological tendencies of the population to accept risk together with the dissemination of knowledge (Yashin 1983a,b). It is to be expected, therefore, that different nations should have different priorities in solving problems at this level. The health care system, in contrast, perceives problems in the context of the observed spectrum of diseases. The objective of medical practice is the elimination of disease, and risk is measured in terms of individual probabilities of mortality due either to treatment or disease condition. The notion of risk, of course, disappears at the individual biological regulation level, but the basic problem of survival at this level is strongly influenced by conditions that are generated by the health care system, socio-economic system, and the natural environment.

The challenge to public health management is to balance these levels harmoniously. It is not simple, however, to anticipate the consequences of a control action in such a complex system. Given the variation in time scales of response and problem orientation, it is not too surprising that the overall system is more often inharmonious. The reason is simple: solution of problems at one level may create unanticipated problems at another level or contravene solutions at the other levels. As will be discussed more below, some successful medical solutions of health problems may degrade measures of the survival of the entire population. Abuse or inappropriate medical treatment can lead to iatrogenic diseases, that is diseases caused by the treatment itself. It does not take much imagination to enlarge this list. Chronic diseases themselves are substantial examples of the difficulties created by uncoordinated activities of institutions.

Despite this current condition of public health management, human social systems are fundamentally *adaptive*. They should be able to cope with new problems. Compensation and risk reduction are, therefore, to be expected of any such system if it has enough adaptation abilities. A recurring theme in the analysis of human systems is the worry that change in the human environment is becoming too fast for reaction to problems. If public health management is to deal with future problems effectively, then it must find ways of coordinating solutions to public health problems that explicitly recognize the hierarchical, multidisciplinary constraints on solutions.

POPULATIONS HETEROGENEITY: BASE FOR POLICY DESIGN

Success of public health policy is often judged by demographic consequences. Because of fundamental heterogeneity of human populations, however, gross demographic characteristics may belie developing problems. The basis of heterogeneity analysis, from a medical point of view, is variation among groups of individuals in susceptibility to various causes of mortality. Vaupel, Manton, and Stallard (1979) and Vaupel and Yashin (1983a) have proposed frailty as a convenient way to characterize population heterogeneity. Their analysis assumes that human populations may be divided into a finite number of groups, and to each group a frailty index may be calculated from the relative risk of death. These and other ways of characterizing population heterogeneity have traditionally focused on age and sex groups, but clearly other groupings are equally if not more important for public health planning.

Justification for explicit consideration of population heterogeneity by health care managers is supported by some unexpected results of heterogeneity analysis. Population structure is dynamic and changes with variation in environmental, socio-economic, or medical factors. Differential response of groups within the population determine changes in population structure, but these changes may be difficult to explain without explicit consideration of the appropriate description of subpopulation structure. The reason for this situation is that cause and effect relationships are obscured by changes in relative size of different groups in the population, and simple correspondence between a policy and population response may not follow. Vaupel, Manton, and Stallard (1979) showed how overcrossing or convergency of cohort, age-specific mortality curves for whites and blacks in the USA was an artifact of heterogeneity in these groups. Assuming the existence of heterogeneity in frailty of a population, therefore, policies directed toward decreasing overall mortality require complex analysis of population structure. Without it, solution of one problem is likely to lead to still other, perhaps more difficult, problems.

An additional dimension to the heterogeneity problem is the existence of a variety of risk factors. Each risk factor creates its own endowment in mortality. If all risk factors are independent, the elimination of a single risk may be calculated in a straight-forward manner (e.g. Preston, Keyfitz, and Schoen 1972). If (as much evidence suggests) risk factors are not independent, the effects of the elimination of the same risk factor is not so simple. Analysis by Vaupel and Yashin (1983a) showed that single risk factor elimination could either increase or decrease the probability of death due to another factor. This result implies that *the relation among cause factors needs to be explored prior to policy implementation.* Possible interdependence of risk factors coupled with population heterogeneity thus suggests that new methods may be needed to aid qualitative analysis of policy implications (Yashin 1983a,c).

A simple example helps illustrate some of these ideas. Assume that a population consists of two groups. A "weak" group has a higher mortality rate and higher birth rate than a "strong" group. Further assume that before the implementation of a medical program, both groups are in equilibrium. Medical intervention intends to decrease mortality of the "weak" group. Success in decreasing their mortality rate will lead to an increase in the number of "weak" individuals and, thus, to an increase in the proportion of the population in the "weak" group. It is easily demonstrated that the total mortality, rt in the population is the weighted sum of the mortalities of the two groups, rw and rs. Because the proportion of "weak" individuals increases under treatment, the average mortality rate of the population will approach the mortality of the "weak" group through time. (For more details see Keyfitz and Beekman 1984.)

A variation of these conditions can show how average mortality rates may decrease for a time and then begin increasing. Assume that intensive social, economical, and medical transformations result in general improvement of living standards and health care for everyone. A case in point is the intensive efforts to bring acute diseases under control during the first 50 years of this century. In Figure 5a, the result is that mortality rates rs, rw, and rt (population mean) drop to rs', rw', and rt'.

Later, health care interventions primarily benefit the "weak" group. Their mortality rate then moves from rw' to rw''. The proportion of "weak" individuals in the population will now increase and the mean mortality rate for the population, rt', will move toward rw''.

The most surprising result of this example is that successful implementation of some social or medical programs may actually decrease life expectancy at older ages. In Figure 5b, we assume that $us(x)$ and $uw(x)$ are the age specific mortality coefficients for the "strong" and "weak" groups respectively. The average age specific mortality of the population as a whole, $ut(x)$, will lie somewhere between $us(x)$ and $uw(x)$, depending upon the proportion of the population in the "weak" group. Suppose that socio-economic development and medical efforts change the $uw(x)$ to $uw'(x)$; again with the consequence that the proportion of "weak" individuals increases in the population. It is then expected that the average age-specific death rate, $ut'(x)$, will tend to the value of $uw'(x)$ with time. Because $ut'(x)$ is higher than $ut(x)$ for any age group, the life expectancy from any age x on will be lower after treatment.

This example, of course, is a bit oversimplified. Nevertheless, more realistic cases can be subjected to similar types of analysis. Where more realistic cases have been examined (e.g. Vaupel and Yashin 1983a), some apparent patterns in mortality change can be shown to be consequences of fundamental heterogeneity in the population. Some other results of heterogeneity can be found in Vaupel and Yashin (1983b). Policy implications are clear: ignoring effects of heterogeneity in evaluating health care interventions can give unreliable indicators of program success.

We have so far argued that current dilemmas confronting public health planning originate with the hierarchical nature of health care regulation and the heterogeneous character of human populations. That public health planners now confront the current spectrum of problems would seem to be a natural consequence of health care initiatives taken in absence of a holistic view of the problem setting. Yet the reality of stress on traditional therapeutic medical solutions is apparent, and new, innovative solutions are required. Holistic views, however, are often easier to propose than to implement.

