HEALTH PRACTICE
RESEARCH

and Formalized Managerial Methods

F. GRUNDY, M.D., M.R.C.P., D.P.H.
Assistant Director-General, World Health Organization, 1961-1965

W. A. REINKE
Professor, Department of International Health, School of Hygiene
and Public Health, The Johns Hopkins University, Baltimore, Md., USA

WORLD HEALTH ORGANIZATION
GENEVA
1973
© World Health Organization 1973

Publications of the World Health Organization enjoy copyright protection in accordance with the provisions of Protocol 2 of the Universal Copyright Convention. For rights of reproduction or translation of WHO publications, in part or in toto, application should be made to the Office of Publications and Translation, World Health Organization, Geneva, Switzerland. The World Health Organization welcomes such applications.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Director-General of the World Health Organization concerning the legal status of any country or territory or of its authorities, or concerning the delimitation of its frontiers.

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by the World Health Organization in preference to others of a similar nature that are not mentioned. Errors and omissions excepted, the names of proprietary products are distinguished by initial capital letters.

PRINTED IN BELGIUM
# CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Introduction</td>
<td>11</td>
</tr>
<tr>
<td><strong>CHAPTER 1. SCOPE AND CHARACTER OF HEALTH PRACTICE RESEARCH</strong></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Use of the scientific and other methods</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>The systems concept and approach</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>The multidisciplinary approach</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Administrative and social considerations</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Example 1. Family planning as an aspect of demographic policy</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Example 2. The need-demand relationship</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Economic considerations</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Models; the scientific approach</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Computing and computer simulation</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Operations research</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>The objectivization of decision-making</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td><strong>CHAPTER 2. THE METHODS OF OPERATIONS RESEARCH APPLIED TO HEALTH PRACTICE</strong></td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>The operations concept</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>Use of models</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>An inventory model applied to recruitment and training</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>A problem in scheduling</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Linear programming techniques</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Problems of estimation</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Prediction : regression and correlation analyses</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Prediction : queuing</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Simulation</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Replacement</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>Decision analysis</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Dynamic programming</td>
<td>76</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 3. HEALTH CARE IN THE COMMUNITY
Outline of a functional analysis study
The information system
Analysis: construction of indices
Dynamics of health actions: transition matrices as predictors

CHAPTER 4. SERVICE UTILIZATION AND PLANNING
Form of analysis and evaluation on which a choice between four stated alternatives can be based
Linear programming formulation when the alternative strategies are not well defined

CHAPTER 5. DISEASE CONTROL
Typhoid fever
Tuberculosis
Cholera

CHAPTER 6. HEALTH MANPOWER REQUIREMENTS
Estimation of present manpower requirements (baseline)
Estimation of future requirements
Recruitment (educational) requirements
Areas of numerical uncertainty and conjecture
Forecasting health manpower requirements in the USSR

CHAPTER 7. WORK STUDY
Change in activity patterns with change in patient mix
Patient mix as determinant of staffing requirements

CHAPTER 8. TRAINING FOR HEALTH ADMINISTRATION AND HEALTH PRACTICE RESEARCH
The basic postgraduate public health curriculum
Continuing education; health services staff colleges
Health practice research training for clinical teachers and practitioners
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Training of non-medical research workers</td>
<td>170</td>
</tr>
<tr>
<td>Undergraduate training</td>
<td>170</td>
</tr>
<tr>
<td>Research training methods</td>
<td>171</td>
</tr>
<tr>
<td>Levels of presentation</td>
<td>172</td>
</tr>
<tr>
<td>Mathematics in training programmes</td>
<td>172</td>
</tr>
<tr>
<td>Impediments to the development of training in research and management</td>
<td>173</td>
</tr>
<tr>
<td>sciences</td>
<td></td>
</tr>
<tr>
<td>Examples of recent curriculum developments</td>
<td>174</td>
</tr>
</tbody>
</table>

Annex. Certain practical consideration in health practice research     | 182 |
Anotated bibliography                                                  | 188 |
The application of scientific and especially mathematical methods to management problems is relatively new. These methods were first employed on a considerable scale in relation to military problems during the Second World War, and they have since spread to industry and commerce to such an extent that operations research is nowadays an established part of management in most large industrial and commercial concerns.

In government administration, operations research has so far been less widely applied, but here too administrators are becoming increasingly aware of its value in clarifying problems and indicating approaches to their solution. For many years, the World Health Organization has been receiving requests from its Member States for help in a variety of research projects, ranging from such traditional subjects of scientific inquiry as methods of treating specific diseases or of controlling disease vectors to systems of financing medical care and methods of compiling health statistics and epidemiological data. At one of its earliest meetings, the WHO Advisory Committee on Medical Research stressed the importance of problems “relating to the logistics of the delivery of health services” as a subject for serious study; and WHO expert committees on the organization of medical care have recommended research on a whole range of health practice problems. A group of WHO consultants met in Geneva in 1968 to consider the scope and character of health practice research and review research approaches and methods and their application in countries at different levels of development.

This volume is an expansion of the conclusions reached by the consultant group. It is intended to describe, as simply as possible, the principles of health practice research and the managerial methods employed in tackling health practice problems. It is hoped that health administrators throughout the world, but particularly in countries with little or no experience of operations research in government administration, will find it of value in dealing with the multifarious problems confronting them in the administration of their health services.
INTRODUCTION

Since the mid-1950s, a more scientific approach to business and economic problems has been widely adopted. Encouraged initially by the successful use of operations research methods in military affairs, governments and business organizations have increasingly applied the methods of science and mathematics to problems of service organization and management.

For the last decade or so, techniques such as systems analysis, critical path analysis, work study and management by objectives have been used increasingly in planning and management by governments and in large-scale industry and commerce. In these and other areas, formalized methods have been widely used for some time to assist policy makers and administrators in making decisions about the planning and running of services, and the adjustments that are constantly needed in complex and changing situations, processes that were previously largely unformalized or intuitive, and often based on inadequate or relatively crude data.

The introduction of some of the newer methods into health planning and administration to complement established procedures has, for fairly obvious reasons, proceeded somewhat more slowly, but their progressive adoption now seems assured.

As long as health services were mainly concerned with environmental medicine, health departments did not as a rule employ personnel in very large numbers, and an unformalized systems approach, backed by statistical and accounting methods, seemed to be sufficient. However, as health departments in country after country became increasingly responsible for the organization of personal health care coverage for whole populations, a new situation arose. Health practice now included the delivery of highly complex services to millions of people through thousands of doctors and other health workers. It became a large-scale enterprise that had to be planned and managed by the best available duction of national health planning meant that health services had to means and controlled by objective measures of performance. The intro-
be related to social security and to other social objectives. The adoption by health departments of management and planning procedures based on a body of related theory also became necessary, not only for reasons of efficiency, but also because competing claims on available resources and priorities had to be examined by economists and others responsible for advising governments on the whole range of public services, regarded as sectors of the national economy.

Many of the newer methods considered in this publication are not unfamiliar in health administration, where epidemiological and statistical approaches especially are traditional, but formalization has proved more difficult in health administration, since objectives are less easy to define and methods less controllable than in some branches of industry. Indeed, one of the main tasks at present is to adapt, for use in the health field, procedures that are almost routine in large-scale industry.

It is proposed, in this publication, to examine the principles, methods and techniques that can be used in health practice, to illustrate their applications and to consider their implications for the education of the medical and allied professions. Many of the principles and methods we shall review are common to planning and management but, though problems related to health planning have not been specifically excluded, the main emphasis will be on the organizational and managerial aspects of administration, and most of the examples cited are in these areas. Comprehensive health planning is a vast subject that has already been dealt with in many WHO publications.

Chapter 1 is intended to establish a terminology and to provide a general introduction to the subject for the reader to whom it is wholly unfamiliar. Chapter 2 lists many of the more important quantitative methods and techniques associated with modern management in general and health services administration in particular. A certain amount of repetition of the material contained in Chapter 1 has been unavoidable, but this has been kept to the minimum necessary to enable Chapter 2 to form a self-contained unit.

The specific applications of the methods discussed earlier, presented in Chapters 3 – 7, are intended mainly for students, and may serve as a framework for teaching examples in postgraduate and advanced public health courses.

The short Chapter 8 is intended primarily for readers interested in the education and training of the medical and allied professions. It has been included because managerial and planning methods are being introduced at the present time in many countries into basic postgraduate public health training and advanced training for health administrators, to meet the requirements of health administrators and planners.
It will be clear that we have not been able, at this stage of the subject's development, to present it in a manner appropriate to any single class of reader. This publication is therefore unlikely to be the kind of volume that many will wish to read from cover to cover. Most readers may find it advantageous to read it through as a whole in the first place, reserving for more careful study those chapters or passages that are of special interest to them. In particular, most readers will be satisfied to read Chapter 1 quickly, and then perhaps to return to it after digesting the details of methods and examples given in Chapters 2–7.

We became acutely aware, as the publication was being prepared, that we faced a problem common to authors who have to introduce mathematics into a general text. Our treatment of the mathematical aspects of the subject may be elementary for some readers but not elementary enough for others. The senior administrator, in particular, who may have lost the habit of thinking mathematically, should be satisfied to grasp the general purport of Chapters 1 and 2. It will almost certainly be sufficient for practical purposes if he is aware of the existence and general character of the newer methods, and is able to recognize their limitations. In this respect, the present subject is not unique. Most of us in the field of health administration make extensive use of the results of population projections and other demographic and statistical procedures that we cannot be expected to have the technical competence to undertake ourselves. We have learned to accept this limitation as unavoidable and perhaps even desirable.

The subject with which this publication is concerned has sometimes administration of personal health care services, the title "health practice health" is not universally understood as including the organization and administration of personal health care services, the title "health practice research" has been adopted.

The present publication is intended only as a brief introduction to the new approaches and methods. It does not claim to be exhaustive or authoritative; it is not a textbook or a manual of practice. We were indeed conscious, while preparing it, that we are engaged in an exploratory exercise rather than in the presentation of an ordered body of knowledge. As we have said, the methods we shall consider are only now beginning to be adapted for use in health administration. The territory we shall attempt to explore is neither well defined nor adequately mapped. As a consequence, some of the definitions we have adopted cannot be expected to command universal acceptance, even for practical purposes, and it would be naïve to suppose that they will satisfy the exacting requirements of research workers and scientists.

Many of the statements made in the following pages may appear to the reader to be dogmatic. It should be understood that they represent
the views of the authors (or of the Consultant Group) and are based on such information as was available at the time of writing.

No attempt has been made to assign credit to the authors on whose works we have drawn nor to the administrators, research workers and teachers from whose experience we have benefited in the course of individual and collective discussions. A selected bibliography is, however, included.
CHAPTER 1

SCOPE AND CHARACTER
OF HEALTH PRACTICE RESEARCH

Health practice research is concerned with organizational problems — with the planning, management, logistics and delivery of health care services. The problems of clinical-pathological medicine and biomedical science therefore lie outside its province. The application of the results of research in biomedical science to individual patient care, etiological studies, pathology, questions of biometrics and human physiology, and laboratory procedure also belong elsewhere, though they all contribute to the body of knowledge and methods that health practice research takes into account and uses. Although health practice research overlaps to some extent with epidemiology and often makes use of the epidemiological method, epidemiology as such is outside its scope.

In any well-designed health-care system, provision is made for assessing its effectiveness and the extent to which it achieves its goals. Strictly speaking this is not research, though the dividing line is not sharp. Data collected for administrative purposes, for instance, are often useful for research, as are comparisons of the results of purely practical investigations. Except for certain sophisticated analytical techniques, the methods used for planning and management are the same as those used in research, and in this publication the primary concern is with methods and approaches.

In health practice research, as in almost every field of research, much effort is devoted not only to formulating questions or problems in such a way that research is possible, but also to refining the methods and instruments of research.

The priority areas in health practice research were identified by a WHO Consultant Group in 1968. The list is not fully comprehensive, but gives a good idea of the kind of problem that health practice research deals with:

---

1 For the purposes of this publication, health practice (public health practice) includes the provision of traditional public health services, namely disease control, environmental control, and other general preventive services, and the planning, administration and management of all forms of personal health care, namely personal preventive services, health surveillance and screening, diagnosis and treatment, and restorative services, both in hospitals and in the community (health care in the community).

---
(1) **Manpower**
   
   (a) Personnel utilization, including the optimal mix of doctors, nurses, and other professional health personnel in different health services — especially in health centres.

   (b) Systematic studies of the education and training needed by different categories of personnel in the health-care team, when their respective functions and activities are rationalized, and in particular, of the education required by the medical team leader ("managerial physician") and the "community physician".

(2) **Organization**
   
   (a) The advantages of separate provisions for the medical care of the sick and personal preventive care, compared with integrated personal health care.

   (b) Regionalization of health-care services, including hospital-system planning.

(3) **Utilization**
   
   Hospital bed utilization and other utilization studies.

(4) **Major problem areas**
   
   Studies to identify the best lines of attack on major problems, such as nutrition, family planning, and specific diseases.

(5) **Quality of health care**
   
   Evaluation of the quality of health care.

(6) **Cost**
   
   Cost-effectiveness and cost-benefit studies, e.g., studies of the cost of certain categories of disease to the community, and of the cost of disease-control systems.

(7) **Terminology; information and research systems; indices; statistical methods**
   
   (a) The standardization of terminology for items of health care, categories of personnel, health care institutions, etc.

   (b) The development of indicators of levels of health and health-care provision.

   (c) The application of mathematical methods and electronic data processing (EDP) in processing and analysing health statistical information, and in the management of certain health services.

   (d) The development of indices of efficiency and effectiveness.

   (e) The development of new economic indices — for example, related to productivity — in many areas of health practice research.
(f) The improvement and simplification of information systems, and particularly the development of methods to identify what is essential in medical records and other data systems.

(8) Need-demand
Health care provision and the need-demand relationship.

(9) Community response studies
Factors influencing community acceptance of services.

Sociomedical studies are seen to have been given secondary importance in this list compared with those concerned with organizational and administrative questions. It would be wrong on this account, however, to under-estimate the relevance and importance of such studies, and especially of studies of “consumer response” and service utilization; though for a variety of reasons, it seems unlikely that there will be many such studies in the foreseeable future. Even in simple medical-care situations, consumer reactions are extremely complex and their study laborious; the techniques required for scientific studies in the field of medical sociology have not yet been adequately developed; there is a shortage of social scientists who are interested in medicine and public health; and there are few health workers with social science training at the research level.

The following main categories of health practice research, grouped according to their aims, can be distinguished:

1. Research applied to immediate objectives

(a) To improve the efficiency of an existing health service. The typical objective is to reduce wasteful activities, to improve timetables, or to determine whether targets have been achieved. When optimization methods are employed, the objective usually is:

(i) to provide a given level of service in the most economical way; or

(ii) to provide the best service possible with the resources available, i.e., to indicate what services should be provided, and how they can best be provided with the funds allocated; this will cover questions such as the optimization of bed utilization, and the optimal allocation of functions to various personnel categories in a health-care team.

(b) To provide data on which policy decisions can be based, i.e., on matters such as priorities, the alternative uses of resources, the identification of major gaps or imbalances in existing services, and ways of correcting such defects. Many of the activities under this heading could equally well be regarded as substantive research or as merely good managerial practice.
II. Research applied to intermediate objectives

(a) Improvement of the processes of health service planning — the provision of basic information on existing needs and services; the definition of trends by reference to epidemiological, demographic, and other statistical data; the development of projections or forecasts based on extrapolations; the infusion of relevant socio-economic and cultural information into health-care systems.

(b) The improvement of research methodology

(i) The definition of health practice problems in precise, and when feasible, quantitative terms.

(ii) The adaptation of operations research and other methods (see p. 41) already employed in industry, etc., for use in the health field.

(iii) The identification and definition of interactions between, on the one hand, health services and health-care systems, and on the other hand, socio-economic, educational, cultural, political and other factors.

It is evident that the scope of health practice research is wide, and also that, as medicine is both scientific and humanistic, a great deal of health practice research falls either between the areas covered by biomedical science and health-care services on the one hand, or between these and wider socio-economic considerations on the other. Because of this, and for other reasons that will be apparent from what has been said, a feature of health practice research is that it involves, more than most research in other fields, collaboration between many disciplines.

The objectives of health practice research are partly substantive, i.e., concerned with formulating and solving problems, and partly devoted to refining the instruments or methods that it uses. At present, most substantive research is limited to investigating particular situations with the aim of indicating where and how improvements might be made. A beginning has barely been made in research in which hypotheses are developed and tested to provide generalizations that have more than local validity. The level of abstraction found in the general theories and laws typical of the exact sciences is rarely, if ever, attained, though considerable progress has been made in formulating widely applicable "norms", and a start made in providing measures of the usefulness and validity of certain methods in a wide range of circumstances.

USE OF THE SCIENTIFIC AND OTHER METHODS

Statistical, accounting and budgetary procedures, case studies, comparative studies of a general character, and historical and other
documentary studies are all widely used in the planning and administration of health services, and can involve research of a high order. They are, however, familiar methods that are well understood and need not detain us here.

Our particular concern is to consider the scientific method or approach in relation to health practice research, where it is used for the solution of problems of a non-scientific character, and consequently has features that would be unusual in research in the natural sciences. Although the distinction between scientific research and the use of the scientific method in research that may be non-scientific in character should not be over-emphasized, it is not without practical significance. The dividing line between understanding and influencing the world must always be somewhat arbitrary, but it is broadly true to say that the objective of pure scientific research is to increase human understanding rather than to influence human decisions and actions and take account of their consequences. It is certainly not directly concerned, for example, with consumer response, risk, cost, profit and loss.

Health practice research, in contrast, is almost invariably greatly concerned with such matters. It is essentially geared to the aim of providing a factual basis for decisions — of introducing objectivity into the decision-making process — of getting something done, of improving some particular health service. In relation to decision-making, it helps to reduce the subjective elements in policy or priority decisions, and to introduce quantitative data into executive decisions. The approach in health practice research is scientific in so far as it depends on an appeal to the facts of a situation, yet it differs in many respects from the scientific method as typically used in biophysical investigations. It is rarely experimental; the situations it studies almost always involve a large number of interdependent variables; many of its data cannot be represented numerically; the systems it studies are less deterministic, in the everyday sense of this term, than physical systems; and the relationships it establishes are usually between indices of sets of occurrences that cannot be measured directly. In addition, health practice research is concerned with the way its conclusions are applied and with the results of their application. Typically, in health practice research, it is not merely the observed facts, but these facts plus an objective and the inter-relations between them that constitute the system studied. Thus, the objective or goal, with which performance is compared, is itself a component of this system.