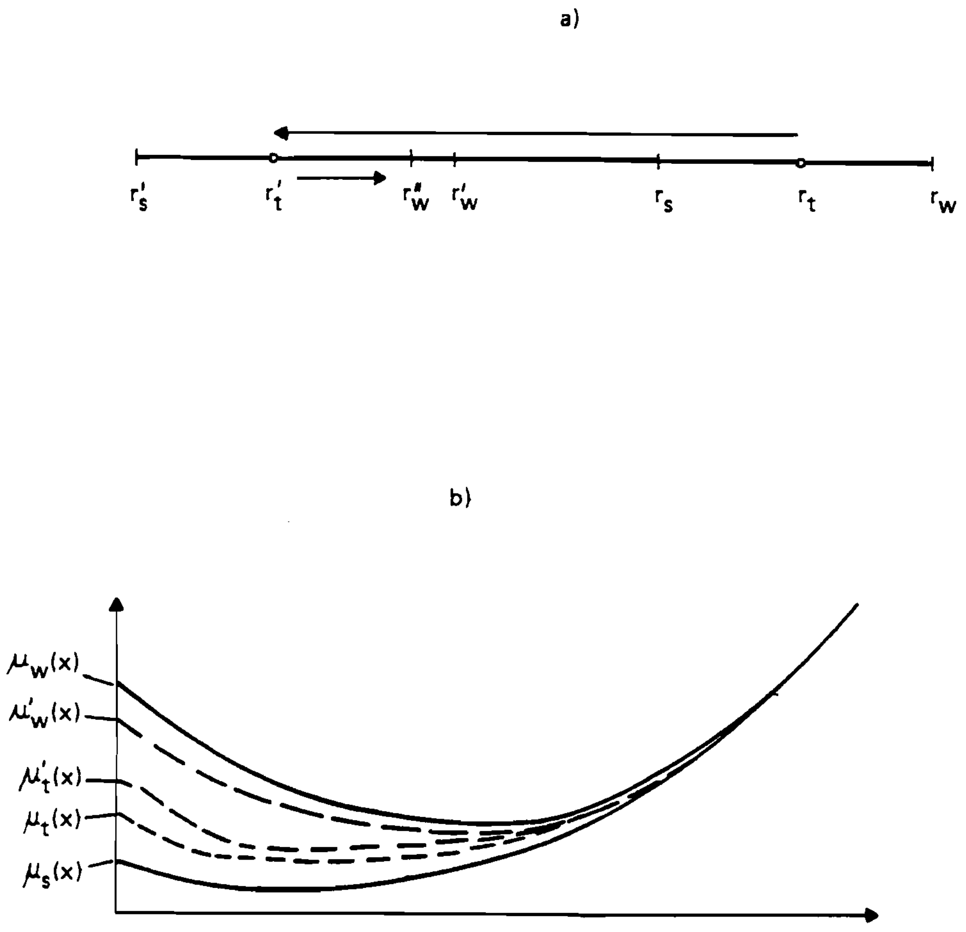

Figure 5. Changes in mortality rates of a population with two subgroups.

Some features of the current problems in public health mangagement give a glimmer of hope for trying alternative management schemes. In the first place, the major causes of death in industrialized nations are outside of the domain of action of the primary health care system. Escalating costs of medical hardware clearly create the need for alternative solutions, and there is increasing evidence that common environmental and life style factors link major chronic diseases. Alcohol consumption, cigarette smoking, diet, exercise level, salt intake, obesity, and stress all are implicated in heart disease, cancer, and other chronic diseases. Although the evidence is far from conclusive, it is suggestive enough to warrant some attempts at non-medical intervention in disease prevention.

The stage thus seems set. Why are there not more attempts at alternative public health initiatives? One key barrier to these types of initiatives is the institutional structure of the overlying socio-economic level in the health care hierarchy. As emphasized earlier, institutions at this level share concern with public health, but there is often no single "planner" who can coordinate the diverse institutions involved. They often are based in different disciplines and have quite different perspectives on the fundamental nature of the problem. Policy is established by political consensus, and the problems of establishing priorities for action in such cases are notoriously difficult. We believe that some new techniques developed in adaptive resource management might help lower these barriers.

MODELING: WAY TO CREATE THE INTERDISCIPLINARY LINKS?

Experience with a wide variety of complex resource management issues suggests that mathematical modeling is a useful tool in aiding decision making processes. One of the best documented example is Adaptive Environmental Assessment and Management (Holling 1978; ESSA 1982). Basically, the procedure consists of a highly structured series of meetings and workshops that seek to produce a computerized simulation model of a resource system. The purposes of the modeling exercise are to promote communication among policy makers, managers, and technical experts, to explore policy options, and to help set priorities for future work.

The results of such analysis procedures is usually an altered awareness of problems and priorities confronting management. Because of institutional inertia in large scale, complex problems, such as public health management, techniques to facilitate communication are required to bring experts and policy makers to joint consideration of the problem and options for solution. This is an iterative process, and creation of a mathematical model is a convenient way to keep the problem in focus. The existence of a mathematical model that represents the understanding of policy makers, managers, and other experts about a specific issue generates still other benefits. Participants in AEAM workshops, in fact, have indicated that information synthesis and policy analysis were very important consequences of the exercise of model building (ESSA 1982). In policy analysis, the model functions as a "what if" gaming tool, and participants can get a qualitative impression of consequences of various policy initiatives. Better understanding of the reliability of traditional measures of policy performance is also a direct consequence of a better understanding of how uncertainty may be propagated through the model. This information synthesis function can be very important where judgements of risk are based on static statistical summaries of processes that are basically dynamic. The success of this type of approach in other resource areas led us to consider an application in public heath planning, where a similar approach was suggested in Venedictov et al. (1977). We were fortunate in having a background of research in public health problems at IIASA that had left expertise and contacts with various health care agencies.

DYNAMICS DESCRIPTION: MATHEMATICS OF MEDICO-DEMOGRAPHIC ANALYSIS

The mathematical tool appropriate for the analysis of public health regulation problems is based on the conception of a medico-demographic population model. This conception presupposes the division of the total population into a finite number of interacting groups by medical, demographical, social and regional status, and a description of the subsequent evolution of this structure. The dynamic properties of the medico demographical processes depend on usual demographical factors (birth, aging, death) as well as on the transitions of the individuals from one group to another (illness, recovery, changing of social status, migration, etc.) Remarkably, statistical data are usually collected for similar social groups and this facilitates the application of statistical estimation methods for identification within the parameters of the demographical model for nonhomogeneous populations (Petrovski and Yashin 1980).