As a consequence of the foregoing, health practice research often takes the following forms:

(1) in relatively simple problems where quantification is feasible, the approach is usually in terms of models, objectives and feedback;
(2) in the study of the complex interactions occurring in organizational systems, it is often feasible to construct general models only. Such models (often little more than elaborate flow charts) cannot be analysed mathematically. They may nevertheless be of great value in displaying relationships and clarifying issues. In as much as health practice research makes extensive use of such models, it is said to have a systems approach or orientation.

Health practice research can thus be broadly defined as the formalized investigation of some aspects of the organization and administration (including the management evaluation) of health services in relation to objectives and socio-economic circumstances. Its main purpose is usually to achieve the optimal use of a system for the delivery of healthcare and other health services, to show where and how improvements might be made, and to help in the development of health planning and research methods. It is usually concerned with providing solutions to a particular problem, and is characterized particularly by:

(1) a systems orientation;
(2) a multidisciplinary approach;
(3) the use of the scientific approach conceived in terms of models, objectives and feedback; and
(4) the objectivization of the decision-making process.

These characteristics will be considered in turn but, before proceeding, we must stress, at the risk of repetition, that the less familiar methods we shall consider do not replace statistical, budgeting, accounting and other well established methods, but rather complement them. The special contribution of the newer methods is in the formalization and objectivization of procedures, most of which have already been widely used in health administration but have hitherto been largely empirical or based on intuition.

THE SYSTEMS CONCEPT AND APPROACH

A health system is an example of a system designed by man for fulfilling a human purpose and subject to human control, and consisting of a combination of human and material resources. Like other social systems, it permits freedom of choice between alternative courses of action that, by modifying its structure and functions, change its operation so that its output approximates more closely to the predetermined objectives.

The systems approach is essentially comprehensive in character. The various components of a health service are not studied in isolation but as interacting elements of the service as a whole. Thus the physical resources, premises, equipment, supplies, health personnel, community
or patient needs, and the results of health care are not considered individually, but in their interactions with one another. The systems approach is also concerned with the objectives of the health service, and with the total situation in which physical resources, manpower and skills, influence and may be influenced by the achievement of such objectives or goals. Finally, it takes account of the fact that the health system in its entirety is both influenced by, and influences, a variety of external forces and circumstances.

"Systems analysis"\(^1\) refers to any formal analysis whose purpose is "to suggest a course of action by systematically examining the objectives, costs, effectiveness, and risks of alternative policies or strategies — and designing additional ones if those examined are found wanting. It is an approach to or way of looking at complex problems of choice under uncertainty; it is not yet a method."\(^2\) The broad purposes of the systems approach are the following:

1. to formalize complex problems by providing value-free (objective) data and increasing the value-free element in decision-making (see p. 42);
2. to indicate the probable consequences of alternative courses of action;
3. to inform debates on values, objectives and the allocation of resources whose purpose is to find ways of improving performance, reducing costs or economizing in the use of manpower or resources;
4. to compare results achieved with objectives specified;
5. generally, to assist the decision-making process in planning and management, i.e., in making adjustments to the components, structure, apparatus for information and communications, and decision-making procedures of an existing organization, in order to improve its performance.

What is to be treated as a system will depend on practical considerations. For some purposes, activities carried out or devices used in health care are regarded as systems; for others, they are studied as sub-systems of a larger complex. An aggregate of health centres and hospitals can usefully be regarded as a system for some purposes, though it is clearly a sub-system of a comprehensive health system, which itself is a sub-system of a larger politico-social system. In ascending order of complexity, the systems studied in health practice research comprise:

1. the individual components of a health service or some particular aspect of these components;
2. the health service in its entirety;

---

\(^1\) In some texts "systems research" is used to mean "systems analysis" plus "systems planning and design". For the sake of convenience, "systems analysis" is used here in the more comprehensive sense.

\(^2\) Definition proposed by E. S. Quade.
(iii) the health service and its components in relationship to socio-economic and other factors. In this area, especially, health practice research for obvious reasons is multidisciplinary in character.

Fig. 1 illustrates in a general way how the boundaries might be drawn in a hierarchy of systems and sub-systems.

Fig. 1. A hierarchy of systems and sub-systems

It will be evident from what has been said that systems analysis applied to health practice is, as Quade concluded, an approach rather than a rigorous method. System boundaries are drawn as widely as a particular problem requires, having regard as far as may be feasible to the open and dynamic character of all health systems. Because it deals with broad and complex problems, it often makes use of the figurative model (see p.). Since the variables involved are numerous and inter-dependent and their parameters indefinite or uncertain, systems analysis can rarely be forced into a mathematical mould. When we read, for instance, that the basic models used in systems analysis can be represented by the equation:

\[ P = f(C_1, U_i) \]

where \( P \) is the performance, \( C_1 \) a set of controllable variables, and \( U_i \) a set of uncontrollable variables, we must not think that this general
equation can be converted into an explicit functional relationship; this is not possible at present. The diagram shown in Fig. 2 takes us a stage further in elaborating the concept of system, as applied to health services.

Fig. 2. The concept of system, as applied to health services

In this diagram, the basic system is depicted as consisting of:
1. inputs (persons needing health care);
2. processes (health care delivered by services);
3. outputs (treated patients); and
4. feedback (effects of processes on future inputs), operating within a number of constraints, such as buildings, equipment, geography and population distribution.

This system, represented diagrammatically as:

```
Input  Process  Output
```

is the prototype operational system.

Parks & Adelman\(^1\) comment that, for all practical purposes, feed-


back has been little used in metropolitan health-care practices, so that the system is unable to move efficiently towards the achievement of its objectives. An understanding and assessment of the results of health care are needed both for improving practices and for rational long-range planning. Without them, the system cannot move towards objectives such as improvements in health-care consumer responses, institutional adequacy, improved cost-effectiveness, and a bigger contribution to wider social aims.

The above-mentioned writers go on to say that "Additionally, the system is affected by its dynamics (6), as opposed to static constraints: e.g. flow of patients; rates of change involving such factors as population variation, community mobility, proliferation of medical technology; and the "channel characteristics" for internal and external communication. Also, a given system never functions independently of other systems (8); their interfacing must be understood. Antecedents (7) of current status must be assessed in terms of historical foundation (for example, the "poor law" tradition). Finally, external forces (9) must be studied for impact both current and future. External forces may take a variety of forms: legislative, cultural, financial, technological, and so forth. System study of metropolitan health care practices must address each of these ten elements."

Before effective research on health systems can become a reality, much more will have to be done to define and quantify such systems, to relate them to each other and to develop better methods than those now available for the study of systems as entities. Moreover, where systems analysis has been adopted, many practical difficulties have been encountered. The major problems include poor quality analysis, the failure to gear analysis properly to the needs of the decision maker, the preference of decision makers for their own intuitive reasoning, the use of analysis to justify programmes that do not need analytical support, poor cooperation between analysts and operational departments, and lack of feedback to the analytical team.

Speaking on the planning-programming-budgeting process, and systems analysis as used by the Federal Government of the United States of America, Andrew M. Rouse suggested "that if the new administration were to judge these techniques only on the basis of their past record, rather than some judgement of potential value, then they would probably be discarded." Yet, he believed "with qualified optimism that those techniques are here to stay."

---

2 Director, Resource Planning Staff of the United States Bureau of Budget.
THE MULTIDISCIPLINARY APPROACH

Health-care organizations make use of a wide range of skills and disciplines. In the situations that confront the health practitioner, problems that can be neatly categorized as clinical, biomedical, social or economic do not exist. Real problems do not have interdisciplinary boundaries — they are seen in different ways according to the viewpoint adopted. In simple situations, the best way of looking at a problem for a given purpose is often clear enough to allow it to be assigned to a particular discipline. When, as is usual in health practice, the situation is complex and the purposes multiple, there is rarely an obvious "best way" of proceeding. Most problems in health practice have to be looked at from the viewpoints of many disciplines, and explanations, policies and procedures broad enough to match the facts have to be derived by combining the results obtained by several different approaches. The whole range of health professions — medicine, epidemiology, dentistry, nursing, health education, sanitary engineering, microbiology and other laboratory professions, veterinary medicine, the mental health professions, nutrition, medical statistics — and a variety of administrative personnel are regularly included in departments of public health, and instruction in most of these areas is given in schools of public health. In spite of their common basic purpose, however, these separate disciplines rarely form a unified whole. Environmental health tends to be a separate sub-discipline, there is a persistent tendency to separate personal preventive and curative services, and to concentrate on disease-specific programmes. The result is that health organizations tend to be composed of more or less autonomous specialized departments whose programmes often affect the community in somewhat similar ways. The rational coordination and integration of health programmes is now a major subject of health practice research.

Coordination and integration do not, however, end here. Because the business of health services is to promote health care in a social setting, the position of health practice research is intermediate between those of the biomedical and the social sciences; because health services form part of a larger system, it is also an aspect of public administration.

The dependence of health practice research on statistics, epidemiology, clinical pathology, public health and latterly on computer technology is well understood. In its wider aspects it also depends on:

(a) the behavioural sciences — sociology, psychology, geography and anthropology;
(b) many areas of political and management science;
(c) economics.
Most organized health services are a part of government administration and as such share the particularities and constraints of the larger system. The apparatus of government is a component part of the network of institutions and groupings that constitute the social structure of a nation. Governments in turn operate within an ecological context, and must constantly adjust their policies and actions to allow for physical, biological, economic, cultural and environmental changes. The same applies to health practice. Health practitioners have to operate within a rapidly changing environment that invariably feeds into the health system inputs beyond their control, yet the system must incorporate these inputs and adjust to them.

The development and testing of new methods and programmes is at the very core of health practice research. Problems usually take the following form: given a certain technological competence, certain population needs, and the existing social situation, what is theoretically the best way of providing services and how far are theoretical expectations realised in practice? To solve such a problem, it is necessary to ensure that a full range of alternatives is generated, evaluated and tested. This means that scientific knowledge and technological capability must be evaluated in the context of the problem and of the available resources and organizational capacity. New methods or programmes, moreover, must not only be feasible but also acceptable to the population for which they are intended, and to the health workers and organizations who are to implement them. They should therefore be compatible with cultural expectations, should not disrupt established social relationships, and should satisfy a wish for change. The requirements to which means of enhancing acceptability must conform are also important in health practice.

Empirical trials of new methods and programmes are not merely procedures for showing up deficiencies and assessing costs and operational feasibility; they are also a means of increasing knowledge of the determinants of acceptance, techniques of organization and evaluation, and the wider consequences of altering one part of a system. We know too little of the way in which health programmes and the larger systems affect each other. The interactions between family-planning programmes and demographic policies, to take one example, are considered later (see p. 28).

Apart from questions of programme design, there is still much to be learned about the way health services and health organizations function. Work study techniques, for example, have been used to ascertain the duties actually performed by various categories of health personnel.
Such studies have usually been related to particular situations, but have sometimes led to general conclusions of administrative significance. Studies of ward work, for instance, have shown that tasks normally performed by nurses might be transferred to less highly trained personnel. Activity sampling, continuous observation techniques, "shadowing", and self-recording methods have been used, and for administrative staff, interview techniques, as a basis for post descriptions. In these studies, as also in the studies aimed at measuring patient satisfaction, staff attitudes, staff turnover, etc., that are needed to provide management with information for the control of services, the techniques of social science can be used.

Organized health-care systems can also be regarded as social systems in their own right. They tend to outlive their usefulness, to base requests for funds on past rather than present accomplishments, and to acquire "spheres of influence". They engender strong attitudes and motivations among their members, who may become pressure groups. It is therefore necessary to scrutinize not only the technical aspects of health services but also their character as social systems.

Staff satisfaction and turnover, productivity, coordination and community attitudes toward programmes, are among the sociological and administrative problems of particular importance to health systems. Such systems include many categories of workers who are expected to act independently but whose actions must be coordinated. They have the difficult task of satisfying both scientific and technological requirements and the wishes and needs of the population. They deal with a public that must be persuaded voluntarily to accept their advice, and with patients who do not always share their aspirations and rarely understand fully the rationale underlying the advice they receive.

Planning is the culmination of the interdisciplinary approach, since it relates the development of health-care systems to wider national plans that can be progressively adjusted. All health planning has therefore to provide for constant feedback in relation both to changes in needs, constraints, populations and opportunities, and to changes in the physical and social environment. The planning organization guides and is guided by research. Like other administrative machines, however, planning organizations are bound to the present, even when preparing for the future. As a consequence, they may fail to break new ground and to explore theoretical issues that have no obvious immediate applications. To do these things is no less important in health practice research than in the basic sciences.

We shall now consider two specific examples of the multidisciplinary approach, each in its own way of fundamental importance.
EXAMPLE 1. FAMILY PLANNING AS AN ASPECT OF DEMOGRAPHIC POLICY

Health status, population characteristics and economic development are all inextricably interwoven in the problem of demographic policy.

In the past, the development economist was concerned mainly with dependency ratios and human capital, while the demographer tended to be preoccupied with fertility and mortality rates. Both became understandably alarmed about the delay with which a decline in mortality rates is followed by a decline in fertility levels. With the development of modern contraceptive devices and procedures, it may have seemed that the problem was largely logistical; all that was needed was to make effective contraception generally available — a matter of administration, organization and economics. The human factor was neglected or ignored.

The less than adequate results obtained by this narrow approach caused increasing attention to be paid to attitudes and motives, so that the behavioural scientist became an important member of the "population" team. As the problem was better understood, it became increasingly accepted that, from both the motivational and logistical standpoints, family planning services should be associated with maternal and child care. Thus the health professional, formerly an opponent, became an ally.

It is now appreciated that the magnitude and difficulty of the problem are such that it may not always be possible to provide the necessary number of trained personnel of the appropriate categories and to ensure that they are correctly distributed. The need to allocate scarce resources suggests a need for systems analysis, operations research and statistical expertise. Even the role of the economist has changed, for it appears that a society's acceptance of family planning may depend in part on a shift from traditional socio-cultural patterns to one in which the individual's ability to control his environment is increasingly recognized.

A family planning programme will therefore require not only an array of health workers, including paediatricians, obstetricians, general practitioners, public health nurses, health visitors, auxiliary nurse-midwives, and basic health and family planning workers, but also behavioural scientists, statisticians, and demographers. There will be a need for an extension educator to help translate attitudes into practices. The identification of alternative approaches and the assessment of their costs and benefits require systems analysis, and problems of personnel allocation and training call for task analysis.
A broad objective in most health planning and in the organization of health services is to meet the "needs" of a population, or to match "supply" and "demand". The concepts of need and demand, however, have not been adequately defined, and there is often a failure to take sufficient account of their interrelations with other factors. The "need" for health care in any community, unless qualified in some way, is virtually unlimited. Similarly, the provision of health care for everyone at the highest possible level is not at present feasible. Need has therefore to be understood mainly in terms of demonstrable disease requiring and amenable to some form of medical care. On this basis, the volume and character of the medical care requirements of the community can be estimated precisely by means of screening surveys of sample populations conducted by medical teams. The screening survey therefore provides an adequate way of estimating "needs". Large-scale population surveys of this kind are costly, however, and consequently it is usual to rely on demand as a measure of need, but the disparity between demand and need must be clearly understood. Demand, which is usually measured by service utilization, gives a fairly good indication of the services likely to be required, provided that the social-cultural setting remains unchanged and that the effects of service expansion on demand are disregarded. Nevertheless, whilst demand is an index of a felt need, it cannot be assumed that it represents a need that can be satisfied. In addition, and more important, "demand" almost invariably underestimates "need". In all communities, a proportion of the people in need of medical care fail to demand it. They may be sick without recognizing the fact; they may accept a disability or disorder as normal; and they may fail to respond to an available service out of ignorance, indifference, resignation, prejudice, fear, laziness — or what would elsewhere be called market resistance. Consumer response is obviously also influenced by factors such as the accessibility of the service in terms of distance, time and cost, by competing claims in other spheres, and by the quality of services and their desirability from the consumer's point of view. All surveys of need have shown that, even in affluent communities provided with comprehensive free services, it greatly exceeds demand or service utilization. The situation also varies from one population sub-group to another, but relatively little is known about the importance of the factors involved for different groups and circumstances. Moreover, it cannot be assumed that everyone benefits from services even when they are readily available and free. Even the various utilization items and the units for measuring them are often inadequately defined.
The lack of agreement between biological and social needs, demands and professionally determined needs is shown diagrammatically in Fig. 3. A broken line has been used for the biological “needs” in order to indicate that they do not have fixed boundaries. It has been suggested that the differences shown are closely related to levels of development, tending to be smaller when standards of living and general education are high.

(a) Biological and social needs

(b) Individual and group demands (utilization)

(c) Professionally determined needs

WHO 20742

Fig. 3. Need-demand relationships

"Need" and “demand” largely depend on a wide range of socio-cultural factors. Neither is, by itself, an adequate basis for decision-making in the health field. Both are needed in order to estimate medical care requirements. The disparity between them affords one indication of the acceptability of services in their existing form. Need is related to the biological and technical basis of health practice, demand to its economic and social basis.

A link between utilization and demand has been provided by recent studies on community demands in both developing and developed countries. These have shown that the consumption of medical care is related to such factors as age, sex, distance from the hospital, health centre, etc., standards of living, family income, education, and health insurance cover. Standard curves of medical care utilization have been
prepared, which show that such utilization can be related to the level of socio-economic development. On this basis it might be feasible, for planning purposes, to forecast future demand more accurately by relating present utilization to trends in socio-economic development.

ECONOMIC CONSIDERATIONS

Economic analysis is a necessary constituent of health planning. Estimates, budgets, cost accounting, and other financial methods are as necessary for controlling and evaluating the performance of health services as they are in other fields. Economic analysis is an accepted tool for resource allocation, and can also shed light on problems of utilization.

The main areas common to economics and health practice include:
1. budgetary and other financial controls and evaluation methods;
2. cost-effectiveness and cost-efficiency measurement;
3. cost-benefit approaches.

The first of these is well understood, and needs little comment here. Cost-effectiveness measurement is a method of comparing the costs of achieving an agreed objective in different ways, while cost-efficiency measurement is a method of comparing the costs in two or more enterprises providing similar services, or in a single enterprise at different times.

The cost-benefit approach is a method of comparing the cost of providing a service with the gain accruing, or likely to accrue from it (i.e., the net estimated gain). Though useful in making policy decisions, it often involves arbitrary assumptions and leads to controversial conclusions. Cost-benefit methods have been useful for demonstrating the economic soundness of certain health services, and especially of mass campaigns for the control of certain communicable diseases, of immunization and nutritional programmes, and of occupational health services. Applied to health care services in general, their value is doubtful.