Health care service (HCS) needs may be estimated for a number of individuals in different groups, their sex-age distribution, mean period of stay in the group according to age, sex, etc. These characteristics are also important for estimation of HCS influence on external economical subsystems.

Consider a population consisting of N social groups and individuals who died (group $N+1$).

Let $u(j,t,x)$ denote the densities of age distributions for the individuals from group j, $j=\overline{1,N}$, where t is the time and x is the age. Assume also that there are functions $g(i,j,x,t)$ and $f(i,j,x,t)$ such that balance relations among different groups of individuals can be represented in the following form:

$$u(j,x,t) = u(j,x-\Delta,t-\Delta) + \sum_{i=1}^{N} q(i,j,x,t)u(i,x,t)\Delta + o(\Delta), \qquad (1)$$

$$x>\Delta, \quad j=\overline{1,N}, \quad t\geq 0$$

$$u(j,0,t)\Delta = \sum_{i=1}^{N} [\int_0^\infty f(i,j,x,t)u(i,x,t)dx]\Delta + o(\Delta) \qquad (2)$$

$$u(j,x,0)=F(j,x), \quad j=\overline{1,N}, \quad x\geq 0$$

Passing to the limit ($\Delta\to 0$) we obtain equation

$$\frac{\partial u(j,x,t)}{\partial t} = -\frac{\partial u(j,x,t)}{\partial x} + \sum_{i=1}^{N} q(i,j,x,t)u(i,x,t) \qquad (3)$$

with initial condition

$$u(j,x,0) = F(j,x), \qquad j=\overline{1,N}, \quad x\geq 0 \qquad (4)$$

and boundary condition

$$u(j,0,t) = \int_0^\infty \sum_{i=1}^{N} q(i,j,x,t)u(i,x,t)dx \qquad j=\overline{1,N}, \quad t\geq 0 \qquad (5)$$

If the additional immigration $Q(j,x,t)$ and emigration flows $J(j,x,t)$, $j=\overline{1,N}$, $t\geq 0$, $x\geq 0$ are known, then equations for $u(j,t,x)$ can be rewritten in the following form:

$$\frac{\partial u(j,t,x)}{\partial t} = -\frac{\partial u(j,t,x)}{\partial x} + \sum_{i} q(i,j,t,x)u(i,t,x) + J(j,t,x) - Q(j,t,x) \quad (6)$$

$$j=\overline{1,N}, \quad x \geq 0, \quad t \geq 0$$

Increasing the number of groups and defining if possible the additional (migration) coefficients, it is possible to obtain similar equations which will include migration flow.

Assume that coefficients $q(i,j,t,x)$, $f(i,j,t,x)$ and functions $u(j,t,x)$, $i=\overline{1,N}$, $j=\overline{1,N+1}$, $t \geq 0$, $x \geq 0$ are independent of time. Then according to (3), (4)

$$F(j,x) = u(j,0,x) = u(j,t,x), \qquad j=\overline{1,N}$$

and for $F(j,x)$, $j=\overline{1,N}$ the following equations

$$\frac{dF(j,x)}{\partial x} = \overset{N}{\underset{i=1}{}} q(i,j,x)F(i,x), \qquad j=\overline{1,N}, \quad x \geq 0 \qquad (7)$$

with initial conditions

$$F(j,0) = \int_{0}^{\infty} \sum_{i=1}^{N} f(i,j,x)F(i,x)dx, \qquad j=\overline{1,N} \qquad (8)$$

is valid.

The system of equation (7) is convenient for investigation because it has two interesting interpretations. On the one hand, equation (7) describes stationary distribution of individuals by group and age. Variable x in this case can be treated as age of individuals in a given population. On the other hand, equation (7) describes the dynamics of the initial cohort of individuals distributed at time $t=0$ in N groups. The initial number of individuals in group j equals $F(j,0)$, $j=\overline{1,N}$. In this case, the variable x can be treated as time after "beginning of cohort life."

In many applications the coefficients $q(i,j,t,x)$, $f(i,j,t,x)$ and functions $u(i,t,x)$, $F(i,t,x)$ are independent of age. In these cases $u(j,t,x)=u(j,t)$, $j=\overline{1,N}$, $x \geq 0$ and equation (3), keeping in mind boundary conditions (5), will have the form

$$\frac{du(i,t)}{dt} = \sum_{i=1}^{N} q(i,j,t)u(i,t) + \sum_{i=1}^{N} f(i,j,t)u(i,t), \qquad j=\overline{1,N}, \quad t\geq 0$$

Various intervention variables may influence transition coefficients and birth and death rates in medico-demographic models. Computer calculation versions of partial differential equations should be used for simulation purposes in the case study.

CASE STUDY: WORKSHOP FOR SLOVAKIA MINISTRY OF HEALTH

BACKGROUND

After a period of collaboration between medical researchers in Czechoslovakia and systems analysts at IIASA, it became apparent that the Slovakia Ministry of Health would be interested in a demonstration of AEAM Workshop activity. For a two day period, April 6 to 7, 1983, therefore, a health care forecasting workshop was held in Bratislava at the Research Institute of Medical Bionics. The workshop involved about 20 people (listed in Appendix A), and the participants represented physicians, health care planners, biomedical researchers, and systems analysts.

HEALTH CARE SYSTEM IN CZECHOSLOVAKIA

The first organized medical care in the region now covered by Czechoslovakia was provided by a hospital established in Prague in 980 AD. In the period up to 1918 when the Republic of Czechoslovakia was formally constituted, the region remained in the forefront of medical education and technology. During the Second World War, a new conception of health care and medical education was proposed that later became the model for the post-war reconstruction. In 1948 a new constitution established free access to proper medical care as the right of all citizens. Organized on socialist guidelines, the resultant system was based on the unity of therapeutic and preventive care under governmental supervision.

In 1966, new legislation was enacted giving the HCS its present structure. The basic territorial units of health care provision today are the Health Districts (Zdravotnicke Obvody). These each contain about 6000 citizens and are served principally by general practitioners. Therapeutic and preventive care in this sector of the system is provided by hospitals and polyclinics on an in-patient and ambulatory basis. Hospital catchment areas (Spadove Uzemie) comprise the Health Districts and are of three types depending on the size and specialization of hospital. Type I provides for general clinical specialties and serves populations of up to 50,000; type II provides for both general and more specialized functions and serves up to 200,000; and type III incorporates very specialized services and teaching functions and serves populations up to 1 million. To give some orders of magnitude: there are approximately 15 million people in Czechoslovakia, 230 hospitals (plus 200 related therapeutic institutes), 185,000 hospital beds, and 39,000 medical doctors. In 1977 the hospitals treated approximately 2.5 million in-patients.