Where accounting systems are adequate, the cost of establishing, maintaining, or extending health services can be estimated without difficulty, provided that agreement is reached on the items to be included; the cost of supplementary diets or re-housing costs, for example, can be charged either to health or to some other account. The demonstration of benefits that are unequivocally attributable to the operation of a health service is, in contrast, a more intractable and, in some cases, an impossible problem. This is true even if the benefits considered are limited to such items as increases in working-life span, reductions in working time lost because of sickness, and reduced need for health and
allied care, all of which can be expressed in monetary terms. It is true, *a fortiori*, if the quality of human life, community morale, social stability, and similar items that cannot be expressed in this way, are included.

Moreover, it has not hitherto been feasible to correlate costs and results with any confidence, since improvements in general levels of health are rarely attributable exclusively to better health services. They are often the result, for example, of rising standards of living. The use of the cost-benefit approach is therefore hampered by difficulties in measuring the effects of health programmes, but this is not the only limitation. Many health care services, e.g., those for the care of the aged infirm and the severely subnormal, are patently unsound in economic terms. Cost-benefit analysis in the health field must therefore be seen as one of the bases for decision-making but not as a sufficient foundation, in itself, for policies and programmes.

It can be used in the evaluation of programmes and services, and can sometimes demonstrate the economic value of health services. The improvement of health is not purely an economic objective, however, and many of the benefits resulting from health services cannot be measured in financial terms; the provision of such services, even if there is no demonstrable economic gain, may none the less be highly worth while on other grounds.

Cost-benefit analysis as applied to family planning programmes affords a good illustration of the fact that the results may vary with the period to which they relate. As the period chosen is independent of the procedure itself, it follows that cost-benefit ratios appropriate to a particular period are not generally applicable; this appears to be the case even when discounting methods are used. Costs per birth prevented can be compared fairly accurately with the cost of providing food, housing, education, health care, etc., for a child during the unproductive years between birth and about 14 years of age. The cost-benefit ratio is favourable, but whether it would remain so if the period were extended to include the productive years, depends on factors such as the demand for labour, the rate of industrialization, and government policies.

MODELS; THE SCIENTIFIC APPROACH

Real situations are invariably so complex that it is essential to simplify, to select and isolate certain features of reality, to develop a more or less idealized situation, and then to construct a model that represents this idealized situation and also, to some extent, certain features of the real situation.

The model is thus a symbolic representation of an idealized system.
It resembles, but does not purport to be a replica of, the situation it represents. It stands for the structural and functional attributes of that situation, not for its substance, and precisely on this account it helps us to visualize what is going on in the real world, brings hidden relationships to light, and provides a basis for logical operations that enable implicit relationships to be made explicit. It enables us to see how things hang together, how our concepts are related to each other; it enables us to discover patterns that are not apparent from the everyday inspection of events.

A model of some kind is usually needed in health practice research, but in contrast to the situation in the physical sciences, a small number of standard and versatile models, from which a selection can be made to suit a particular problem, has not yet been developed.

Types of models

Models are said to be figurative when they are diagrammatic or geometric in form, or non-figurative when they assume a mathematical form. They are classified as:

(a) deterministic, when the parameters are constant or vary in a predictable manner; or

(b) stochastic, when their magnitude depends partly on chance or when the model takes account of variability, e.g., rates of arrivals at clinics, hospital admission rates, and queue formation.

Alternatively, models may be described as:

(a) static, when the magnitudes of the parameters are independent of each other, and vary in a way that does not alter with time; or

(b) dynamic, when this is not so; such models take account of changing circumstances and the manner in which decisions will affect or be affected by these circumstances.

Finally, according to the purpose they serve, models are said to be:

(a) descriptive;

(b) predictive; or

(c) prescriptive.

The descriptive model displays in convenient form the essential characteristics of the idealized system it represents; the predictive model provides a basis for deductions (extrapolations either in time or range of representation) that can be compared with observations in the real world; the prescriptive model is used to indicate what should be done to achieve or approach a stated objective. A single model often combines two of these functions, or all three of them.

The inventory model dealt with on p. 38, for instance, is initially descriptive, but then becomes prescriptive when it defines conditions for
optimization. The network on p. 35 is predictive when used to indicate the expected timing of the terminal event, and prescriptive when used to show where attention should be concentrated to avoid delay in completing the project.

Examples of figurative models will be found in many places in this publication. Such models are notational devices that use boxes and arrows, or nodes and arcs, to represent the essential elements and relationships of complicated situations. The simplest example is the flow chart, which displays sequences or relationships without reference to time or other quantities. A flow chart of optimum newborn care is shown in Fig. 4.

![Flow chart of optimal newborn care](image)

Fig. 4. Flow chart of optimal newborn care

In network analysis\(^1\) (see Fig. 5), an arc represents an activity, and a node its completion (event), so that a time factor is introduced.

\(^1\) The best-known form of network analysis is PERT (Program Evaluation and Review Technique). This and other forms of network analysis are described more fully in Chapter 2.
Typically, network analysis provides a basis for the planning, scheduling and controlling of complex, non-repetitive projects.

![Network Model Diagram]

**Fig. 5. Network model**

In the ecological model whose general form is indicated in Fig. 6, "state" populations are related by rates of transition from one state to another, leading, in some instances, to a set of equations that can be solved either by differential calculus or by the method of finite differences.

All of the foregoing are examples of figurative models, as also are many forms of graphs and diagrams commonly used in health practice. Disease incidence graphs, epidemic curves, and population pyramids are also primarily figurative models, though, like the PERT network and the state-transition models, they may lead to arithmetical and other mathematical operations.

As Chapter 2 is devoted largely to analytical methods based on models, it will be sufficient here to refer to the basis of two prototype mathematical models — the linear programming model and the inventory model. Both are discussed at greater length in Chapter 2.

---

1 Epidemiological examples of this type of model are given in Chapter 5, p. 104. In the hypothetical example shown in Fig. 6, for instance, individuals are recruited to State 1 by births and immigration and are lost to State 1 by becoming sufferers or carriers (and by deaths and emigration). Similarly, the size of the State 2 population is dictated by additions due to transitions from State 1 and by losses, as sufferers revert to State 1, become carriers, or die.
Fig. 6. Diagram of ecological model

The linear programming model\textsuperscript{1}

The linear programming model is a static deterministic model, but of quite a different kind from the inventory model. Typically, it is

\textsuperscript{1} See also Chapter 2, p. 54.
used for the solution of "best route" and "best mix" problems, of which examples are given later.

A linear equation is written, based on the facts of the problem, in the form:

\[ Au + Bv + Cw + Dx + \ldots = P \]

in which the coefficients \( A, B, C, D, \ldots \) are known, and the maximal or minimal value of \( P \) (the objective function) is to be ascertained. This is done by introducing alternative sets of admissible values for the variables \( u, v, w, x, \ldots \), and then selecting the highest (or lowest) value thus obtained for \( P \).

The admissible sets of values for the variables are obtained graphically or by the solution of sets of simultaneous linear equations derived from the so-called restraint conditions of the problem.

For non-trivial problems, matrix methods are used, with the aid of a computer. Readers unfamiliar with the method are referred to the account of the mathematical basis of linear programming given by Bristoe.\(^1\)

It will be sufficient here to glance at a hospital transport example of the "best route" problem, mainly in order to establish a notation for later use (see p. 101). The problem is the following.

At locations 1, 2, 3, \( \ldots (i) \ldots \) n, there are \( N_1, N_2, N_3, \ldots (N_i) \ldots N_n \) patients respectively; there are also a number of hospitals 1, 2, 3 \( \ldots (j) \) \( \ldots \) n, each having a known number of vacant beds to which the patients are to be conveyed. \( N_{ij} \) represents the number of patients conveyed from location \( i \) to hospital \( j \), \( N_{i1} \) the number conveyed from location \( i \) to hospital \( 1 \), and so on; generally, \( N_{ij} \) represents the number of patients conveyed from location \( i \) to hospital \( j \). The distance between location \( i \) and hospital \( 1 \) is \( D_{i1} \), between location \( 1 \) and hospital \( 2 \) \( D_{12} \), etc.; generally, the distance between location \( i \) and hospital \( j \) is \( D_{ij} \).

Thus, for instance, for three patient locations and two hospitals the situation can be represented diagrammatically as shown in Fig. 7.

The problem is to find the number of patients who should be taken from each location to each hospital so that the total transport mileage (the objective function, \( P \)) is minimal, i.e., to find the minimal value of:

\[ D_{11}N_{11} + D_{12}N_{12} + D_{21}N_{21} + \ldots \ldots = P \]

or, generally:

\[ \Sigma D_{ij}N_{ij} = P \]

\(^1\) Bristoe, J. D. (1967) *An introduction to linear programming*, Boston, Heath.
The $D_{ij}$ are known and alternative sets of the $N_{ij}$ are to be ascertained from the limiting or constraint conditions of the problem. Examples of the constraints include:

1. each $N_{ij}$ is necessarily zero or a positive integer, i.e., $N_{ij} \geq 0$ and $N$ is a positive integer;
2. the total number of patients moved from location $i$ is $N_i$, i.e.,
   \[ \sum N_{ij} = N_i; \]
3. the total number of patients received in hospital $j$ from all locations cannot exceed the number of vacant beds in the hospital.

Equations based on these and other constraints enable alternative admissible sets of values of the $N_{ij}$ to be derived and hence alternative values of $P$ to be obtained, of which the lowest is selected.

**A mathematical inventory model**

The inventory model is a prototype deterministic model. The aim is to determine the optimal ordering policy for an inventory item, e.g., a drug or immunizing agent. Frequent small orders will keep the cost of carriage low, but each time an order is placed, regardless of its size, a certain administration cost will be incurred. The problem is to determine the ordering policy that minimizes the sum of these costs.

Suppose that, during the period of concern:

- $C_V = \text{total cost}$
- $C_i = \text{cost of carrying one inventory unit}$

---

1. See also Chapter 2, p. 48.
\( N_i \) = average number of units carried  
\( C_o \) = cost of placing an order  
\( N_o \) = number of orders placed  

Then:
\[
C_T = N_i C_i + N_o C_o
\]

If \( U \) is the number of units issued, and \( Q \) the quantity ordered at any one time, then \( N_i = Q/2 \), and \( N_o = U/Q \). It follows that:
\[
C_T = \left( \frac{Q}{2} \right) C_i + \left( \frac{U}{Q} \right) C_o
\]

so that \( C_T \) is minimal\(^1\) when:
\[
Q = \sqrt{2U\left(\frac{C_o}{C_i}\right)}
\]

Though seemingly trivial, this example of the inventory model illustrates the importance of precise definitions, the explicit recognition of the essential factors in a problem, and the manner in which these factors are related to each other and to the objective.

Like other mathematical models, because of its formalism, the inventory model is highly versatile.

*The use of models in health practice research*

We are now in a position to see the place of model-making in relation to the scientific approach to practical problems involving planning and management decisions, and reasoned, goal-directed actions.

In this approach, the steps to be taken, in order, are:

1. the idealization or conceptualization of the problem;
2. symbolization — the construction of a model that represents the idealized problem;
3. manipulation of the model — the performance of logical operations on the model so as to find a solution to the idealized problem;
4. evaluation — testing the ability of the model to represent the real situation by comparing model-based predictions with real observations, or by comparing the results of model-based actions with real world objectives;
5. the formulation, in some instances, of generalizations or hypotheses that become the starting point for a new investigation.

---

\(^1\) Differentiation with respect to \( Q \) gives:

\[
f'(Q) = -2Q/C_i + 4U/C_o
\]

Equating to zero and solving for \( Q \):

\[
Q^* = 2U(C_o/C_i)
\]
The above steps are shown in flow-chart form in Fig. 8.

In practice, many subsidiary steps are involved at every stage of the sequence. The “right” questions or hypotheses have to be selected, situation data have to be examined, and variables rigorously defined and whenever possible quantified. Trial runs to demonstrate feasibility, adequacy and the suitability of the method are often needed, and the final stage in every project is the interpretation of results in the light of the existing knowledge of the subject and related theory. At this stage, as in selecting the “right” questions, a good deal usually depends on intuition.

Some observations on the identification of problems, project design, sources of data, and other methodological considerations are made in the Annex (see p. 182).

COMPUTING AND COMPUTER SIMULATION

In simulation, the starting point is a set of parameters together with the relations between them; a computer can then be programmed to explore the range of situations that these parameters imply. By means of empirical and probability methods, the computer is often able to propose solutions to numerical problems that are insoluble by formal mathematical analysis, and can show what would probably happen in a variety of hypothetical situations. Simulation, in effect, makes it possible to perform experiments on a computerized model of a situation, and to compare the results obtained with reality. In particular, it is now feasible to explore epidemic situations by this method in a manner that was previously impracticable because of the prohibitive amount of
calculation involved. Examples of this application of simulation will be found in Chapter 5.

OPERATIONS RESEARCH

An operation can be defined as a set of interdependent or interacting activities that are necessary for the occurrence of a desired outcome; both activities and outcome can be treated as defined variables in this set of activities.

By operations research is meant any formalized quantitative analysis whose purpose is to improve efficiency in a situation where "efficiency" is clearly defined. Typically, operations research is used to optimize an objective function (see pp. 36 and 54) that is defined in quantitative terms.

When the optimization method is employed, the usual objectives are either to provide a given level of service in the most economical way, or to provide the best service with the given resources, i.e., to indicate what service should be provided and how this can best be done with the resources available.

Operations research does not, however, necessarily require the use of special techniques, and does not exclude other management and planning procedures. With this qualification, operations research can be said to be the use of the scientific approach in the study of operations.

The special techniques that it employs for operations on models include:

1. network analysis (PERT, critical path analysis);
2. linear programming and other optimization procedures;
3. computer simulation procedures (already mentioned); and
4. applications of queueing theory (see Chapter 2, p. 62).

It also employs statistical analysis, projection and extrapolation methods, budgetary and accountancy methods, including, in particular, cost-effectiveness analysis, work studies and, perhaps more controversially, applications of decision-tree theory and gaming exercises.

Operations research may be contrasted with systems analysis. The latter is usually concerned with problems in which the difficulty lies in deciding what ought to be done, not simply how to do it most efficiently. Both systems analysis and operations research have to deal with practical problems of choice or decision, but with a difference. Systems research is concerned mainly with the strategy of choice, operations research with the tactics. Only rarely are the problems fully understood in either case, but they are more completely specified in opera-
tions research than in systems analysis. The models used in operations research, though often tentative as compared with those of pure science, are more circumscribed and better defined than those used in systems analysis. When objectives are unambiguous, criteria precisely defined and data adequate, the models of operations research are quantitative and incorporate quantified relationships. Typically, they are mathematical in form and employ optimization techniques that are rarely feasible in systems analysis.

THE OBJECTIVIZATION OF DECISION-MAKING

Two broad categories of administrative decisions can be distinguished:

1. **Policy decisions**: these involve the definition of objectives that commit an organization to some overall purpose, and usually involve a choice between conflicting aims;

2. **Operational or managerial decisions**: these relate to the implementation of policy decisions. They include allocation decisions authorizing the utilization of resources within the constraints of an adopted policy, and coordinating decisions for maintaining organizational integrity.

Priority decisions are a sub-class of policy decisions. They are concerned with:

(i) establishing a time order for various programmes and with such matters as coverage (e.g., local; regional; national; industrial groups; social groups);

(ii) need-demand rankings (e.g., vulnerable groups); and

(iii) economic ratings relating to an overall allocation of resources. They answer questions such as when and for whom something should be done and, broadly, the means to be employed.

Operational decisions are also concerned with timing and coverage, as well as with cost and efficiency, but with the difference that they are taken in the context of the policy decisions they are intended to implement.

In the final analysis, all decisions depend on value judgements or on the allocation of priorities — policy decisions more evidently so than operational decisions — and no information system or analytical technique can alter this fact. When, as in optimization procedures, for instance, it appears superficially that decisions on ways and means are entirely formalized and value-free, it turns out that this is so only because a value-dependent decision to optimize in some regard has been taken for granted. In a sense, indeed, optimization is the converse
of decision-making, in so far as it is the consequence of a decision, namely that a certain parameter should, in some respect, be maximized or minimized.

Whilst in theory managerial alternatives, however complex, can be reduced to a sequence of two-way or yes-no decisions that can be handled by a computer, it remains true that the ultimate responsibility for making decisions rests overtly or covertly on managerial personnel or other individuals or groups.

There is, then, a value element in all decision-making that, though it varies greatly in importance, no conceivable procedure can eliminate entirely. It tends to be large in policy decisions and small, or even negligible, at the operational end of the scale. This is shown diagrammatically in Fig. 9.

![Diagram of decision spectrum]

**Fig. 9. The value element in the decision spectrum**

The aim of rationalizing the decision-making process is to reduce the value element (the shaded area in Fig. 9) to a minimum, i.e., to maximize objectivity, by means of analytical methods. It is necessary, for this purpose:

1. to identify the irreducible human values on which decisions are based;
2. to reveal internal inconsistencies and conflicts in the system of values;
3. to minimize the value element in decisions;
4. to objectivize the residual value-free area by means of an explicit statement of the facts, aims and reasoning on which decisions are based.
Complete objectivity in decision-making, i.e., a situation in which any competent person or body in the same position, and given the same facts and goals, would make the same decision and, a fortiori, would repeat an earlier decision in similar circumstances on a later occasion, is probably an unattainable ideal. This is not to say, however, that decision-making cannot be systematized. On the contrary, decision-making can be substantially rationalized by reducing it to an orderly sequence of steps or stages, as follows:

1. the classification of the problems and objectives involved;
2. the definition of alternative approaches and means, based if necessary on trials;
3. the collection of relevant information about the alternatives;
4. a comparison of the advantages and disadvantages of each, having regard especially to feasibility and the time factor in the assessment of probable benefits, i.e., to the relative weights to be assigned to short-term and long-term benefits;
5. the evaluation, at intervals, of the results of implementing decisions, and the use of feedback for modifying and adjusting subsequent action. (The measurement of progress towards a target is given precision by the division of projects into performance units, and objectivity is enhanced by defining and assigning weights to value judgements on such matters as health and welfare, social well-being, and living standards.)

The way in which formalized decision analysis is structured is illustrated in the example in Chapter 2, p. 70.

In human affairs, decision-making is, as a rule, less simple than the procedure just described. Almost invariably, both policy and executive decisions are provisional, not final. As decisions are made in sequence, later decisions are likely to be affected by the observed consequences of earlier decisions. Evaluation is not only a formal review of operational experience, but also an element in the feedback on which subsequent decisions are partly based. In addition, situations often change whilst the decision-maker is obtaining information and considering the facts at his disposal. Finally, especially in public services, decisions are made not by one person but by committees, boards and other groups. The decision-making machinery itself may then influence the outcome no less than the decision-making process.