Czechoslovakia is a federation of two states: the Czech Socialist Republic (CSR) and the Slovak Socialist Republic (SSR). Each state has a separate ministry of health responsible for long-range planning and day-to-day running of the HCS. The CSR is divided for administrative purposes into eight regions and the SSR into four. Assisting the ministries are a number of specialized research institutes whose scientists work on problems confronting the HCS. One example is the Institute of Medical Bionics (Vyskumny Ustav Lekarskej Bioniky) set up in 1967 in Bratislava, the capital city of Slovakia. Its main aim is the application of the principles of cybernetics to problems in the medical field. In recent years, encouraged by the Slovakian Ministry of Health and in conjunction with other institutes in Czechoslovakia and other countries, the Institute has developed greater interest in applying this paradigm to the managerial aspects of public health regulation. One outcome of this is the current collaboration with IIASA.

PROBLEM DEFINITION FOR WORKSHOP

Because the workshop was an initial trial step in a new methodology, the workshop had a restricted set of objectives. In addition to judging the suitability of simulation models for problems in health care planning and forecasting, participants wanted to explore the more general influence of environmental and social factors normally outside of the health care system. In particular, the needs of the Slovakia Health Ministry for better use of prognosis and understanding of the effects of various sources of uncertainty were emphasized. Underlying issues, therefore, included:

- Change in the ill population over the next 3 to 5 years,
- Sensitivity of various measures of social impact to changes in prevalence of chronic disease, and
- Validity of various "rules" commonly used to judge the success of various treatment and other health care initiatives.

To focus efforts of the participants on these issues, the development and treatment of heart disease was selected as an initial problem.

In many ways, heart disease is a good prototype of the more general problems of the prevention and treatment of chronic diseases. Environmental factors, work conditions, life style, and stress are, in many cases, outside of the scope of health care system abilities, but they ultimately influence the risk of chronic disease onset and subsequent treatment. For the workshop, Slovakia was chosen as the population region, and the period of simulation would be 30 years starting in 1980. Participants felt that annual statistical summaries were sufficient, but that while their normal planning horizon was 3-5 years, they wanted to examine a longer time horizon to view the effects of current demographic structure. To constrain the level of detail in the model further, participants agreed to a limited set of interventions or actions that they would like to consider as well as indicators of the performance of these actions.

Actions contemplated included a range of interventions both in and out of the health care system.

EXTENDED HEALTH CARE ACTIONS

Participants suggested an analysis of the consequences of the following possible changes in health care:

* Change in effectiveness of treatment
* New screening and risk identification techniques
* Changes in general health of population

These actions, of course, represent a highly aggregated series of options for a Health Ministry or other local and regional government agencies. For example, effectiveness of treatment may be influenced by additional construction of primary health care facilities or new treatment innovations. As is discussed below, however, the simulation allows for exploration of qualitative response to combinations of initiatives in this area. The results of improved health care systems, in contrast, may be viewed quite differently at various levels in the larger health care system (e.g. Figure 4). To span this range of views, the participants also requested some aggregate indicators:

INDICATORS FOR HEALTH CARE SYSTEM

* Socio-economic measures (work disability, invalidity, mortality, and hospitalization)
* Incidence of heart disease
* Prevalence of heart disease

As a first step, participants divided into two groups for submodel development. To help understand the difficulties in linking known population heterogeneity and multilayered characteristics of public health management, these two submodels focused on risk group dynamics and heart disease treatment.

DESCRIPTION OF SUBMODELS

Conceptually, the submodel division into two submodels (Figure 6) is similar to the general structure of a health care system discussed above (Figure 4). The core population model includes three risk groups from which annual incidence of heart disease is calculated. Using annual incidence data, the heart disease submodel distinguishes only between severe and mild cases. These calculations then indicate overall prevalence of disease and its social effects. Details of submodel structure are summarized below, and the model code is included in Appendix B.

RISK GROUP SUBMODEL

The core population model includes three risk groups (normal, hypertensive, and diabetic) and four age groups (0-20, 21-40, 41-60, and 61 and older). Basic data for prevalence of the hypertensive risk group and other demographic data for 1980 are summarized in Table 4 (CSSR zdravotnictvi 1981).

These data guided subsequent parameter estimation. Diabetes prevalence and incidence were estimated by expert opinion. Parameters and variables for the risk submodel are identified in Table 5, and the initial values are in lines 300-360 in the code listed in Appendix B. The dynamic portion of the model and rules of change in risk groups are in lines 500-740 in Appendix B.

The calculation sequence begins with computation of number of births from the 21-40 year old age group of each risk group. Next the transition from healthy to hypertensive or diabetic is computed from an estimated transition probability I(i,j). Non-heart disease mortality for each risk group is computed next. Survival of individuals in each risk group is a function of the fraction of the risk group being treated, PT(j), and the basic survival rate for each risk and age group, S(i,j). Treated hypertensives and diabetics are assumed to have the same survival probability as the same aged normal individuals. Population aging then occurs by assuming that 1/20th of the numbers in each age group go to the next age group. The final computation in the risk submodel is the