Ideally, leadership would be uninfluenced by personal interests and attitudes, and would adequately reflect the viewpoint of those whom it claims to represent. Decisions would be made rationally, after fair-minded, dispassionate discussion based on the relevant facts. This situation rarely, if ever exists in practice. Much would often be gained, therefore, from subjecting the decision-making machinery itself to the same kind of analytical study as is applied to decision-making.
Organizations are not, however, usually given to encouraging an objective scrutiny of this aspect of their activities. They tend, on the contrary, to assume and insist that they are properly led and appropriately structured, and that they employ procedures that are not to be examined with an open mind. Nevertheless, the beginnings of a rational approach to this question can be seen in the simulation exercises known as "gaming". These are based on a model of a real decision-making set-up, in which participants in structured groups are presented with a "situation" in which decisions have to be made. Procedural approaches to the problem, the form taken by discussions, requests for further information, susceptibility to extraneous influences, etc., are investigated in the course of such an exercise, using analytical techniques, controls, debriefing and retrospective appraisals. This kind of game, which is akin in its experimental potentialities to computer simulation may, perhaps, prove to be a decision-making technique that encourages an objective exploration of the appropriateness of different decision-making organizational structures and procedures.

CONCLUSION

It may be seen from what has been said above that health practice research is based essentially on the following three principles:

1) the adoption of a multidisciplinary approach, i.e., one not limited by the artificial boundaries between different disciplines;

2) the use, as far as possible, of formalized and objectivized investigatory and decision-making procedures;

3) the explicit statement of aims or objectives in precise terms, whenever the evaluation of results is contemplated.

Of these, the third is fundamental. It is impossible to propose an itinerary for a traveller who has not decided where he wishes to go; it is meaningless to inquire if he has reached his destination if he has no particular destination in mind.
CHAPTER 2

THE METHODS OF OPERATIONS RESEARCH
APPLIED TO HEALTH PRACTICE

The main purpose of this chapter is to consider in greater detail the whole range of operations research techniques, but it is first necessary to define a number of terms. These include "scientific tool", "scientific technique", "scientific method" and "methodology", which have been defined by Ackoff\(^1\) as follows:

1. "By a scientific tool we mean a physical or conceptual instrument that is used in scientific inquiry." Mathematical symbols and tables of random numbers are therefore tools, according to this definition;

2. "By a scientific technique we refer to a way of accomplishing a scientific objective, a scientific course of action. Techniques, therefore, are ways of using scientific tools." Stratified random sampling is thus a technique; it employs the random numbers tool;

3. "By a scientific method we refer to the way techniques are selected in science; that is, to the evaluation of alternative courses of scientific action. Thus, whereas the techniques used by a scientist are results of his decisions, the way these decisions are made is the result of his decision rules. Methods are rules of choice; techniques are the choices themselves." Thus the choice between simple random sampling, stratification, and other sampling designs is a matter of scientific method. The rules for making the choice must be such that the result is based on fact and is reproducible, and not the biased product of the technique selected;

4. "The study of scientific methods is frequently referred to as methodology. The objective of methodology is the improvement of the procedures and criteria employed in the conduct of scientific research."

THE OPERATIONS CONCEPT

Operational systems are characterized by processes that serve to translate inputs into outputs or results. Typically, some of the inputs are uncontrollable disturbances, whereas others are subject to control. Thus the administrator of an emergency care service has little control over patient needs but can control, in large measure, the staff input to the service process.

Control over inputs is inevitably subject to constraints, in terms of the money, manpower, facilities, or time available. The fact that a process exists for converting inputs into outputs (or results) suggests that alternatives are usually available, e.g., two emergency care services may differ markedly in the way their services are organized and delivered. The assessment of results involves value judgements, which may be difficult to make. Finally, elements of uncertainty pervade the entire system, from the type and magnitude of the problems that arise (patient admissions) to the possible effectiveness of alternative treatments (survival rates). Uncertainties of outcome are especially frustrating because of the dynamics of most operations; not only are immediate results indefinite, but those results usually lead to further decisions that yield equally uncertain results. The operations research techniques to be described are therefore largely concerned with means of dealing with resource constraints, the assignment and maximization of values, and the appraisal of alternatives in an uncertain, dynamic environment.

USE OF MODELS

The use of a model of some sort is the basis for each application of an operations research technique. Because of their versatility, lack of ambiguity, and ease of manipulation, mathematical models are the ideal, but this ideal is frequently unattainable in health practice research. As a minimum, any model must: (1) convey information (not always quantitative); (2) illuminate appropriate variables and their relationships to each other, including factors of uncertainty or chance; (3) provide a structure for analysis or simulation; and (4) be an abstraction of such a character as to allow manipulation without misrepresenting the real situation. Within this broad framework, models can be descriptive, predictive, or prescriptive (see p. 33).

A model that enables precise, quantitative relationships to be expressed unequivocally for prescriptive purposes is the classical inventory model described earlier (see p. 38).

A programme administrator requires the services of 48 laboratory technicians; since they remain for only two years on the average, he must recruit and train a new batch of candidates at intervals. Frequent training courses are costly, but are necessary if there is not to be unavoidable overstaffing at times to allow for attrition during the intervals between replacements. Should training courses be conducted annually, semi-annually, or quarterly?

It is necessary to identify the relevant costs involved, describe their relationship, and predict the effect of the relationship on the total costs of the alternative training patterns. Suppose that a training course costs $2000 to conduct, regardless of the size of class. Suppose further that any technicians available in excess of the 48 required are temporarily assigned to work that could be done by less highly qualified staff who are paid $125 per month less than the technicians.

The relevant factors are:

\[ N_e \] = average number of excess technicians available;
\[ C_e \] = extra cost of carrying one excess technician for one month ($125);
\[ N_c \] = number of training courses conducted per year;
\[ C_c \] = cost per training course ($2000);
\[ C_t \] = total annual cost of a given training pattern.

They are related as follows:

\[ C_t = 12C_cN_e + C_cN_e \]
\[ = 1500N_e + 2000N_e \]
\[ \text{.......................... (1)} \]

The value of \( N_e \) can be 1, 2 or 4. It remains to determine the corresponding value of \( N_e \). Since the technicians remain for two years on the average, the administrator must count on replacing 24 of them each year. If he does so by means of a single annual training course, the 24 graduates will be absorbed over the course of an entire year. As a result, in an average month, 12 will be in excess, causing an extra charge of $18 000 for the year. On the other hand, two semi-annual groups of 12 graduates each will result in an excess ranging from 12 to 0, or an average of 6, at an annual cost of $9000. In general, the number of graduates is \( 24/N_e \) and \( N_e \) is half as large, or:

\[ N_e = \frac{12}{N_e} \]
\[ \text{.................................................. (2)} \]
Therefore, from Equation 1:

\[ C_t = \frac{(1500)(12)}{N_e} + 2000N_e \]
\[ = \frac{18000}{N_e} + 2000N_e \] \hspace{1cm} \text{(3)}

By substituting values of 1, 2 or 4 for \( N_e \) in Equation 3, we obtain the results shown in Table 1.

Table 1. Illustrative costs of alternative training patterns for laboratory technicians

<table>
<thead>
<tr>
<th>No. of training courses ((N_e))</th>
<th>Average no. of excess technicians (\bar{N}_e = \frac{12}{N_e})</th>
<th>Extra cost of excess technicians (18000 \frac{1500N_e}{N_e} = \frac{270000}{N_e})</th>
<th>Cost of training (2000N_e)</th>
<th>Total cost ((C_t))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>18000</td>
<td>2000</td>
<td>20000</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>9000</td>
<td>4000</td>
<td>12000</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>4500</td>
<td>8000</td>
<td>12000</td>
</tr>
</tbody>
</table>

Equation 3 describes the cost inter-relationships, from which one can predict the results of specified training patterns, as given in Table 1. Such predictions, however, do not necessarily provide the optimal pattern. In order to obtain this, we must first state explicitly the objective of the optimization. In the present case, we obviously seek to minimize \( C_t \); in Equation 3; this is therefore identified as the objective function. In general, objectives are of two types: (1) those that retain things of value (input minimization); and (2) those that obtain things of value (output maximization). Attempts to achieve concurrently the highest output and the lowest input are impossibly ambiguous.

Having specified an objective function, it is frequently possible to obtain an optimal solution. In the present example, use of the differential calculus (see p. 39) yields the minimum cost \( C_t = 12000 \), for \( N_e = 3 \). Alternatively, the optimal solution can be obtained graphically, as in Fig. 10, which makes clear the problem of balancing the opposing costs. To the right of the optimal solution, the cost of excess technicians increases faster than the corresponding training costs decrease, whereas to the left of the optimal solution the converse is true.

It might be argued that the above approach to the problem is oversimplified. It is unrealistic to assume, for example, that the health technicians terminate employment at an exactly constant rate. It is
likewise naive to expect that every trainee will satisfactorily complete the course. These and other complicating chance factors can, however, be incorporated into the model. The question is whether the greater realism thus achieved would lead to conclusions sufficiently different from those reached above to make the additional effort worth while.

A PROBLEM IN SCHEDULING

Realistically or not, we were able in the preceding illustration to insert quantitative information into a clearly defined mathematical model for the purpose of prescribing an optimal course of action. At the other extreme, certain situations lend themselves at best to systematic description falling far short of precise quantification. Networks of activities associated with the scheduling of large-scale multifaceted
projects are typical of such situations. As before, the example presented is stripped of everything except the basic elements necessary to demonstrate network analysis techniques.

A systematic description of the problem begins with the listing of all the discrete activities to be performed, each with a well-defined endpoint denoted by an event. For example, the development of a multiphasic screening programme might include such activities as the installation of an X-ray unit and the provision of a supply of cervical cytology kits. The corresponding events would be identified by such statements as “X-ray unit in place” and “cervical cytology kits received”, indicating the completion of the activities concerned.

Typically, the scheduling of the activities is somewhat constrained by sequencing requirements. The installation of the X-ray unit cannot begin, for instance, until floor construction has reached a certain stage. It is possible, therefore, that the opening of the multiphasic screening unit would appear to be delayed, e.g., by the absence of an X-ray unit, when in fact the cause of the delay can be traced to a much earlier stage. This sequencing constraint on activities makes network analysis far more than a trivial display of programme events.

To illustrate the technique, let us suppose that an earthquake in a certain area has created a sudden need for an emergency relief centre. Orders have been issued for the construction, staffing, and supplying of the centre within a fifteen-day period. Is this feasible?

The analysis begins with a listing (see Table 2) of the individual jobs

Table 2. List of events involved in activating an emergency relief centre

<table>
<thead>
<tr>
<th>Event no.</th>
<th>Event description</th>
<th>Estimated time (days)</th>
<th>Predecessor event</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Start</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1</td>
<td>Building framework in place</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Electrical wiring installed</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Plumbing installed</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Cement floor ready for use</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Brick outer wall completed</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Inside walls plastered and dry</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Roof installed</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Drug list authorized</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>Drugs ordered</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>Drugs received</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>11</td>
<td>Personnel authorized</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>Personnel recruited</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>13</td>
<td>Personnel trained</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>14</td>
<td>Finish: relief centre operating</td>
<td>2</td>
<td>2,4,5,6,7,10,13</td>
</tr>
</tbody>
</table>
that must be done; this consists of a brief description of the associated events, to which reference numbers are arbitrarily assigned. It is also necessary to record the estimated time (in whatever units are most suitable) for the performance of each of the tasks. In view of the problem of sequence, we must also identify for each task the last job that must be completed before the one in question can be started (the predecessor event). For example, Job No. 5, which involves the laying of bricks to form the exterior wall of the building, cannot be begun until the basic framework, associated with Job No. 1, is in place.

Once Table 2 has been compiled, the network of Fig. 11 can be drawn; this shows the individual events in their required sequence and lists the estimated times involved. Network analysis can then be carried out, either on the basis of the diagram itself or, in more complicated cases, a computerized analogue of the network.

Many paths lead from the start to the finish of the project. Presumably, one of these will require more time to traverse than any of the others, and thus will be of special concern. In Fig. 11, this so-called critical path is the sequence 0-1-6-14; this is denoted by a double line. Only by finding ways to reduce the time required for the critical path can the overall project time be reduced. In the example, the estimated time required to traverse this path is 16 days, i.e., one more than the number of days initially allotted to the project.
Every path except the critical path has *slack time*; this is the difference between the time for the critical path and that associated with the path concerned. Thus the estimated time required for path 0-11-12-13-14 is 12 days, so that this path has four days slack time.

Such estimates are useful for two reasons. In the first place, the non-critical path with the least slack time shows the maximum reduction in total project time that can accrue from modifications of the critical path. Suppose, for example, that the project director, recognizing Job No. 6 to be critical, decides to consider the use of a more costly, prefabricated substitute for plaster. If this change reduces the time required for Job No. 6 from ten days to six, the time required for what was formerly the critical path will be reduced by four days, but total project time will be reduced by only two days. This is because path 0-8-9-10-14 will then become critical, so that the only saving in project time will be the two days of slack time formerly associated with this path.

The second use of slack time is to provide flexibility. Thus path 0-11-12-13-14 has two days more slack time than path 0-8-9-10-14. Both paths entail administrative procedures in the form of personnel authorization in the first case and drug authorization in the second. Recognizing that these two administrative tasks are of different degrees of urgency, the project director might choose to take early, perhaps costly, action to expedite the drug authorization, even at the expense of a slight increase in personnel authorization time. In order better to visualize the possibilities in this direction, the project director would probably compile a list of *late start* and *late finish* times for each job. These indicate the maximum delay that can be tolerated in the initiation or completion of any activity without affecting the total project time.

The approach to network analysis just described is called the critical path method (CPM). It suffers from the disadvantage that it fails to take account of one major factor, namely the possibility of error in the time estimates. The programme evaluation and review technique (PERT) is the best known approach that does take this factor into account. In PERT, the estimator provides not only an expected time requirement for each activity, but "most pessimistic" and "most optimistic" estimates as well. The calculated required time is a weighted average in which the best estimate is given four times as much weight as either of the other two. It is then possible to calculate, e.g., the likelihood of completion by the target date, the most probable completion date, etc.

The procedure known as PERT/COST enables resource costs to be added to the schedule produced by the PERT procedure. As we have seen in our simple illustration of plastering, time can often be purchased at a price. Even apart from this, the allocation of expenditures is im-
important in its own right. Similarly, PERT/MANPOWER takes account of the importance of personnel allocation and utilization.

Since a plan usually includes several projects, a technique known as resource allocation and multiproject scheduling (RAMPS) has been developed. Where results can be achieved in a variety of ways, the alternative sets of activities can be analysed by means of decision CPM.

Greater sophistication in approach may yield more meaningful results, but it also requires more and better information and greater analytical effort. Even in the form of CPM, however, network analysis is useful in providing a framework for the orderly consideration of complex problems.

LINEAR PROGRAMMING TECHNIQUES

Every linear programming formulation requires the specification of an objective function, whether in terms of benefits to be maximized or costs to be minimized. Suppose, for example, that a family planning programme is intended to maximize the number of births prevented annually, and that four woman-years of IUD protection or two woman-years of oral contraception are required to prevent one birth. What is the ideal contraceptive mix to be sought in order to maximize births prevented?

It is clear that 1000 births can be prevented by providing 4000 women with the IUD for one year, whereas only 2000 oral contraceptors would be required to achieve an equivalent result. In the interests of maximizing births prevented, however, unlimited numbers of both types of acceptors are desirable. If these conditions are represented graphically, a series of lines depicting specific members of births prevented by various contraceptive mixes is obtained (see Fig. 12A), the numbers increasing as we move upward and to the right in the graph. The linear (straight line) relationship results from the assumption that each additional contraceptive user exerts the same impact on births as previous users.

In practice, monetary, manpower, or other constraints force us into an "either-or" situation, instead of one in which the opportunity for benefit is unlimited. Consider possible manpower limitations first. Let us suppose that our family planning clinic has only four workers, each available for 2000 hours per year, and that they require three hours of activity for each oral contraceptive and two hours for each IUD user. This means that the 8000 total available hours can be devoted to at most 4000 IUD users, 2667 oral contraceptors, or to some particular
Fig. 12. Diagrams illustrating the application of linear programming to a family planning programme; B = number of births prevented.
combination of the two. Even so, as shown by Fig. 12B, many feasible contraceptive mixes exist.

In the relatively simple problem considered here, the principles of the technique are more readily understood if the problem is solved graphically rather than by means of a set of rules for arithmetical manipulation. Any point within the triangle AOC in Fig. 12B represents a feasible mixture of oral and IUD contraceptors, in the sense that sufficient manpower is available to serve them. Point X, for example, represents 1000 oral contraceptors and 2000 IUD users. At three hours each for the former and two hours each for the latter, this combination would require:

\[(1000) \times 3 + (2000) \times 2 = 7000 \text{ hours}\]

This is less than the 8000 hours that are available.

Fig. 12B also shows five of the infinite number of lines corresponding to all the contraceptive mixes that would serve to prevent a given number of births. Point X, for instance, represents one of the many mixes associated with the prevention of 1000 births per year. If we take any such line, we know that a parallel line to the right and above it will necessarily correspond to greater benefits still (more births prevented). Since our goal is to maximize the number of births prevented, we choose the line farthest from the origin 0, but inside the feasible area AOC. This leads us to point C, which is just feasible. In effect, we are led to the conclusion that the programme should be restricted to oral contraceptives. With 8000 service hours available, we can provide \(8000/3 = 2667\) woman-years of protection. With each two woman-years serving to prevent one birth, this approach would prevent a total of 1333 births.

Now let us introduce a financial constraint. We shall suppose that each woman-year of oral protection costs $80, each woman-year of IUD protection costs $15, and the programme has a total budget of $100 000. Thus it could support at most 1250 oral contraceptors, 6667 IUD users, or some particular combination of the two. This constraint is included in Fig. 12C, from which it can be seen that finance is principally a barrier to the use of oral contraception. In effect, the additional financial constraint has served to bend line AC of Fig. 12B to form line ADC' in Fig. 12C. The feasible area is now AOC'D.

Using the same approach as before, we arrive at point D. This means that the high costs associated with the oral programme would suggest a shift to a combined IUD-oral programme. The optimal mix would consist of approximately 700 oral users and 2950 IUD users. This would utilize the 8000 hours of available time and the $100 000 allocation to prevent a maximum of:

\[(700) \times 0.5 + (2950) \times 0.25 = 1088 \text{ births}\]
Financial limitations therefore serve to reduce the number of births prevented by:

\[ 1333 - 1088 = 245 \]

Under these conditions, the cost per birth prevented is $92. In the absence of financial constraints, a programme restricted entirely to oral contraceptives would be recommended, at a cost of:

\[ (2667) \times (80) = \$213,360 \]

Thus the additional 245 births prevented would cost an extra $113,360, or $463 per birth prevented. This high cost is the consequence of the need to make the best use of limited manpower resources. The next step is therefore to consider the situation in which additional manpower is available but additional funds are not. In this case, constraint line AD of Fig. 12C would be removed and an extension of line CD would take its place. Benefits would then be maximized by putting the entire $100,000 budget into an IUD programme capable of handling 6667 women at a cost of $15 each. This programme would prevent 1667 births annually at a cost of $60 each, but would require 20,000 service hours, i.e., a staff of 10 workers.

In summary, the linear programming approach ultimately yields an optimal value of an objective function, and does so in a finite number of steps, proceeding systematically from one “corner” to another within the area of feasible solutions. Furthermore, in the course of finding a solution, it reveals the effects of the constraints imposed. In addition, the particular objective function selected has an important bearing upon the conclusions reached. Instead of maximizing programme benefits in the present case, for example, we might have chosen to minimize costs, subject to the constraint that a specified minimum number of women-years of protection should be afforded by the programme.

A number of highly specialized algorithms have been developed to handle particular types of problem. One particularly important type concerns the allocation of the output from a number of different sources to a variety of destinations. A typical practical example is the transportation problem in referring widely scattered clinic patients to geographically separated hospital facilities. This is known as the transportation problem, and the associated transportation technique is used for its solution, but has much wider applications to other problems that are essentially of the same type. Similarly, inventory models need not always deal with stocks of commodities.

Suppose that five clinics, with the monthly referral loads shown in Table 3, send patients to three hospitals, whose capacities to accept
referrals are also shown. Provided that unit costs can be quantified and are constant, as shown in Table 3, the transportation technique of linear programming can be used to establish the least costly referral pattern. Starting with any feasible arrangement, the technique guides one stepwise to the optimal solution, as shown in Table 4.

Table 3. Data for determining optimal referral pattern

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Clinic A (monthly referral load: 30)</th>
<th>Clinic B (monthly referral load: 50)</th>
<th>Clinic C (monthly referral load: 40)</th>
<th>Clinic D (monthly referral load: 60)</th>
<th>Clinic E (monthly referral load: 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (capacity: 90)</td>
<td>10</td>
<td>20</td>
<td>5</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Y (capacity: 40)</td>
<td>2</td>
<td>10</td>
<td>8</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>Z (capacity: 80)</td>
<td>1</td>
<td>20</td>
<td>7</td>
<td>10</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 4. Optimal referral pattern based on data of Table 3

<table>
<thead>
<tr>
<th>To hospital</th>
<th>From clinic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>X</td>
<td>—</td>
</tr>
<tr>
<td>Y</td>
<td>—</td>
</tr>
<tr>
<td>Z</td>
<td>30</td>
</tr>
</tbody>
</table>

PROBLEMS OF ESTIMATION

In its simplest form, uncertainty is merely the ignorance associated with incomplete information; we sample a population but are unsure of the characteristics of the totality. This situation is extremely common, largely because reasonably precise estimates can often be made at a cost lower than that of a complete enumeration.

Questions of sample selection, adjustment for day of week or season, and related matters lie in the realm of survey design and sampling theory, which are largely outside the scope of this publication. We are concerned, however, with the statistical techniques available for handling uncertainty once we are assured of an unbiased representation of the universe under investigation. For example, suppose that the data shown in Table 5 are the results of a random sample, covering a ten-day
Table 5. Distribution of patient visits on random sample of ten days

<table>
<thead>
<tr>
<th>Sample day</th>
<th>No. of patients</th>
<th>Deviation from average</th>
<th>Square of deviation from average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29</td>
<td>-18</td>
<td>324</td>
</tr>
<tr>
<td>2</td>
<td>54</td>
<td>7</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>46</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>41</td>
<td>-6</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>63</td>
<td>16</td>
<td>256</td>
</tr>
<tr>
<td>6</td>
<td>51</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>43</td>
<td>-4</td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>13</td>
<td>169</td>
</tr>
<tr>
<td>9</td>
<td>28</td>
<td>-19</td>
<td>361</td>
</tr>
<tr>
<td>10</td>
<td>55</td>
<td>8</td>
<td>64</td>
</tr>
<tr>
<td>Total</td>
<td>470</td>
<td></td>
<td>1292</td>
</tr>
<tr>
<td>Average</td>
<td>47</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

period, and that from them we wish to estimate the long-run average daily patient load.

The sample data yield an average of 47 patients and a standard error of 3.8.\(^1\) From tables of the “t” distribution, it can be seen that there are nine chances in ten that the sample average will differ by as much as 1.83 standard errors, or 7 patients, from the long-term average. On the basis of this degree of uncertainty, therefore, we estimate that the average patient load lies between 40 and 54 patients daily. There is one chance in ten that the true average will be outside this range, but we consider that possibility to be sufficiently unlikely for it to be disregarded for working purposes.

---

\(^1\) The standard error (SE) is defined as:

\[
SE = \sqrt{\frac{SSQ}{(n)(n-1)}}
\]

where:

- SSQ = sum of squared deviations from average
- n = no. of observations in sample

From Table 5 we have:

\[
SE = \sqrt{\frac{1292}{(10)(9)}}
\]

\[
= \sqrt{14.36}
\]

\[
= 3.8 \text{ patients.}
\]
The incompleteness of sample information is an important but by no means the sole source of uncertainty. Even with a complete record of patient visits, factors such as the day of the week, the season, weather conditions, and a host of others, would remain. If the effect of these conditions on patient visits were known, one could more precisely estimate the number to be expected on a rainy Monday in June. Time is yet another factor in uncertainty: an adequate understanding of present circumstances does not guarantee perfect estimates of the future.

For removing as much of the uncertainty as possible regarding the future state of some factor, techniques are available for analysing its relationship to other factors that can be measured in advance. In order to predict with reasonable accuracy the number of hospital beds needed in a given area in 1980, for example, one might identify the factors that significantly affect utilization rates. If these factors have clearly defined trends, the corresponding trend in bed demand can then be predicted with confidence.

Multiple regression analysis is commonly employed in this connexion. Feldstein & German,\(^1\) for example, assumed that the number of hospital patient-days per thousand population (P) in the states of the USA is a function of at least six factors: (1) median family income in dollars (E); (2) percentage of the population with hospital insurance coverage (I); (3) percentage of population aged 55 and above (A); (4) percentage of population residing in urban areas (U); (5) average daily two-bed hospital room rate in dollars (R); and (6) percentage of population non-white (N). The following model was proposed:

\[
P = k_1 + k_2E + k_3I + k_4A + k_5U + k_6R + k_7N 
\]

(4)

where \(k_1, k_2, \text{ etc.},\) are numerical coefficients. In contrast to our earlier illustrations of mathematical models, however, the coefficients in this equation could not be quantified in any obvious way.

Instead, the multiple regression technique was used to derive a set of coefficients on the basis of empirical evidence. For example, information on each variable for selected years was subjected to regression analysis to produce Equation 5; this gives predicted values of P that correspond as nearly as possible to the actual values obtained from the 47 geographical areas studied:

\[
P = 220.18 + 0.08E + 0.72I \\
+ 18.58A -4.80U -10.11R -1.86N 
\]

(5)

This equation indicates, for instance, that, for each 1% increase in A (percentage of population aged 55 and above), the number of patient-days per 1000 population tends to increase by rather more than 18, other things remaining constant.

While the regression equation (Equation 5) provides a basis for predicting changes in P on the basis of changes in related factors, it does not indicate how precise the predictions are or the relative importance of the individual factors, from the point of view of their contribution to the overall precision. Information on this point can be obtained from the standard errors of the factor coefficients, listed in Table 6. From tables of the "t" distribution, we find that, with the number of observations available in this case, a "t" value of at least ± 1.68 is necessary to show that the factor concerned really does have a significant effect on the value of P. Thus, while increasing room rates and percentages of non-whites in the population would seem to result in a somewhat lower hospital utilization rate, the evidence is not conclusive. In contrast, income and insurance coverage clearly have an important effect on utilization. We must bear in mind, however, that the regression equation and the estimated standard errors apply only to circumstances similar to those under which the data were collected: their applicability in the future, therefore, cannot simply be taken for granted.

Table 6. Factor coefficients and their significance

<table>
<thead>
<tr>
<th>Factor</th>
<th>Coefficient (k)</th>
<th>Standard error (S)</th>
<th>t = k/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income (E)</td>
<td>0.08</td>
<td>0.03</td>
<td>2.67</td>
</tr>
<tr>
<td>Insurance (I)</td>
<td>0.72</td>
<td>0.23</td>
<td>3.13</td>
</tr>
<tr>
<td>Age (A)</td>
<td>18.58</td>
<td>10.04</td>
<td>1.85</td>
</tr>
<tr>
<td>Urbanization (U)</td>
<td>— 4.80</td>
<td>2.22</td>
<td>—2.16</td>
</tr>
<tr>
<td>Room rate (R)</td>
<td>—10.11</td>
<td>8.64</td>
<td>—1.17</td>
</tr>
<tr>
<td>Non-white (N)</td>
<td>—1.86</td>
<td>2.80</td>
<td>—0.66</td>
</tr>
</tbody>
</table>

If the combined influence of all the factors of concern is taken into account, multiple regression analysis then shows that the standard error of P is 125 in the present case. Thus the number of patient-days per 1000 population predicted for a state from Equation 5 could be in error by as much as:

± (1.68) (125) = 210 patient-days per 1000 population.

Multiple regression is often used, largely because it permits the details of a mathematical model to emerge naturally from empirical
data instead of being specified in advance. This feature can also lead to misuse, for the following reasons: (1) the form of the model, if not the coefficients, must be postulated in advance, and relationships are not always simply additive, as assumed in Equation 4; (2) the regression technique sometimes has difficulty in separating out the effects of the individual factors; and (3) a set of coefficients that provide an equation of “best fit” for one set of data cannot necessarily be applied to another set of observations made at another time. In short, any mathematical model must be an appropriate representation of reality, and regression models are not exempt from this requirement.

PREDICTION: QUEUEING

The operation of, for example, a paediatric clinic is only partially described by stating that it accommodates, on the average, 100 patients per day. We also need to know the arrival patterns in the course of the day, the variability in service time per patient, the typical number of patients waiting to be seen at any given time, the time patients spend at the clinic, and the proportion of clinic staff idle time due to lack of patients. The administrator will also want to predict what would happen if the patient load increased or if the method of processing patients were altered in some way.

For purposes of illustration, we shall suppose that a paediatric service is operated as a 24-hour walk-in non-appointment clinic, and that the probability that a patient will arrive at the clinic at a given moment remains constant with time. Thus an arrival at 9.12 a.m. is equally as likely as one at 8.27 p.m. Such a situation is defined mathematically by the Poisson probability distribution.

We assume further that the clinic always has on duty one doctor who sees patients on a first-come-first-served basis. Finally, we suppose that, during the time that the doctor is seeing the patient, there is a constant likelihood that the consultation will terminate at the next moment. Thus the probability that a patient who entered the doctor’s office twenty minutes ago will finish his consultation during the next minute is exactly the same as that of a patient who has been with the doctor only ten minutes. Technically, this situation is described by a negative exponential probability distribution.

Admittedly, the assumed circumstances are somewhat unreal, but the adjustments necessary to bring them into line with reality can be incorporated into a more complex analytical model or allowed for by means of computer simulation. The illustrative model may nevertheless
be more realistic than intuition would suggest. It has been shown, for example, that the duration of telephone conversations often tends to follow a negative exponential distribution. It is not true, therefore, that a person who has already been talking for an hour has nearly finished, whereas one who has been talking for only five minutes will continue for some time to come.

Any Poisson probability distribution can be completely described once the average arrival rate has been determined. For example, if we know that, in an average hour, four patients arrive at the clinic, we can calculate from the Poisson formula the likelihood that, by chance, as many as 10 patients might arrive during a particular one-hour interval. Similarly, the negative exponential distribution permits a complete assessment of service time variability once the average service time is known. For purposes of analysis, it is useful to relate the arrival rate (A) to the service rate (R) as the ratio (A/R). In practice, this ratio must never exceed unity, since the queue will otherwise increase in size indefinitely; patients will arrive faster than they can be accommodated.

As a health service begins operation, patients arrive in a random fashion and are served in such a way that the system progresses gradually towards a so-called steady state in which its long-term characteristics develop. Five such characteristics are of special interest: (1) the mean number of waiting individuals; (2) the mean number in the system, either waiting or in the process of being served; (3) the mean time a patient waits to be served after his arrival; (4) the mean time a patient spends in the clinic, including both waiting and service time; and (5) the proportion of time in which the clinic staff is idle because no patients are waiting to be served.

These characteristics are all completely dependent on the mean service time and the ratio (A/R) of the arrival rate to the service rate. For purposes of illustration, we shall assume that an average of 10 minutes of service time is required per patient. We can then proceed to determine the operating characteristics for various patient loads.

The results of the computations are summarized in Table 7. The second row, for example, shows what to expect if the arrival rate is half the service rate, i.e., if patients arrive at intervals of 20 minutes, on the average, and require 10 minutes of physician time. Because arrivals are not uniform, tending instead (by chance) to bunch, and service times are likewise variable, the typical patient must wait for 10 minutes to be seen, thereby spending 20 minutes in all at the clinic. Under these conditions there is an average of one patient in the clinic at a time. Because of the bunching associated with patient arrivals, the doctor can expect to be utilized in patient care only half the time, in
spite of the fact that patients must wait an average of 10 minutes to be seen by him.

It can be seen from Table 7 that, as the arrival rate approaches the service rate, there is a marked tendency for patients to begin clogging the clinic. If patient time and satisfaction are of serious concern, one of three things must be done: (1) an appointments system or other means of removing chance from the arrival pattern must be introduced; (2) the clinic must be designed to handle less than its potential capacity of six patients per hour; or (3) another form of service delivery must be tried, such as the employment of two physicians. By providing a method of foreseeing the need to consider these alternatives before this becomes obvious in practice, the model can assist in forestalling serious difficulties. Moreover, if a quantitative value can be attached to patient delay and dissatisfaction, so that comparison with the cost of staff idle time is possible, an optimal pattern of services can be devised.

Table 7. Steady-state operating characteristics of paediatric clinic

<table>
<thead>
<tr>
<th>Mean interval between arrivals (min)</th>
<th>Mean service time (min)</th>
<th>Ratio of arrival rate to service rate (A/R)</th>
<th>Patient-oriented characteristics</th>
<th>Staff-oriented characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean time (min)</td>
<td>Mean no. of patients in clinic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Waiting</td>
<td>Total</td>
</tr>
<tr>
<td>40.0</td>
<td>10</td>
<td>0.25</td>
<td>3</td>
<td>13.</td>
</tr>
<tr>
<td>20.0</td>
<td>10</td>
<td>0.50</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>13.3</td>
<td>10</td>
<td>0.75</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>11.1</td>
<td>10</td>
<td>0.90</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>10.5</td>
<td>10</td>
<td>0.95</td>
<td>190</td>
<td>200</td>
</tr>
<tr>
<td>10.1</td>
<td>10</td>
<td>0.99</td>
<td>990</td>
<td>1000</td>
</tr>
</tbody>
</table>

SIMULATION

In certain situations, arrival patterns may change with the time of day or the season. A clinic may serve several different segments of the population, each with its own arrival pattern. In practice, some patients may be tempted to leave without being served, depending on the number already waiting.

On the service side, the order of patient consultations may be based on a priority system of some kind, rather than the rule of first-
come-first-served. Staffing patterns may be more complex. Several doctors, nurses, and other personnel may attend patients simultaneously, or a given patient may pass sequentially through several stations in the course of a single clinic visit.

Although all of the foregoing possibilities can be reduced to mathematical form, the resulting models are in many cases too unwieldy for rigorous analytical solution. Instead, the individual factors must be expressed in quantitative terms, and their combined influence "observed" by means of computer simulation. If each of the important factors that affect the patient's experience in the system are thus handled in turn, a computer can process in a few minutes a large number of hypothetical patients so as to yield the equivalent of several years of actual experience. This saving of time, however, is not the only advantage of simulation; it can also uncover potential mistakes and inefficiencies that could be very costly in practice.

Although the form of mathematical models varies from case to case, most are probabilistic in nature. While it may be known, for example, that one in ten of the patients has a skin condition, a patient flow model cannot realistically assume that every tenth patient will be a "skin case"; instead, skin conditions are randomly distributed throughout the universe of patients. Computer simulations therefore make abundant use of random number generators, and for this reason the approach is termed the Monte Carlo technique. Correspondingly, manual simulations (which we shall employ for illustrative purposes) rely on published tables of random numbers.¹

To illustrate the simulation process, we shall suppose that, in a small health centre, on any given day there is a 60% probability of a new admission (but not more than one). It is then assumed that, for each patient included in the census of a given day, there is a 20% probability that he will be discharged on the following day. From this information we wish to determine the pattern of admissions, fluctuations in bed utilization, and the average length of stay.

We begin by supposing that it is Day 1 and asking: will a patient be admitted today? In view of the assumed 60% probability, we answer the question by applying the following rule: select a random number; if it is 0, 1, 2, or 3 the answer is no; otherwise the answer is yes, and a patient is "admitted". In fact, a table of random numbers was consulted and an 8 was selected, as shown in Table 8. Thus a hypothetical patient was admitted.

¹ Random number tables have been produced in such a way that each number — from 0 to 9 — has an equal chance of being selected for any position in the table. Moreover, any sub-set of numbers selected for simulation purposes retains the property of randomness, i.e., no correlation exists between any pair of numbers in the sub-set.
We then proceed to Day 2 and repeat the procedure. This time the number 5 was selected, indicating the admission of another patient. On Day 2 we must also ask whether the first patient was discharged. In this case the following rule applies, in view of the 20% probability of discharge: select a random number; if it is 8 or 9, the patient is discharged; otherwise he remains an in-patient. Since the number selected was a 9, the patient was "discharged", and the fact that he remained in the health centre for one day is shown in Table 8.

Table 8. Simulated experience of patient admissions and discharges: first 20 days

<table>
<thead>
<tr>
<th>Day</th>
<th>Random no. for admission</th>
<th>Patient</th>
<th>Discharge determinations</th>
<th>Length of stay (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>A</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>B</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>C</td>
<td>4 1 0 1 8</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>D</td>
<td>4 0 6 3 5 1 8</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>E</td>
<td>1 1 1 9</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>F</td>
<td>7 8</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>G</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>H</td>
<td>2 1 3 6 0 7 8</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>I</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>J</td>
<td>1 4 5 1 5 4 0</td>
<td>Incomplete</td>
</tr>
<tr>
<td>11</td>
<td>4</td>
<td>K</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>L</td>
<td>3 0 5 3 6</td>
<td>Incomplete</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>M</td>
<td>3 5 6 1</td>
<td>Incomplete</td>
</tr>
<tr>
<td>14</td>
<td>4</td>
<td>N</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>O</td>
<td>2</td>
<td>Incomplete</td>
</tr>
</tbody>
</table>

As the procedure is continued, we find that on Day 5 the selection of a 2 indicates that a new patient was not admitted. Patients C and D admitted on Days 3 and 4 remain, however, since in neither case was an 8 or a 9 selected.