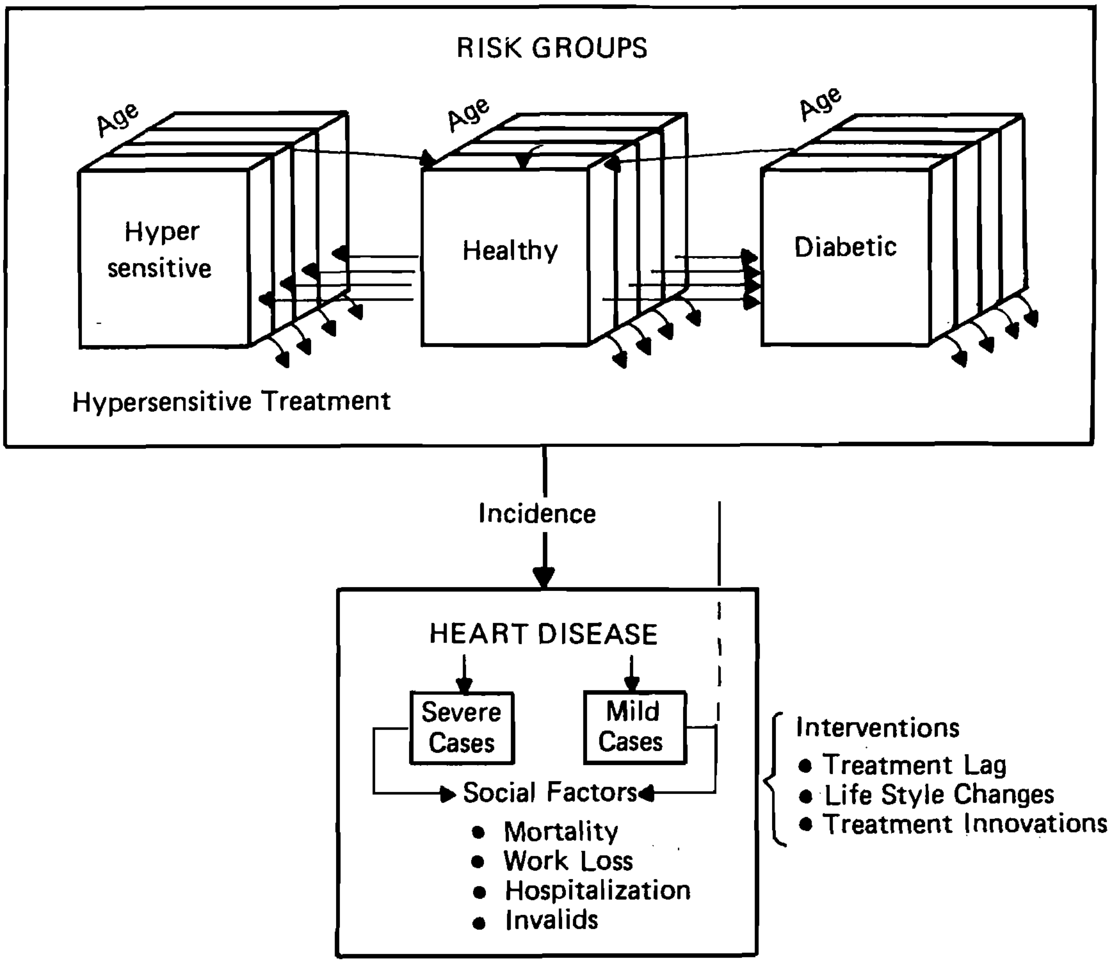

Figure 6. Schematic diagram of Slovakia Model.

incidence of heart disease. The total number of susceptible individuals, PZ(j), is computed for each risk group. Incidence from each risk group is then a function of the group specific probability of heart attack, IH(j), and a relative risk, RF(j), for individuals receiving no treatment for the risk condition. The computed annual incidence, IC, is then passed to the heart disease submodel.

Table 4. Summary of Various Demographic and Disease Data for the Population of Slovakia in 1980.

SLOVAKIAN POPULATION						
Age Groups	# of Males (Thousands)	# of Females (Thousands)	Total Population (Thousands)	# of Birth	Total Mortality (Per Thousand)	*C-V* Mortality (Per Thousand)
0-20	870	839	1,709	984	4.56	1
20-40	780	762	1,542	89,748	1.4	1
40-60	419	563	982	626	7	4
60-80	265	326	591	0	61	4

HYPERTENSIVE PREVALENCE			
Age Groups	Hypertensive	Hypertensive Death Rate (Per Thousand)	Incidence Rate (Per Thousand)
0-20	85	1.82	0.04
20-40	300	8.04	0.05
40-60	350	15.78	0.03
60-80	180	52.44	0.03

40,000/Year	-	Incidence Rate
150,000/Year	-	Prevalence
40,000/Year	-	Death Rate
4,000/Year	-	Incidence of Invalid from C-V Diseases
40%/Year	-	Mortality Rate Among Invalids

Table 5. Definition of Variables in the Risk Group Submodel

VARIABLE	DESCRIPTION
BR	Birth rate coefficient
I(i,j)	Risk group transition probability
IC	Incidence of heart disease
IH(i)	Probability of heart disease for age group (i)
NI	Intermediate variable for incidence
P(i,j)	Number of people in age group (i) and risk group (j)
PO	Total population
PT(j)	Fraction of risk group (j) treated
PZ(j)	Total population in each risk group (j)
RF(j)	Relative risk of heart disease in group (j)
S(i,j)	Survival rate of age group (i) and risk group (j)
T	Dummy variable
TA	Age interval for each age group

HEART DISEASE SUBMODEL

The heart disease submodel treated all new incidences as a single group, but distinguished between severe and mild cases. Severe cases were those in which a heart attack resulted in invalidity or death. Code for this submodel is in lines 105-120 (initial conditions and parameter values) and 1005-1010 (dynamic model change rules) in Appendix B. Parameters and variables are defined in Table 6.

Each year of the simulation, the calculation sequence begins by partitioning incidence into severe and mild cases. This partition coefficient, AB, is a random variable $\approx U(A1, AZ^{2})$. Prevalence of invalids (AA) and mild heart disease victims (AE) are preserved separately. By expert opinion, it was estimated that 30% of severe heart attacks result in death and that 40% of the survivors of one severe heart attack will die each year. For mild cases, however, only 20% die of an initial heart attack and subsequent mortality is 30% per year. Work loss was estimated to be 30 days per first heart attack survived and 15 days for subsequent survived heart attacks. Finally, hospitalization was estimated to be 33% of work days lost for new cases and 67% of work days lost for subsequent heart attacks.

Table 6. Definition of Variables in the Heart Disease Submodel.

VARIABLE	DESCRIPTION
AA	Number of invalids [prevalence]
AB	Fraction of incidence invalid
AC	Survival of incident invalids
AD	Survival of prevalent invalids
AE	Mild case prevalence
AF	Survival of incident mild cases
AG	Survival of prevalent mild cases
AH	Prevalence of heart diseases
AI	Total mortality
AJ	Working days lost
AK	Working days lost [WDL]/new incidence
AL	Working days lost/prevalence
AM	Fraction of incidence WDL in hospital
AN	Fraction of prevalence WDL in hospital
AP	Hospitalization fraction
AR	Dummy
AS	Dummy
AV	Treatment lag
AU	Life style coefficient
AW	Innovations in treatment
AZ	Variance of invalid fraction
A1	Mean of invalid fraction

INTERVENTION SCHEMES

The health care simulation model was programmed for an Apple computer in an interactive style. At any time during the simulation, the program may be halted by pressing any key, and selecting desired interventions. The current version provides for 5 interventions that correspond to the range of actions desired by the participants. The computer prompt and explanation of each intervention is given below:

PROPORTION OF HYPERTENSIVES TREATED:

By entering a value between 0 and 1, the proportion of hypertensives in the population that are detected and treated may be varied. Intensive screening, public education, and other actions beyond primary health care are simulated by this option.

PROPORTION OF DIABETICS TREATED:

This provides the same screening and treatment for diabetics as for hypertensives and a value between 0 and 1 may be entered.

% DECREASE IN TREATMENT LAG:

Through public education or general improvement of health of population, the severity of heart attacks may be reduced. One way is to reduce the time lag between heart attack and first treatment. A value between 0 and 100 can be entered.

% MORTALITY DECLINE FOR LIFE STYLE:

If the general health of the population were to improve, several factors might change in survival of heart disease. Accordingly, a value between 0 and 100 will decrease the fraction of severe heart attacks and increase survival of heart attacks.

% MORTALITY DECLINE DUE TO INNOVATION:

This intervention is similar to the one above and accomplishes similar ends. Again, only a value between 0 and 100 can be entered.

RESULTS OF SIMULATIONS

The simulation model was designed to allow the participants to try several health care management scenarios and examine their consequences. To give an impression of the range of policy actions that could be attempted, we show two sample scenarios. The first (Figure 7) is a baseline projection with no interventions. Keeping in mind that much of the population trend is already established by current demographic structure of the population, the scenario shows an increasing number of individuals in the 60+ age group. The effects of this demographic trend on the prevalence of heart disease and various social factors, however, increase more rapidly than population aging. The number of working days lost and number of hospitalizations increase respectively.

In the second scenario (Figure 8), two sets of interventions are explored. First, in year 10, a new drug is assumed to come into use. It reduces mortality by 50%. In addition, an intensive program of screening and treatment leaves 90% of hypertensives treated. Prevalence of heart disease is not affected dramatically, but its rate of increase compared to Figure 6 is slowed. Social factors, however, show a marked decrease. In year 20, it is next assumed that screening for hypertensives is eliminated. The clear rise in prevalence and social consequences indicates the importance of maintaining these kinds of programs.

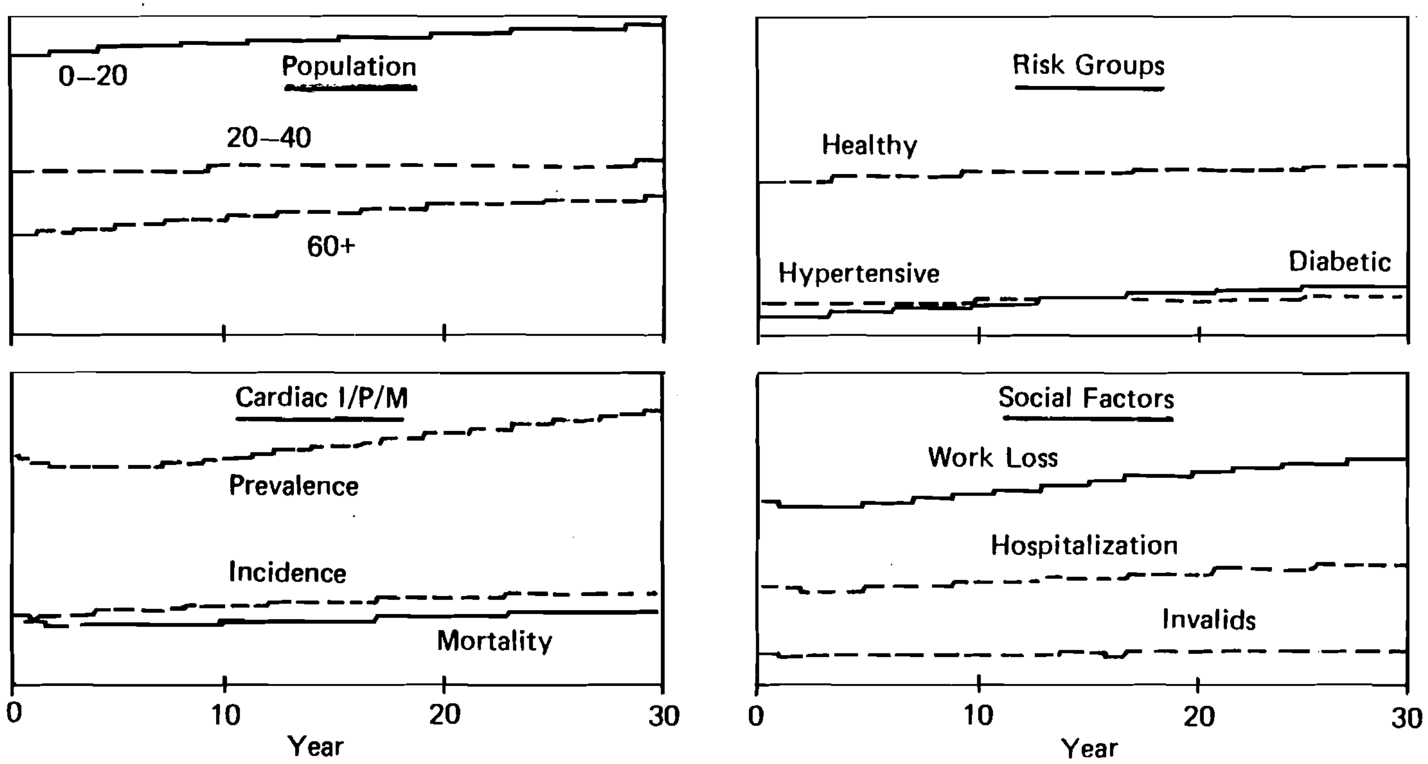

Figure 7. Baseline scenario of Slovakia Model.