The simulation was carried on for 60 days, the first 20 of which are summarized in Table 8. As indicated earlier, admissions tend by chance to occur in bunches; there are admissions on each of the first four days, then only two on the next six days, and then again on each of the next eight days. Even more striking, after an admission on Day 29 (not shown in Table 8) none occurred again until Day 37.
The simulated daily census of patients is shown in Fig. 13. If the 60 days are thought of as two months of 30 days each, the census figures may appear to be strikingly high during the latter part of both "months". The low census figures in the early part of the first month are really due, however, to the fact that the simulation has just begun and has not yet reached a steady state. In contrast, the trough during the early portion of the second "month" is the result of the above-mentioned chance decline in admissions at that time. It is therefore necessary to accumulate enough simulated experience to provide confirmation of the operating characteristics of the system. Furthermore, several simulations should be run on the basis of a single set of decision rules in order to provide a measure of the reproducibility of the results, thereby permitting systematic patterns to be distinguished from chance variations.
The example given is exceptional in that the underlying circumstances are simple enough to enable us to predict much of the system performance without the necessity of lengthy simulations. The 60% probability of an admission, for example, suggests that in 60 days there should be about:

\[ 60 \times 0.6 = 36 \text{ admissions} \]

In fact, the simulation produced 37 admissions, which is unusually close to expectation. Moreover, the 20% daily probability of discharge indicates that the average length of stay should be about five days. In the simulation, the 37 hypothetical patients remained 5.1 days on the average, again a remarkably close correspondence to expected performance. About seven or eight \((37 \times 0.2 = 7.4)\) patients could have been expected to be discharged after one day. The simulated results, shown in Table 9, reveal that 11 patients were discharged after one day. This simply reinforces our earlier warning that simulated findings can lead to confident conclusions only if sufficient “experience” is generated under reasonably realistic circumstances.

<table>
<thead>
<tr>
<th>Length of stay (days)</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>2-4</td>
<td>7</td>
</tr>
<tr>
<td>5-7</td>
<td>9</td>
</tr>
<tr>
<td>8-10</td>
<td>8</td>
</tr>
<tr>
<td>11 and above</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>37</strong></td>
</tr>
</tbody>
</table>

Simulations are most often useful in providing comparisons of predicted system performance under alternative circumstances. Hence we might ask: what would happen if the probability of discharge on any given day were increased from 20 to 30%? Ideally this would require a separate series of runs based on the application of the rule that the random number 7, as well as 8 or 9, counts as a “discharge”. Short of a completely new simulation, we can obtain some evidence of the impact of such a change in policy by referring to Table 8. The revised practice would affect patients F and H, reducing their lengths of stay by one day each. Of the entire group of 37 patients, 14 would be affected, and the mean length of stay would be reduced from 5.1 days to 3.5 days.
We have been dealing with individuals who become disabled, are hospitalized, and in time are discharged. The converse of this situation is one in which pieces of equipment operate satisfactorily for a time and then fail and must be replaced. Although the two sets of circumstances are entirely different in practical terms, their mathematical representations are quite similar. Problems of maintenance and replacement, therefore, like queueing problems, are of considerable interest. They are readily modelled and analysed for purposes of prediction as well as prescription.

Consider a health service, for example, that maintains a certain type of battery-operated device at each of 100 different locations. Batteries are subject to chance failure, and last for one, two, three or four months, with probabilities of 10, 20, 30, and 40 %, respectively. The cost of each battery is $10, and an additional cost of $10 is incurred on the average during the time that the equipment is inoperative before the battery is replaced. The additional cost could be avoided, of course, if batteries were replaced before they failed, but this would increase the number and cost of the batteries consumed annually. The question is whether the reduction in the cost incurred as a result of inoperative equipment would more than offset the additional cost of battery consumption.

Let us first review the existing situation. Of 100 batteries, 10 give one month of service, 20 give two months, etc., or:

\[10 \times 1 + 20 \times 2 + 30 \times 3 + 40 \times 4 = 300 \text{ months of service}\]

This amounts to an average life of three months each, or four replacements per year, corresponding to an annual cost of:

\[400 \times (10 + 10) = \$8000\]

An alternative policy would be to replace after three months or at time of failure, whichever comes first. In this way we could avoid the added $10 cost incurred as a result of the substantial number of potential failures during the fourth month.

Does this intuitively appealing argument stand up to scrutiny? Under the proposed conditions, 100 batteries would provide:

\[10 \times 1 + 20 \times 2 + 70 \times 3 = 260 \text{ months of service}\]

The average life is therefore 2.6 months, on the average. In order to meet the annual requirement of 100 \times 12 = 1200 service-months, therefore, we should require:

\[
\frac{1200}{2.6} = 462 \text{ batteries}
\]
Of these, 60 %, or 277, would incur the full $20 cost, while the remainder would incur a cost of only $10. The annual cost would therefore be:

\[ 277 \times 20 + 185 \times 10 = $7390 \]

Adoption of the proposed policy would thus give a saving of $610.

Should we move further in the direction of preventive maintenance, replacing after two months, or at failure, whichever occurs first? In this case, calculation shows a need for 632 batteries annually, 70 % (442) of which would be pre-failure replacements. The annual cost would then be:

\[ 190 \times 20 + 442 \times 10 = $8220 \]

We conclude that the optimal policy is to replace after three months, or at failure, whichever occurs first.

The concept outlined can, of course, be applied to more realistic, though complex, situations. Suppose, for example, that each health facility had two devices. If a call is made for the replacement of a part in one device, in what circumstances would it be advisable to perform preventive maintenance on the other? Even if there is only one device per location, it might be desirable for the maintenance technician to travel to a nearby location to take some preventive action. Many business organizations, for instance, have achieved substantial cost savings by moving away from a policy of replacing only burned-out light bulbs and instead assigning someone to move through the establishment in order to carry out a pre-determined cyclic schedule of mass replacement.

**DECISION ANALYSIS**

Sound decisions depend upon clearly defined objectives. Once these have been formulated, the decision process includes three basic elements:

1. the alternative strategies or means available for achieving the stated objectives, must be listed;
2. since the decision-maker cannot usually guarantee that the outcome will be precisely what is intended, he must cite the foreseeable possible outcomes and their relative probabilities. A given treatment does not always result in a cure, for example, so that the physician must be aware of the likelihood of partial failure, side-effects, and even death;
(3) values must be assigned, consciously or unconsciously, to the possible outcomes.

If, for instance, one physician rejects the use of a given treatment because it results in five deaths per 100 cases, whereas another uses the same treatment because of its beneficial effects in the remaining 95% of cases, they obviously differ in their valuation of life and well-being.

A formal scheme of decision analysis has been developed in recent years to accommodate systematically all three elements of the decision process. The scheme makes use of "decision trees", constructed to depict all the possible courses of action under consideration, their various results, and the ultimate outcomes that might ensue.

The problem of screening for disease affords a useful basis for comparing decision analysis with other epidemiological and statistical approaches. Any appraisal of a contemplated screening programme must consider disease prevalence rates, sensitivity and specificity levels, and false positive and false negative rates. In addition to quantifying these probability factors, decision analysis takes the additional step of assigning explicit values, or utilities, to the possible consequences of screening. The alternative courses of action are then compared in terms of these numerical probabilities and utilities.

Let us suppose that three alternative strategies are possible:

1. to screen the entire population and administer early, preventive measures to individuals with positive findings;
2. to screen only a selected high-risk group, in spite of the fact that more costly later treatment of other persons who subsequently develop the disease in question will be necessary;
3. not to screen at all.

Table 10 specifies the disease status of a hypothetical population of 100,000 and the anticipated results of screening. We see, for example, that 10% of the high-risk group is in the "true positive" state, compared with 4% of the low-risk group. The available screening technique can identify 95 of every 100 true positives (sensitivity 95%) and 80% of the true negatives (specificity 80%).

Decision analysis also requires the list of values contained in Table 11. To some extent, these reflect the monetary costs of screening and treatment, but also include such intangible factors as the temporary anxiety produced when a "true negative" is identified as a "suspected positive" in screening. Methods of assessing these subjective utilities (or disutilities) form an important part of decision analysis, and are discussed below. The values given in Table 11 are thus relative utilities, rather than purely monetary assessments. Late treatment, for instance, is deemed to be 10 times as costly as the preventive care of true
Table 10. Disease status of population and anticipated results of screening

<table>
<thead>
<tr>
<th>Screening results</th>
<th>High-risk group</th>
<th>Low-risk group</th>
<th>Total population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>True status</td>
<td>True status</td>
<td>True status</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>Negative</td>
<td>Total</td>
</tr>
<tr>
<td>Positive</td>
<td>1900</td>
<td>3600</td>
<td>5500</td>
</tr>
<tr>
<td>Negative</td>
<td>100</td>
<td>14400</td>
<td>14500</td>
</tr>
<tr>
<td>Total</td>
<td>2000</td>
<td>18000</td>
<td>20000</td>
</tr>
</tbody>
</table>

positives. Apart from treatment costs, there are the costs of performing the screening. It has been assumed (see Table 11) that identifying and selectively screening the high-risk group is one-third more costly than the across-the-board screening of the entire population.

Table 11. Hypothetical utilities for use in decision analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Utility per individual (utils)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screening entire population</td>
<td>30</td>
</tr>
<tr>
<td>Selective screening</td>
<td>40</td>
</tr>
<tr>
<td>Early treatment of true positive</td>
<td>100</td>
</tr>
<tr>
<td>Early treatment of false positive</td>
<td>50</td>
</tr>
<tr>
<td>Late treatment</td>
<td>1000</td>
</tr>
</tbody>
</table>

The data given in Tables 10 and 11 can be incorporated into a decision tree for analytical purposes (see Fig. 14). The three alternative courses of action are shown as branches from the "discretionary action" node at the top of the figure. While the action is discretionary, its application to a given member of the population leads to an indefinite outcome; thus the tree gains additional branches stemming from each "chance" node. For example, the decision not to screen carries with it a probability of 0.052 (5200/100 000, see Table 10) that a case will be treated belatedly. This, and other similar probabilities, are shown in parentheses in the diagram. Whenever a case of illness develops in this way, the cost of treatment is 1000 "utils", as indicated in the appropriate outcome box.
Fig. 14. Hypothetical decision tree
The procedure for evaluating alternative courses of action is illustrated in Fig. 15 for the “high-risk screening” course of action. Of the individuals in the screened groups, 9.5% are true positives who incur early treatment costs of 100 utils each, or:

$$0.095 \times 100 = 9.5 \text{ utils per caput}$$

![Decision Tree Diagram]

If the treatment costs for all four outcomes are combined, we obtain an average cost of:

$$0.095 \times 100 + 0.180 \times 50 + 0.720 \times 0 + 0.005 \times 1000 = 23.5 \text{ utils per screened individual.}$$

Similarly, the average cost per low-risk individual is 40.0 utils.

The cost of screening is 40 utils per person, and 20% of the population is in the high-risk group to be screened. In total, the “high-risk screening” alternative involves a cost of:

$$40 + 0.2 \times 23.5 + 0.8 \times 0 = 44.7 \text{ utils}$$
Comparable analysis of the "no screening" and "total screening" alternatives produces average costs of 52.0 and 47.0 utils, respectively. Hence we conclude that high-risk screening is the optimal strategy.

While the preceding example has served to illustrate the structure of decision analysis, actual situations are usually more complex in that they require a series of decisions to be made in sequence. In other words, several discrete actions are interspersed between various chance outcomes over which the administrator has no control. The real merit of decision analysis lies in its ability to apply systematically and sequentially the above procedures to each of the interrelated aspects of a complex problem.

Although the mechanics of decision analysis may seem straightforward, their application may appear impractical because of the reliance that must be placed on subjective judgements. Ways of quantifying attitudes have, however, been devised, such as the "standard gamble", described below.

Suppose that a given medication either produces recovery without side-effects within two days of the onset of illness, recovery in that period with attendant nausea, or recovery without side-effects after three days of illness. How can we compare a patient's feelings about the experience of nausea compared with his attitude toward delayed recovery? One possible way of doing this is to provide him with a series of hypothetical alternatives and analyse his choices.

We might start by offering him two hypothetical drugs, one of which is guaranteed to cure him without side-effects in three days, whereas the other will cure him in two days, but has a 50% probability of producing nausea. Suppose he chooses the latter; our analysis then proceeds as follows. We assign any two utilities arbitrarily, just as we arbitrarily define 0° and 100° on the centigrade scale of temperature. We might assign a value of 100 to a two-day recovery without side-effects and a value of 60 to a three-day recovery; the unknown relative value of a two-day recovery with nausea is called X. From the hypothetical probabilities and the patient's response, we then conclude that he feels that the value of the second drug, namely $100 \times 0.5 + X \times 0.5$ utils, exceeds 60 utils, the value of the first. Mathematical manipulation then shows that X is greater than 20 utils. If X were only 10 utils, then $100 \times 0.5 + 10 \times 0.5 = 55$ utils, which would indicate a preference for the three-day cure, contrary to the patient's response.

In the light of the first response, we might ask the patient: "What if the two-day cure had a 60% probability of producing nausea? Would your preference shift? If he answers "yes" we conclude that $100 \times 0.4 + X \times 0.6$ is less than 60, or X is less than 33.

The two responses combined place X somewhere between 20 and
33. Further questioning along similar lines would serve to define $X$ more precisely and to check the consistency of the patient's responses. If we finally determined that $X$ was 25, we should conclude that, on this patient's relative value scale in which a two-day cure without nausea has a value of 100, a three-day cure without nausea is worth 60 utils, and a two-day cure with nausea is worth 25 utils. In other words nausea is more objectionable than one day of delay in recovery.

In assessing a subjective value, we defined two points on an arbitrary scale and manipulated hypothetical probabilities in order to determine the unknown value in question. In assessing subjective probabilities, the approach shifts to the assignment of values, or "payoffs", to hypothetical bets. Consider, for example, the question of the likelihood of a testing procedure producing a "Disease A" or a "Disease B" finding. Suppose that the age, sex, and previous history of illness of a given patient causes a certain physician to offer a colleague to bet $4 against $1 that, if the test results are positive, the findings will be for Disease B. If the second physician refuses this bet, it means that he feels that his chances of winning $4 are insufficient to justify his risk of losing $1. In effect, he is saying that the odds in favour of Disease A are more than four to one. On the other hand, he might be willing to accept the prospect of winning $6 while taking a risk of losing $1. This means he considers the odds in favour of Disease A to be less than six to one. In the end, he might consider a bet of "$5 against $1" to be neither favourable nor unfavourable to him, indicating that subjectively he considers the probability of a Disease A finding to be five times as high as that for Disease B. In this way, probabilities of 5/6 and 1/6 would be derived.

**DYNAMIC PROGRAMMING**

Useful as descriptive and predictive models can be, our need is usually for prescriptive models, i.e., those that guide us in some sense toward optimal conditions. Optimality, however, implies a scale of values, and such scales are difficult to derive and agree upon in relation to health matters. Nevertheless, even subjective judgements can be quantified and assessed systematically and analytically, as has already been seen.

Problems of another order arise when the relationships to be optimized are not static. Decisions made at one time then tend to give rise to commitments that reduce the number of options available in future decisions. If the time horizon incorporated into each decision is inadequate, the full cost of the consequent inflexibility will not be appreciated.
Even at a particular time, an unduly narrow approach can lead to erroneous conclusions, for it may be unrealistic to consider a set of relationships in isolation from all other factors. An optimal measles immunization programme, for example, might disrupt an existing DPT programme. Moreover, the separate analysis of two programmes that are to be optimized might be, in total, less effective than a single comprehensive appraisal. Consideration of the various elements of a multiphasic screening programme provides a case in point.

Dynamic programming simplifies the solution of large-scale problems by breaking up the total analysis into segments that are handled sequentially. It can be applied either to the simultaneous review of multiple factors or to multiple time periods, but we shall confine ourselves to the latter. Suppose that the health department of a small province wishes to establish a rational basis for phasing the construction of additional health units in anticipation of rising demands for health services. Construction plans are reviewed prior to each five-year plan period, but the provincial health director recognizes the need to consider the impact of each decision over two or three plan periods. At present 10 health units are in operation. These are just sufficient to satisfy existing demand, but there is a strong possibility that one or two additional units will be needed during a given five-year period. In particular, the health director estimates that there are three chances in ten that two new units will be needed, a 50-50 chance that demand will increase by one unit, and two chances in ten that there will be no additional demand.

He decides to enter three costs into the decision process: the construction cost, the cost of unmet demand, and the cost of excess supply. Since the last two costs must allow for such intangibles as patient dissatisfaction and low staff morale as a result of inactivity, direct expression in monetary terms is not adequate. Suppose, for the sake of argument, that the health director has somehow concluded that unmet demand for the services of one health unit during a plan period should be costed at 40 utilis, and building a unit at 20 utilis, and that, if the unit proves not to be needed, an additional cost of 10 utilis per plan period is incurred.

Granted the advantage of a 15-year planning horizon, matters would be much simpler if the events of the first 10 years were known, since we then face only the more manageable task of planning for a single five-year period. The dynamic programming approach begins, in fact, with the last period, taking account of the possible states of affairs that could prevail at that time, and proposing an optimal course of action for each.

Suppose, for example, that there is a demand for 12 units by the
end of the second plan \((D_2 = 12)\), and that only 11 units are in operation \((S_2 = 11)\). Our task then would be to determine the optimum value of \(S_2\), the value of \(D_3\) being 12, 13, or 14, with a corresponding probability of 0.2, 0.5, and 0.3 respectively. Table 12 summarizes the costs associated with various values of \(S_3\) and shows that expected costs would be minimized if \(S_3 = 13\).

The detailed calculations shown in the table follow the first set of general formulae shown in the footnote to the table. The terms in the formulae depend on the relation of \(S_3\) to 13. If fewer than 13 health units are planned, there is no possibility of excess supply; if more than 13 units are planned, there is no possibility of unmet demand; if exactly 13 units are planned, there is a fixed likelihood of having one health unit too many or one too few.