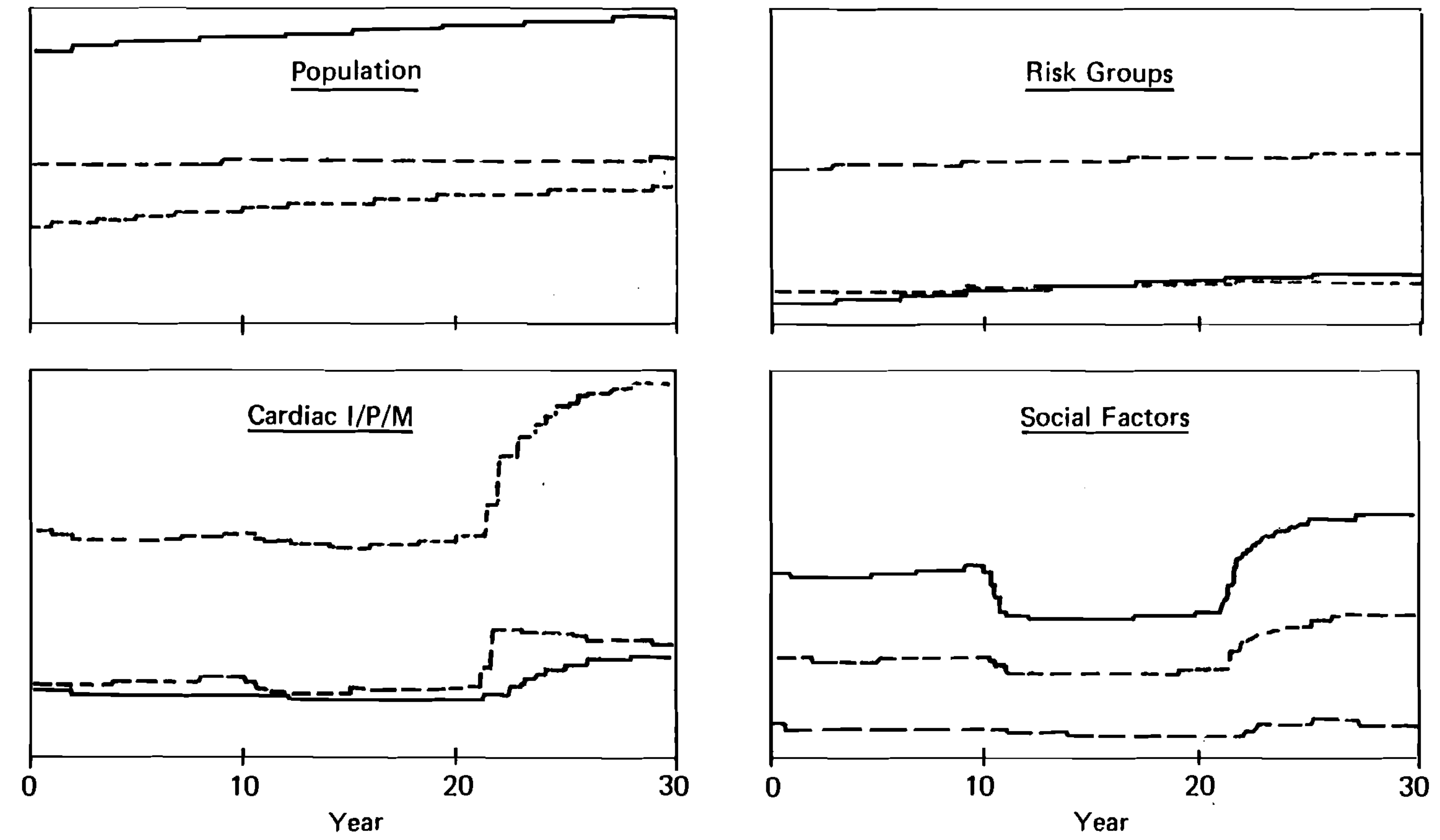

Figure 8. Intervention scenario for Slovakia Model. In year 10, fraction of hypertensives is raised to 0.9 and a treatment innovation reducing mortality by 50% is assumed. In year 20, hypertensive treatment is reduced to zero.

CONCLUSION: NEXT STEPS

Our purpose in writing this paper was to illustrate the need for new approaches to public health planning. We also summarized our experience with a first trial of a new approach to health care problems. In many industrialized countries, the current mix of health care problems follows from hierarchichal characteristics of the health care system and population heterogeneity. Solutions, therefore, must address the problems in their context. We have shown the feasibility of developing simulation models to facilitate joint analysis of public health problems by teams of policy makers, physicians, and other specialists drawn from different levels of the health care hierarchy. Our first trial demonstrated that quick development of computer models could break down communication barriers and focus attention on alternatives to existing health care policies.

The work we summarize here, however, is clearly a tentative beginning only. Nevertheless, priorities for future work can be stated. First, given the level of interest already established, future analytical work in this area should be closely coupled to the interests and needs of real policy makers. Communication and joint problem formulation are essential features of the trial, and they need to be preserved in future work. There is no doubt, however, that this first step is simplistic. Its specific deficiencies should be discussed with the Slovakian Ministry of Health, and then modifications should be made. Future workshops or consolidation activities need to be planned. Because of the requirements of development of credibility and trust among participants, a period of several years may be needed to bring this experiment to a conclusion.

According to these results and to the needs of health care, it seems necessary to broaden the scope of diseases under consideration to the other chronic diseases such as Cancer, Chronic Obstructive Pulmonary Disease, Thyreopathy, Chronic Glomerulonephritis, etc. The studies of such diseases would require participation of a large number of specialists in different types of medicine. It would be beneficial, therefore, to continue such activities in closer collaboration between IIASA and the NMO countries on a comparative basis. IIASA could contribute to the overall effort by developing general methodology and software and by coupling health care problems with those of industrial development, many of which are being studied in different IIASA projects.

A very important role in this effort could be played by the World Health Organization, particularly the regional office for Europe with its programs: Health Planning and Evaluation; and Model Health Care and Quality Assurance. They could possibly help IIASA in general methodology building as well as in data collection and the gathering of specialists. We again want to emphasize that advocating wholistic views of problems is far easier than implementing them. We have here a first start, and it should be nurtured.