<table>
<thead>
<tr>
<th>(S_3)</th>
<th>Cost of construction (units)</th>
<th>Expected cost of</th>
<th>Total expected cost (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Excess supply</td>
<td>Unmet demand</td>
</tr>
<tr>
<td>11</td>
<td>—</td>
<td>—</td>
<td>40(0.2 \times 1 + 0.5 \times 2 + 0.3 \times 3)</td>
</tr>
<tr>
<td>12</td>
<td>20 \times 1</td>
<td>—</td>
<td>40(0.5 \times 1 + 0.3 \times 2)</td>
</tr>
<tr>
<td>13</td>
<td>20 \times 2</td>
<td>10(0.2 \times 1)</td>
<td>40(0.3 \times 1)</td>
</tr>
<tr>
<td>14</td>
<td>20 \times 3</td>
<td>10(0.2 \times 2 + 0.5 \times 1)</td>
<td>—</td>
</tr>
<tr>
<td>15</td>
<td>20 \times 4</td>
<td>10(0.2 \times 3 + 0.5 \times 2 + 0.3 \times 1)</td>
<td>—</td>
</tr>
</tbody>
</table>

* General formulae:

<table>
<thead>
<tr>
<th>Value of (S_3)</th>
<th>Excess supply</th>
<th>Excess demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&lt; 13)</td>
<td>20(S_3 - 11)</td>
<td>+ 40(12 - S_3) + 44</td>
</tr>
<tr>
<td>13</td>
<td>20(S_3 - 11)</td>
<td>+ 14</td>
</tr>
<tr>
<td>(&gt; 13)</td>
<td>20(S_3 - 11)</td>
<td>+ 10(S_3 - 12) - 11</td>
</tr>
</tbody>
</table>

General formulae for other values of \(S_2\) and \(D_2\), on the assumption that \(S_3\) is at least as large as \(S_2\):

<table>
<thead>
<tr>
<th>Value of (S_3)</th>
<th>Excess supply</th>
<th>Excess demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&lt; D_2 + 1)</td>
<td>20(S_3 - S_2)</td>
<td>+ 40(D_2 - S_3) + 44</td>
</tr>
<tr>
<td>(D_2 + 1)</td>
<td>20(S_3 - S_2)</td>
<td>+ 14</td>
</tr>
<tr>
<td>(&gt; D_2 + 1)</td>
<td>20(S_3 - S_2) + 10(S_3 - D_2)</td>
<td>- 11</td>
</tr>
</tbody>
</table>

The first set of formulae in the footnote to Table 12 can be extended to cover other values of \(S_2\) and \(D_2\). Thus, even though we must consider all possible states of affairs that might exist at the end of Planning Period 2, they can be conveniently summarized and the following general decision rule established:

Regardless of the state of affairs after Period 2, increase the number
of health units in Period 3 to one more than the Period 2 demand level. Then the Period 3 expected costs (EC₃) will be minimized at:

\[ EC₃ = 20(S₃ - S₂) + 14 \] .......................... (7)

We have so far excluded as inappropriate most of the courses of action that might have been considered for Period 3. Moreover, we have consolidated the remaining alternatives into a clearly formulated decision rule. As a result, we can move back in our thinking to the end of Period 1, and begin planning for Periods 2 and 3 with only a little more difficulty than would be required to plan for Period 2 alone.

At this stage, the analysis is similar to that shown in Table 12 and produces similar equations, except for the addition of a term to cover Period 3 expected costs. In particular, Equations 8, 9, and 10 below summarize the combined costs applicable to Periods 2 and 3 (EC₂₃):

For \( S₂ < D₁ + 1 \):
\[ EC₂₃ = 20(S₂ - S₁) + 40(D₁ - S₂) + 44 + EC₃ \] .......................... (8)

For \( S₂ = D₁ + 1 \):
\[ EC₂₃ = 20(S₂ - S₁) + 4 + EC₃ \] .......................... (9)

For \( S₂ > D₁ + 1 \):
\[ EC₂₃ = 20(S₂ - S₁) + 10(S₂ - D₁) + 44 + EC₃ \] .......................... (10)

In testing possible values of \( S₂ \) in these formulae, we discover that expected costs are minimized if \( S₂ = D₁ + 2 \). The appropriate decision rule is therefore as follows:

Regardless of the state of affairs that might exist at the end of Planning Period 1, increase the number of health units in Period 2 to two more than the Period 1 demand level. Periods 2 and 3 expected costs (EC₂₃) will be minimized at:

\[ EC₂₃ = [20(S₂ - S₁) + 10(S₂ - D₁) - 11] + [20(S₂ - S₂) + 14] \]
\[ = 20(S₂ - S₁) + 10(S₂ - D₁) + 3 \] .......................... (11)

On the basis of similar calculations, it can be shown that the optimal policy at the end of Period 0 (now) is to increase the number of health units to two more than the present demand level. As we review the entire process of analysis, we see that, in failing to look beyond a single planning period, the apparently optimal policy conservatively fixes the number of health units at the level of anticipated demand. In contrast, a longer-range view yields an optimal policy that fixes the number of health units at the level of maximum demand during the five-year planning period. In effect, the longer-range approach recognizes that, even though the prospects for the immediate maximal use of the proposed health unit are not good, the cost of construction
will have to be incurred sooner or later, and there is some advantage in incurring it sooner.

In this example, we have shown the advantage of using a ten-year (two-period) planning horizon instead of a single five-year horizon, but that nothing is gained by extending the horizon to 15 years. This type of finding is important, for in practice one would be led to a rolling reference period whereby plans would be made at five-year intervals, the subsequent ten years being borne in mind at each five-year review. This could lead, in turn, to more frequent reviews of rolling ten-year planning horizons.

In summary, the dynamic programming technique can be useful for indicating how comprehensive the view of a given set of circumstances should be. The technique also serves to divide the total problem into manageable parts, while still providing an optimal solution applicable to the whole.
CHAPTER 3

HEALTH CARE IN THE COMMUNITY

Comprehensive analyses of health care delivery systems are virtually non-existent because of the multiplicity of factors and the diversity of units of measure involved. Ideally, we should be able to compile a list of community health problems and to relate them to the available resources in terms of the specific services provided. In practice, however, this is not easy.

To begin with, the patient with a problem sees it from the viewpoint of his “complaint”, whereas the health professional thinks of it as a diagnostic category. The problems identified vary from such non-specific entities as “cough” or “fever” to diagnosed cases of “active tuberculosis”. Moreover, the translation of health problems into “needs” for specific health services is by no means unambiguous. A short-lived low-grade fever may have entirely different care implications from a fever lasting for a week or more and associated with persistent cough, and in either case there may be disagreement about the health care implications.

From the point of view of resources, it is usually known that, during a particular period, a certain number of doctor-hours, nurse-hours, X-ray units, etc., will be available. The difficulty then arises of attempting to disentangle the enormous number of service mixes and organizational arrangements that might be derived from these resources.

Notwithstanding such difficulties, however, it is clear that services provide the common denominator whereby health problems and resources can be related in a comprehensive systems analysis. In assessing these services, we should not be limited by traditional organizational boundaries, such as paediatrics, internal medicine, or public health. It has proved to be more informative to base the analysis on functional categories, such as well child care, family planning, medical relief, and mass control of communicable diseases. Within each functional area to be investigated, the specific activities of the various personnel categories can then be portrayed with respect to the health problems in question.
The time devoted to the various functions might be analysed as shown in Table 13. Such a table shows, for example, the current distribution of well child care activities among different types of professional personnel, and would enable the time devoted to such care to be compared with the level of care required, as indicated by demographic and other evidence of community need. Such a table also shows the distribution of total health effort relative to available manpower.

In addition to the descriptive insights provided by the table, it might also have predictive and prescriptive uses. Given that the relationships inherent in the table were sufficiently clear, the changes in the functional balance that might result from the employment of an additional public health nurse, for example, might be estimated; we might thus hope to use the table for predictive purposes. The ultimate aim might be to vary the functional emphasis in accordance with the distribution of needs, and to prescribe an optimal reallocation of effort among the various professional categories, transferring responsibilities, wherever possible, to less highly qualified personnel.

OUTLINE OF A FUNCTIONAL ANALYSIS STUDY

The conceptual framework outlined above is, for the present, in many respects, an ideal. Field research along these lines has been undertaken, however, since 1965 in a project covering several rural health centre areas in Turkey, India and Taiwan. The achievements and future prospects of this research are summarized in this example, first in terms of the comprehensive information system that has been developed for descriptive purposes, and then in terms of more sophisticated analyses applicable to particular aspects of health care delivery.

The basic aims of the project are as follows:

(1) to measure community health needs, with particular reference to the development of an improved method of allocating priorities to such needs;

(2) to measure the quantity and quality of the health resources currently available for health programmes;

(3) to identify ways in which health resources are currently utilized to satisfy effective demand for care;

(4) to quantify specific activities of health centres, both in the centres and in the community;

(5) to define desirable and practical alternatives for the reorganization of health centres, in terms of both programme priorities and job descriptions;
Table 13. Analysis of time devoted to various functions by different categories of personnel

<table>
<thead>
<tr>
<th>Functions</th>
<th>Time devoted by:</th>
<th></th>
<th></th>
<th></th>
<th>Existing functional balance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Family and friends</td>
<td>Indigenous practitioners</td>
<td>Auxiliary sub-professionals</td>
<td>Nurses</td>
<td>Physicians</td>
</tr>
<tr>
<td>Well child care</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical relief</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass control of communicable diseases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effort by individual category</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manpower available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(6) to identify the implications of modified health centre personnel job descriptions for professional and auxiliary training.

Broadly, the goal was to develop an information system embracing the first four factors in a manner that would permit a systematic and objective assessment of the last two. Although a number of data sources were utilized, two formed the core of the study in each health centre area, namely a community health survey of three selected villages in the area, and the work status of the health centre personnel.

The three villages were selected on the basis of varying degrees of accessibility to the health centre services. Within each village, 25 households were randomly selected for interview at fortnightly intervals throughout an entire year. The information collected about the household and its members fell into four categories. Firstly, certain general characteristics were identified, including age, sex, education, and economic level. Secondly, specific indices of exposure to health hazards were developed. These included source of drinking-water, means of waste disposal, immunization status, attitudes and practices concerning family planning, and degree of social awareness, in terms of such diverse measures as urban contacts, radio listening, and use of improved seeds and fertilizers. Thirdly, specific episodes of illness were characterized with respect to presenting symptoms, duration, amount of time lost from normal activities, types of practitioners consulted, mode and distance of travel for services, and cost. Finally, note was taken of interactions with health workers unrelated to specific illness episodes. These included reported visits by family planning workers, insecticide sprayers, trachoma workers, and others, as well as attendance at meetings convened for health education purposes.

THE INFORMATION SYSTEM

Because the above factors were measured in simple concrete terms, they could be individually summarized so as to portray community characteristics, morbidity levels, and patterns of seeking care, as well as community differences in respect of these factors. This is shown, for example, by the following partial description of two villages within the same health centre area in Punjab State, India. One, located within two miles of the health centre, reported an average of 2.4 episodes of illness per person per year and 54 practitioner consultations per 100 episodes. In contrast, the second, located near the limit of the effective range of the health centre, reported 2.9 episodes per person per year and 40 consultations per 100 episodes. Although we cannot, of course, rely solely upon these meagre statistics, they suggest the importance of
health centre accessibility. Moreover, only half the dwellings in the first village had access to adequate drainage for waste disposal, compared with two-thirds in the second village. Health hazards associated with inadequate means of waste disposal, therefore, did not appear to have an overriding effect on morbidity levels.

**ANALYSIS: CONSTRUCTION OF INDICES**

The value of these descriptors increases substantially when they are subjected to more refined statistical analysis and comparison. For example, indices were devised to measure the extent to which individual morbidity experience and health actions deviated from a calculated "norm". These indices could then be analysed with respect to the specific characteristics of the individual and his exposure to health hazards.

To illustrate the technique, consider a family consisting of a father, age 31, a mother, age 27, and a child, age three. Suppose that the experience accumulated throughout the entire study was as shown in Table 14, i.e., an average or "norm" for pre-school children of 6.2 illness episodes annually, resulting in 5.6 practitioner consultations, 47% of which involve the government health centre; the norms for adults (males and females) are also shown.\(^1\) Suppose further that the corresponding results for the family under consideration were as shown in Table 15.

The *episode deviation index* is then obtained by dividing the square of the difference between the observed results and the norm by the norm itself.

**Table 14. Study experience regarding illness episodes and health actions (hypothetical)**

<table>
<thead>
<tr>
<th>Category of individual</th>
<th>Mean no. of episodes</th>
<th>Mean no. of practitioner consultations</th>
<th>Percentage of consultations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Per episode</td>
</tr>
<tr>
<td>Children 1-5</td>
<td>6.2</td>
<td>5.6</td>
<td>0.90</td>
</tr>
<tr>
<td>Females 15-49</td>
<td>2.8</td>
<td>3.5</td>
<td>1.25</td>
</tr>
<tr>
<td>Males 15-49</td>
<td>1.4</td>
<td>2.1</td>
<td>1.50</td>
</tr>
</tbody>
</table>

\(^1\) The figures quoted are hypothetical and the number of items considered is limited to five to simplify the discussion.
Table 15. Study experience for a particular family (hypothetical)

<table>
<thead>
<tr>
<th>Individual</th>
<th>Number of episodes</th>
<th>Consultations</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>Government health centre</td>
</tr>
<tr>
<td>Child</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Mother</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Father</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Thus, for the child:

\[
\frac{(\text{norm} - \text{observed})^2}{\text{norm}} = \frac{(6.2 - 4)^2}{6.2} = 0.78.
\]

Similarly the indices for the mother and father are found to be 0.01 and 0.11, respectively.

By assigning to every individual covered by the study an episode deviation index, patterns can be discerned both among family members and among specific population segments. For example, another preschool child with only two illness episodes would be assigned an index of 2.85, which contrasts strikingly with the index of 0.78 above. Individuals with especially high indices can in turn be further analysed to identify common factors that might contribute to such large deviations.

Family indices can also be used. In our example, we find a total of eight illness episodes for the family, as compared with an expected total of \(6.2 + 2.8 + 1.4 = 10.4\). The family episode deviation index is thus:

\[
\frac{(10.4 - 8)^2}{10.4} = 0.55.
\]

At this stage, individual family indices within a village can be correlated with economic status, source of drinking-water, and other family characteristics. Finally, village indices can be derived and compared with respect to accessibility of services and other village characteristics.

Referring again to Tables 14 and 15, we can construct utilization indices for each individual. Since, from Table 14, we see that the typical preschool child has 0.90 consultations per episode, we might expect the four episodes of the child in Table 15 to generate:

\[0.90 \times 4 = 3.60\] consultations.
Likewise, from Table 14, we note that 47%, or $3.60 \times 0.47 = 1.69$ of these consultations could be expected to involve the government health centre. Thus the health centre utilization index for the child in question is:

$$\frac{(1.69 - 5)^2}{1.69} = 6.48.$$ 

This kind of approach can obviously be applied to the family as a whole, and extended to both indigenous practitioner and total utilization. When the entire array of indices is displayed, the extent to which the aggregation of individual behaviour tends to produce family or village patterns becomes evident.

**DYNAMICS OF HEALTH ACTIONS**

**TRANSITION MATRICES AS PREDICTORS**

The analysis of health actions can be refined still further so as to depict their dynamics. Suppose that, of 1000 individuals interviewed at some particular time, 261 reported experiencing an episode of illness during the preceding fortnight. As shown in Table 16, 96 of these had not seen a health practitioner, 85 had seen an indigenous healer, and the remaining 80 had been to a government health centre. If the initial

<table>
<thead>
<tr>
<th>Status at first interview (time 1)</th>
<th>Number at first interview</th>
<th>Transition rate (%) at second interview (time 2)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well</td>
<td>739</td>
<td>Well: 80, Self-treatment: 10, Indigenous practitioner treatment: 5, Health centre treatment: 5</td>
<td>100</td>
</tr>
<tr>
<td>Health centre treatment</td>
<td>80</td>
<td>Well: 70, Self-treatment: 10, Indigenous practitioner treatment: 5, Health centre treatment: 15</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>1000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
status of each individual is noted, and if he is interviewed again a fortnight later to ascertain his status at that time, it is then possible to identify patterns of transition in the care of an illness episode, and to answer such questions as: do those who at first rely on self-treatment go eventually to a practitioner? Does someone who seeks treatment, keep to a particular type of practitioner or change from one to another? To what extent that patients do change, do they go first to the indigenous healer and then to the formal health care system or conversely?

In order to answer such questions, we construct a transition matrix, as shown in Table 16. This indicates, for example, that, on the average, 80% of the 739 "well" individuals at the first interview could be expected to remain healthy during the subsequent two weeks. Of the 20% who fell ill, 10% would rely on self-treatment, 5% would consult an indigenous practitioner, and 5% would go to the government health centre.

The transition matrix helps us to predict changes with time in the distribution of individuals in the various health care states, provided that the matrix itself remains constant. It is therefore possible to estimate the numbers in each care state at the time of the second interview. "Well" individuals will include 80% of the 739 previously well, 50% of the previous "self-treatment" cases, etc. Specifically, we can expect at time 2:

\[739 \times 0.8 + 96 \times 0.5 + 85 \times 0.5 + 80 \times 0.7 = 738 \text{ well individuals.}\]

Similar calculations for the other states yield the distribution shown in Table 17. We see that the distribution differs little from that at time 1. Circumstances at time 3 are likewise expected to be similar.

**Table 17. Variation in distribution of individuals in specified health states with time (hypothetical)**

<table>
<thead>
<tr>
<th>Health care state</th>
<th>Transition matrix, Table 16</th>
<th>Transition matrix, Table 18</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time 1</td>
<td>Time 2</td>
</tr>
<tr>
<td>Well</td>
<td>739</td>
<td>738</td>
</tr>
<tr>
<td>Self-treatment</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td>Indigenous practitioner</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treatment</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Health centre treatment</td>
<td>80</td>
<td>81</td>
</tr>
</tbody>
</table>
Apparently the forces inherent in the original situation have been operating for a sufficient period of time to produce stability. When patients first consult a practitioner they are equally likely to consult an indigenous healer or the government health centre. Subsequent visits, however, tend to be returns to the type of practitioner first selected.

Now consider what would happen if 50% of all visits to indigenous practitioners were made to the health centre instead. The transition matrix would then be as shown in Table 18.

<table>
<thead>
<tr>
<th>Status at first interview</th>
<th>Transition rates (%) at second interview</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Well</td>
</tr>
<tr>
<td>Well</td>
<td>80</td>
</tr>
<tr>
<td>Self-treatment</td>
<td>50</td>
</tr>
<tr>
<td>Indigenous practitioner treatment</td>
<td>50</td>
</tr>
<tr>
<td>Health centre treatment</td>
<td>70</td>
</tr>
</tbody>
</table>

Application of the new transition probabilities to the initial distribution of individuals produces the immediate reaction anticipated, as shown in Table 17. The total number of individuals in the “indigenous practitioner treatment” state is halved and the number receiving health centre care is increased correspondingly.