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APPENDIX B: LISTING OF SLOVAKIA HEALTH FORECASTING MODEL

```
1      DIM Z(20),ZO(20),ZY(20),ZC(20)

3      DIM P(5,3),I(4,3),S(4,3),IH(4)

20     RESTORE : GOSUB 9000

30     VTAB (24)

50     X =  PEEK ( - 16384): POKE  - 16368,0: IF X > 127 THEN  GOSUB 5000

90     NA = 10:NC = 3:P1 = 4:P2 = 6

105    READ AA,AJ,AH,AI,AP: DATA  2.3E1,1.0E2,1.5E2,3.0E1,5.0E1

110    READ AC,AD,AF,AG,AK,AL: DATA    .7,.35,.8,.25,30,15

115    READ AM,AN,AZ,A1: DATA .33,.67,.05,.15:B1 = 1

120    AE = (1 - A1) * AH:AA = A1 * AH

300    BR = .06:TA = 20

310    PT(1) = 1:PT(2) = .5:PT(3) = .8

320    RF(1) = 1:RF(2) = 4:RF(3) = 1.5
```

```
331    DATA  .003,.011,.014,.003
332    DATA .0008,.0016,.0016,.001
333    FOR J = 2 TO 3: FOR A = 1 TO 4: READ I(A,J): NEXT : NEXT
340    DATA 1709,1542,982,591
341    DATA 85,300,350,180
342    DATA 0,15,18,20
343    FOR J = 1 TO 3: FOR A = 1 TO 4: READ P(A,J): NEXT : NEXT
350    DATA   .9987,.999,.997,.98
351    DATA   .9987,.999,.992,.98
352    DATA  .99,.97,.95,.9
353    FOR J = 1 TO 3: FOR A = 1 TO 4: READ S(A,J): NEXT : NEXT
360    DATA 0,.0006,.004,.03: FOR I = 1 TO 4: READ IH(I): NEXT
490    FOR TI = 0 TO 30
500    X =  PEEK ( - 16384): POKE  - 16368,0: IF X > 127 THEN  GOSUB 5000
600    P(1,1) = P(1,1) + BR * (P(2,1) + P(2,2) + P(2,3))
610    PO = 0: FOR A = 1 TO 4: FOR J = 1 TO 3:PO = PO + P(A,J): NEXT : NEXT
620    FOR A = 1 TO 4: FOR J = 2 TO 3:T = I(A,J) * P(A,1)
630    P(A,1) = P(A,1) - T:P(A,J) = P(A,J) + T
640    NEXT : NEXT
660    FOR A = 4 TO 1 STEP  - 1: FOR J = 1 TO 3
670    P(A,J) = P(A,J) * (S(A,1) * PT(J) + S(A,J) * (1 - PT(J)))
675    IF A = 4 THEN 690
680    T = P(A,J) / TA:P(A + 1,J) = P(A + 1,J) + T:P(A,J) = P(A,J) - T
690    NEXT : NEXT
710    IC = 0: FOR J = 1 TO 3:PZ(J) = 0: FOR A = 1 TO 4:PZ(J) = PZ(J) +
       P(A,J)
```

```
720    NI = IH(A) * P(A,J) * (PT(J) + RF(J) * (1 - PT(J)))

730    P(A,J) = P(A,J) - NI:IC = IC + NI

740    NEXT : NEXT

1005   AB =  RND (15) * AZ + A1:AI = AB * (B1 - AC) * IC + AD * AA

       :AA = AA + AB * AC * IC - AD * AA

       :AI = AI + (B1 - AB) * (B1 - AF) * AC + AG * AE

       :AE = AE + (B1 - AB) * AF * IC - AE * AG

       :AH = AA + AE

1010   AR = AK * IC:AS = AL * AH:AJ = AR + AS:AP = AR * AM + AS * AN

2000   D = PO - PZ(1) - PZ(2) - PZ(3) + AI: PRINT  INT (D);"  "; INT (AI)

3000   Z(1) = ZY(1) + Z7 * (UN - P(1,1) / ZM(1))

3010   Z(2) = ZY(2) + Z7 * (UN - P(3,1) / ZM(2))

3012   Z(3) = ZY(3) + Z7 * (UN - P(4,1) / ZM(3))

3020   Z(4) = ZY(4) + Z7 * (UN - IC / ZM(4))

3030   Z(5) = ZY(4) + Z7 * (UN - AH / ZM(4))

3040   Z(6) = ZY(4) + Z7 * (UN - AI / ZM(4))

3050   Z(7) = ZY(4) + Z7 * (UN - AA / ZM(4)):Z(8) = ZY (4) + Z7 * (UN - AJ

       / ZM(5)):Z(9) = ZY(4) + Z7 * (UN - AP / ZM(5))

3059   PZ(3) = PZ(3) * 10

3060   FOR I = 10 TO 12:Z(I) = Z7 * (UN - PZ(I - 9) / ZM(10)): NEXT

3100   FOR I = 1 TO 16: IF Z(I) < 0 THEN Z(I) = 0

3110   NEXT

3200   IF TI = 0 THEN 3900

3300   ZO = (TI - 1) * ZX:ZN = TI * ZX

3310   FOR I = 1 TO 6: HCOLOR= ZC(I): HPLOT ZO,ZO(I) TO ZN,Z(I): NEXT

3400   ZO = ZO + Z4:ZN = ZN + Z4
```

```
3500  FOR I = 7 TO 12: HCOLOR= ZC(I): HPLOT ZO,ZO(I) TO ZN,Z(I): NEXT

3900  FOR I = 1 TO 16:ZO(I) = Z(I): NEXT

4000  NEXT TI: GET Y$: GET Y$: PRINT : GOTO 20

5000  VTAB (24): REM  INTERVENTIONS HERE TO 7000

5010  INPUT "PROP OF HYPERTENSIVES TREATED:";A$: IF A$ < > "" THEN PT(2)

      = VAL (A$)

5020  INPUT "PROP OF DIABETICS TREATED:";A$: IF A$ < > "" THEN PT(3) =

      VAL (A$)

5100  INPUT "% DECREASE IN TREAT. LAG:";Y$: IF Y$ < > "" THEN AV = VAL

      (Y$) / 100:A1 = A1 / (1 + AV):AV = 0

5105  INPUT "% MORT. DECL. FOR LIFE SYTLE:";Y$: IF Y$ < > "" THEN AU =

      VAL (Y$) / 100: GOSUB 5150

5110  INPUT "% MORT DECL. DUE TO INNOVATION:";Y$: IF Y$ < > "" THEN AU

      = VAL (Y$) / 100: GOSUB 5150

5115  GOTO 5200

5150  A1 = A1 / (1 + AU):AK = AK * (1 - AU):AC = 1 - (1 - AC) / (1 + AU)

      :AF = 1 - (1 - AF) / (1 + AU):AU = 0: RETURN

5200  REM

7001  RETURN

9000  HGR : HCOLOR= 3: ROT= 0: SCALE= 1

9005  Z7 = 75:Z8 = 84:UN = 1:ZX = 130 / 30:Z4 = 149

9006  ZY(1) = 0:ZY(2) = 0:ZY(3) = 0:ZY(4) = 84

9007  ZM(1) = 2000:ZM(2) = 2000:ZM(3) = 2000:ZM(4) = 200:ZM(5) = 6000:ZM(

      10) = 10000

9008  ZC(1) = 3:ZC(2) = 1:ZC(3) = 5:ZC(4) = 5:ZC(5) = 6:ZC(6) = 3:ZC(7) =

      2:ZC(8) = 3:ZC(9) = 5:ZC(10) = 1:ZC(11) = 2:ZC(12) = 3
```

```
9010  HPLOT 0,0 TO 0,Z7 TO 130,Z7 TO 130,0 TO 0,0
9020  HPLOT 149,0 TO 149,75 TO 279,75 TO 279,0 TO 149,0
9030  HPLOT 0,84 TO 0,159 TO 130,159 TO 130,84 TO 0,84
9040  HPLOT 149,84 TO 149,159 TO 279,159 TO 279,84 TO 149,84
9041  HPLOT 43,73 TO 43,75: HPLOT 43,157 TO 43,159: HPLOT 86,73 TO 86,75
      : HPLOT 86,157 TO 86,159
9042  HPLOT 192,73 TO 192,75: HPLOT 192,157 TO 192,159: HPLOT 235,73 TO
      235,75: HPLOT 235,157 TO 235,159
9050  ZN$ = "POPULATION":X = 35:Y = 7: GOSUB 10854
9060  ZN$ = "CARDIAC I/P/M":X = 30:Y = 90: GOSUB 10854
9070  ZN$ = "RISK GROUPS":X = 185:Y = 7: GOSUB 10854
9080  ZN$ = "SOCIAL FACTORS":X = 165:Y = 90: GOSUB 10854
9085  ZN$ = "YEAR:":X = 0:Y = 80: GOSUB 10854:X = 149: GOSUB 10854
9090  ZN$ = "10":X = 34:Y = 80: GOSUB 10854:X = 183: GOSUB 10854
9091  ZN$ = "20":X = 77: GOSUB 10854:X = 226: GOSUB 10854
9092  ZN$ = "30":X = 121: GOSUB 10854:X = 265: GOSUB 10854
9100  RETURN
10854 ROT= 0: FOR I1 = 1 TO  LEN (ZN$):II =  ASC ( MID$ (ZN$,I1,1)) - 3
      1: IF II < 1 THEN II = 1
10855 DRAW II AT X + 6 * I1,Y: NEXT : RETURN
```