When the transition matrix is applied to the revised distribution to produce a time 3 distribution, we find an additional decrease in the number of users of indigenous services. This is due to the above-mentioned tendency for patients to revisit the practitioner they first consult. In addition, we find a slight increase in the proportion of the “well” population. This is because of the greater tendency for a transition to “well” from “health centre treatment” than from “indigenous practitioner treatment”. These effects will continue to exercise their influence through fourth and subsequent time periods until ultimately a new level of stability is reached.

This exercise shows that the ultimate consequences of a particular change often go beyond its immediate effect. Moreover, the nature and extent of the impact may not be entirely clear from existing static relationships. Analysis of these relationships, however, can often enable an accurate forecast to be made of the ultimate effects to be expected.
CHAPTER 4
SERVICE UTILIZATION AND PLANNING

This example illustrates certain quantifiable aspects of hospital service planning by reference to:
(i) a hypothetical situation in which the problem is to choose from a small number of proposed alternative solutions; and
(ii) a more general approach using linear programming in a situation where alternative strategies are not defined.

FORM OF ANALYSIS AND EVALUATION ON WHICH A CHOICE BETWEEN FOUR STATED ALTERNATIVES CAN BE BASED

A region (see Fig. 16) consisting of five districts has a population of 900 000 and is served by the establishments shown below:

<table>
<thead>
<tr>
<th>Establishment</th>
<th>No. of beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>One regional hospital</td>
<td>400</td>
</tr>
<tr>
<td>Four intermediate hospitals with 100 beds each</td>
<td>400</td>
</tr>
<tr>
<td>11 primary health centres, of which nine have 10 beds each and two have five beds each</td>
<td>100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>900 beds</strong></td>
</tr>
</tbody>
</table>

Therefore:
bed/population ratio = 1 per 1000 population.

Annual admissions, average length of stay, and occupancy rates are shown in Table 19, and the discharge rate distribution in Table 20.

It is estimated that the population of the region will have increased to 1 million in ten years time. Changes in the proportions of industrial and rural workers, improvements in communications and referral systems, and changes in population attitudes, etc., will also occur and will influence hospital discharge rates.

It is assumed that:
(a) the hospital occupancy rate should be reduced from 102 % to 80 %;
Fig. 16. Diagram showing districts and areas of the region, and location of hospitals and health centres

Table 19. Annual admissions, average length of stay, and occupancy rates

<table>
<thead>
<tr>
<th>Type of establishment</th>
<th>Annual admissions</th>
<th>Patient-days</th>
<th>Average length of stay (days)</th>
<th>Occupancy rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional hospital</td>
<td>12 000</td>
<td>180 000</td>
<td>15</td>
<td>123</td>
</tr>
<tr>
<td>Intermediate hospital, each</td>
<td>2 000</td>
<td>36 000</td>
<td>18</td>
<td>98</td>
</tr>
<tr>
<td>Sub-total for four</td>
<td>8 000</td>
<td>144 000</td>
<td>18</td>
<td>98</td>
</tr>
<tr>
<td>Primary health centre (each) with 10 beds</td>
<td>200</td>
<td>1 200</td>
<td>6</td>
<td>32</td>
</tr>
<tr>
<td>Sub-total for 11 centres (of which two have five beds)</td>
<td>2 000</td>
<td>12 000</td>
<td>6</td>
<td>32</td>
</tr>
<tr>
<td>TOTAL</td>
<td>22 000</td>
<td>336 000</td>
<td>15.2</td>
<td>102</td>
</tr>
</tbody>
</table>
Table 20. Discharge rate distribution (number of hospital discharges per 1000 population at risk per year)

<table>
<thead>
<tr>
<th>District and area</th>
<th>Annual no. of discharges</th>
<th>Population in thousands</th>
<th>Discharge rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>District 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area a</td>
<td>8000</td>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>area b</td>
<td>500</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>area c</td>
<td>750</td>
<td>75</td>
<td>10</td>
</tr>
<tr>
<td>area d</td>
<td>750</td>
<td>75</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>10000</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td><strong>District 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area e</td>
<td>1500</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>area f</td>
<td>500</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>area g</td>
<td>500</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2500</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td><strong>District 3</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area h</td>
<td>1900</td>
<td>75</td>
<td>25.3</td>
</tr>
<tr>
<td>area i</td>
<td>200</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>area j</td>
<td>200</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>area k</td>
<td>200</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2500</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td><strong>District 4</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area l</td>
<td>2000</td>
<td>80</td>
<td>25</td>
</tr>
<tr>
<td>area m</td>
<td>500</td>
<td>40</td>
<td>12.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2500</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td><strong>District 5</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area n</td>
<td>1800</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>area p</td>
<td>350</td>
<td>30</td>
<td>11.7</td>
</tr>
<tr>
<td>area q</td>
<td>350</td>
<td>40</td>
<td>8.75</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2500</td>
<td>130</td>
<td></td>
</tr>
</tbody>
</table>

**Gross total** | 20000*                   | 9000                    |

**Notes:**
1. The regional hospital R located in area 1a registered 12,000 discharges per year, made up of 10,000 discharges of patients living in District 1 plus 500 discharges of patients living in each of Districts 2, 3, 4 and 5.
2. The intermediate hospital V located in area 2a registered 2000 discharges per year, but 500 patients living in that district were referred to the regional hospital R. The same applies to districts 3, 4, and 5.
3. Excluding discharges from primary health centres.
Table 21. Estimated future annual discharges

<table>
<thead>
<tr>
<th>District and area</th>
<th>Population in thousands</th>
<th>Expected discharge rate</th>
<th>Estimated annual number of discharges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>District 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area a</td>
<td>265</td>
<td>80</td>
<td>21,200</td>
</tr>
<tr>
<td>area b</td>
<td>50</td>
<td>20</td>
<td>1,000</td>
</tr>
<tr>
<td>area c</td>
<td>70</td>
<td>20</td>
<td>1,400</td>
</tr>
<tr>
<td>area d</td>
<td>70</td>
<td>20</td>
<td>1,400</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>455</td>
<td></td>
<td>25,000</td>
</tr>
<tr>
<td><strong>District 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area e</td>
<td>60</td>
<td>60</td>
<td>3,600</td>
</tr>
<tr>
<td>area f</td>
<td>30</td>
<td>25</td>
<td>750</td>
</tr>
<tr>
<td>area g</td>
<td>25</td>
<td>25</td>
<td>625</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>115</td>
<td></td>
<td>4,975</td>
</tr>
<tr>
<td><strong>District 3</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area h</td>
<td>80</td>
<td>50</td>
<td>4,000</td>
</tr>
<tr>
<td>area i</td>
<td>25</td>
<td>15</td>
<td>375</td>
</tr>
<tr>
<td>area j</td>
<td>25</td>
<td>15</td>
<td>375</td>
</tr>
<tr>
<td>area k</td>
<td>30</td>
<td>20</td>
<td>600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>160</td>
<td></td>
<td>5,350</td>
</tr>
<tr>
<td><strong>District 4</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area l</td>
<td>90</td>
<td>50</td>
<td>4,500</td>
</tr>
<tr>
<td>area m</td>
<td>40</td>
<td>20</td>
<td>800</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>130</td>
<td></td>
<td>5,300</td>
</tr>
<tr>
<td><strong>District 5</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area n</td>
<td>70</td>
<td>50</td>
<td>3,500</td>
</tr>
<tr>
<td>area p</td>
<td>30</td>
<td>20</td>
<td>600</td>
</tr>
<tr>
<td>area q</td>
<td>40</td>
<td>20</td>
<td>800</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>140</td>
<td></td>
<td>4,900</td>
</tr>
<tr>
<td><strong>Gross total</strong></td>
<td>1,000</td>
<td>45,525 (average)</td>
<td>45,525(^a)</td>
</tr>
</tbody>
</table>

\(^a\) Excluding 2000 from primary health centres.

(b) the average length of stay for the whole system should be reduced to 13 days; and
(c) admissions to primary health centre beds will remain the same.

On this basis, a table of estimated future annual discharges is constructed, as shown in Table 21.
Accordingly, for the whole region:

\[
\text{bed/population ratio} = 45.525 \times \left( \frac{13}{365 \times 0.85} \right) = 1.91
\]

Thus for a population of 1 million, 1910 beds will be needed; 1100 new beds will therefore have to be provided.

The following assumptions are then made:

(a) each primary health centre is 20 kilometres distant from the nearest intermediate or regional hospital, and each intermediate hospital is 40 kilometres distant from the regional hospital, R (see Fig. 16);

(b) the cost of transporting an individual patient from home to hospital and return is one monetary unit per kilometre;

(c) the building cost per new bed in the regional hospital is 30,000 monetary units; in an intermediate hospital, the figure is 35,000 monetary units, as the central and technical services would have to be rebuilt in case of a large extension;

(d) there are, at present, five doctors in the regional hospital and one doctor in each of the four intermediate hospitals. The government has adopted a standard of one doctor per 40 beds. The 2000 beds therefore require a staff of fifty doctors, but it will be possible to appoint only thirty, to be distributed amongst the regional and intermediate hospitals.

The problem is to find the most economical of four solutions (see below) to the problem of where to build the additional 1100 new beds, taking into account transportation, building and running costs.

The four solutions proposed for consideration are:

(1) To refer 80% of patients requiring hospitalization from primary health centres direct to the regional hospital, and to use the intermediate hospitals mainly as half-way houses for convalescent and chronic cases. The length of stay in the regional hospital should be reduced to 10 days and, in the intermediate hospitals, increased to about 20 days. The running cost per annum of a bed in the regional hospital would be 10,000 monetary units, and 5000 in an intermediate hospital.

The intermediate hospitals would remain practically the same and the 1100 new beds should be added to the regional hospital.

(2) To refer 80% of patients from primary health centres to intermediate hospitals and only the most serious cases (20%) to the regional hospital. The length of stay in the regional hospital would be about 15 days and that in the intermediate hospitals, 10 days. The running cost per annum of a bed in the regional hospital would be 12,000 monetary units, and 8000 in the district hospital. This increase in running costs is the result of the increase in the specialized equipment and qualified staff required.
(3) To distribute the 1100 new beds equally between the regional and the four intermediate hospitals (220 beds in each). The running cost per annum would then be 9000 monetary units in all hospitals.

(4) To strengthen the regional hospital by adding 500 new beds, to construct 400 new beds in one of the intermediate hospitals, and only 66 beds in each of the three remaining intermediate hospitals. The running cost would then be 10 000 monetary units per annum in the two remodelled hospitals and 6000 in the other three hospitals.

The following assumptions and working rules are adopted in the evaluation of the alternative solutions:

(i) The given prospective data are taken at their face value.

(ii) Statements made about primary health centres are regarded as applicable to intermediate hospitals. For example, in solution No. 1, the proposal to refer 80% of patients from the primary health centres to the regional hospital is also applicable to the intermediate hospitals.

(iii) Since the proposals refer only to the five hospitals, the services offered by the primary health centres are ignored.

Table 22. Excess round trip distances

<table>
<thead>
<tr>
<th>From area:</th>
<th>R</th>
<th>V</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>b</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>c</td>
<td>0</td>
<td>70</td>
<td>20</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td>d</td>
<td>0</td>
<td>70</td>
<td>70</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>e</td>
<td>80</td>
<td>0</td>
<td>115</td>
<td>160</td>
<td>115</td>
</tr>
<tr>
<td>f</td>
<td>70</td>
<td>0</td>
<td>120</td>
<td>135</td>
<td>80</td>
</tr>
<tr>
<td>g</td>
<td>70</td>
<td>0</td>
<td>80</td>
<td>135</td>
<td>120</td>
</tr>
<tr>
<td>h</td>
<td>80</td>
<td>115</td>
<td>0</td>
<td>115</td>
<td>160</td>
</tr>
<tr>
<td>i</td>
<td>40</td>
<td>40</td>
<td>0</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>j</td>
<td>80</td>
<td>105</td>
<td>0</td>
<td>105</td>
<td>160</td>
</tr>
<tr>
<td>k</td>
<td>40</td>
<td>85</td>
<td>0</td>
<td>40</td>
<td>85</td>
</tr>
<tr>
<td>l</td>
<td>80</td>
<td>160</td>
<td>115</td>
<td>0</td>
<td>115</td>
</tr>
<tr>
<td>m</td>
<td>80</td>
<td>160</td>
<td>105</td>
<td>0</td>
<td>105</td>
</tr>
<tr>
<td>n</td>
<td>80</td>
<td>115</td>
<td>160</td>
<td>115</td>
<td>0</td>
</tr>
<tr>
<td>p</td>
<td>70</td>
<td>80</td>
<td>135</td>
<td>120</td>
<td>0</td>
</tr>
<tr>
<td>q</td>
<td>70</td>
<td>120</td>
<td>135</td>
<td>80</td>
<td>0</td>
</tr>
</tbody>
</table>
(iv) For the purpose of computing transportation costs, it is assumed that the population of each area is concentrated at the location of the relevant primary health centre, intermediate hospital or regional hospital. (The justification for this assumption is that any prospective patient is assumed to report first to the health facility available in the area concerned).

(v) For the purpose of computing the distances between the various health centres and the hospitals, direct roads linking the health facilities are assumed to exist. The respective distances have been normalized by subtracting the minimum possible distances, then doubled to cover the return journey (see Table 22). As an illustration, any patient from area “c” has to travel at least 20 km each way, since the nearest hospital, R, is 20 km away. Although the actual distance from area “c” to hospital “X” is approximately 30 km, the excess amount of travel is only 10 km and hence a distance of 20 km is taken to represent the excess round trip distance from area “c” to hospital “X”.

Solution No. 1

Proposal: 80% of patients requiring hospitalization will be referred to the regional hospital and the 1100 new beds will be added to this hospital.

Analysis: admission figures and transportation costs would be as shown in Table 23.

Hospital running costs per annum = 1500 \times 10000 + 400 \times 5000 = 17 000 000 units.

Total operating costs per annum including transportation costs = 18.27 million units, approx.

In order to compute the utilization factors, it will be assumed that 20% of the 21 200 admissions from area “a” require an average of 20 days stay in the hospital. Then:

Number of patient-days per annum required in the regional hospital = 40 660 \times 10 + 4250 \times 10 = 449 100

\[
\text{Utilization factor for hospital R} = \frac{449 100}{1500 \times 365} \times 100 \%
\]

= 82% approx.

It is possible to decrease the utilization factor of the regional hospital by referring some of the patients from area “a” to the intermediate hospitals, but this would result in an increase in transportation costs.
Table 23. Admissions and transportation costs for solution no. 1

<table>
<thead>
<tr>
<th>From area:</th>
<th>Admissions to hospital:</th>
<th>Total admissions</th>
<th>Transportation costs in 1000 units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>V</td>
<td>X</td>
</tr>
<tr>
<td>a</td>
<td>2120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>800</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>1120</td>
<td>150</td>
<td>130</td>
</tr>
<tr>
<td>d</td>
<td>1120</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>e</td>
<td>2880</td>
<td>720</td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>600</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>500</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>h</td>
<td>3200</td>
<td></td>
<td>800</td>
</tr>
<tr>
<td>i</td>
<td>300</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>j</td>
<td>300</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>k</td>
<td>480</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>l</td>
<td>3600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>640</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>2800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>480</td>
<td></td>
<td></td>
</tr>
<tr>
<td>q</td>
<td>640</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total:</td>
<td>40660</td>
<td>1195</td>
<td>1220</td>
</tr>
</tbody>
</table>

Solution No. 2

Proposal: 80% of patients requiring hospitalization will be referred to the intermediate hospitals, and only the most serious cases (20%) will be referred to the regional hospital. It is further stated that the average length of stay in the regional hospital will be about 15 days, and that in the intermediate hospitals about 10 days. The overall average length of stay will be less than that for solution No. 1. For the sake of consistency, it will be assumed that the average length of stay in the intermediate hospitals is 11 days.

Analysis: each bed in the intermediate hospitals, at 80% utilization, can be used by an average of 26.5 patients annually. The annual running cost differential between a bed in the regional hospital and one in the intermediate hospitals is 4000 monetary units. However, the cost of transporting an average of 26.5 patients from area "a" to one of the intermediate hospitals is 80 × 26.5 = 2120 monetary units. Thus, it is more economical to transport 80% of the patients from area "a" to the intermediate hospitals rather than provide them with service in the regional hospital.

The admission figures and transportation costs would be as shown in Table 24.
Table 24. Admissions and transportation costs for solution no. 2

<table>
<thead>
<tr>
<th>From area:</th>
<th>Admissions to hospital:</th>
<th>Total admissions</th>
<th>Transportation costs in 1000 units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>V</td>
<td>X</td>
</tr>
<tr>
<td>a</td>
<td>4250</td>
<td>4185</td>
<td>3765</td>
</tr>
<tr>
<td>b</td>
<td>200</td>
<td>800</td>
<td>—</td>
</tr>
<tr>
<td>c</td>
<td>280</td>
<td>—</td>
<td>1120</td>
</tr>
<tr>
<td>d</td>
<td>280</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>e</td>
<td>720</td>
<td>2880</td>
<td>—</td>
</tr>
<tr>
<td>f</td>
<td>150</td>
<td>600</td>
<td>—</td>
</tr>
<tr>
<td>g</td>
<td>125</td>
<td>500</td>
<td>—</td>
</tr>
<tr>
<td>h</td>
<td>800</td>
<td>—</td>
<td>3200</td>
</tr>
<tr>
<td>i</td>
<td>75</td>
<td>—</td>
<td>300</td>
</tr>
<tr>
<td>j</td>
<td>75</td>
<td>—</td>
<td>300</td>
</tr>
<tr>
<td>k</td>
<td>120</td>
<td>—</td>
<td>480</td>
</tr>
<tr>
<td>l</td>
<td>900</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>m</td>
<td>160</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>n</td>
<td>700</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>p</td>
<td>120</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>q</td>
<td>160</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>8865</td>
<td>9165</td>
<td>9165</td>
</tr>
</tbody>
</table>

It is assumed that the 1100 new beds are added to the intermediate hospitals, i.e., 275 new beds are added to each hospital of this type. The building cost of one bed in the regional hospital is 30 000 units, and in an intermediate hospital, 35 000 units.

Hospital running costs per annum = 1500 × 8000 + 400 × 12 000 = 16 800 000 units.

Total operating costs per annum including transportation costs = 18.51 million units approx.

Additional capital expenses = 5000 × 1500 = 7.5 million units approx.

Utilization factor for the regional hospital =
\[
\frac{8865 \times 15}{400 \times 365} \times 100\% = 90\% \text{ approx.}
\]

Utilization factor for the intermediate hospitals =
\[
\frac{9165 \times 11}{375 \times 365} \times 100\% = 75\% \text{ approx.}
\]

It is possible to decrease the utilization factor of the regional hospital by building some of the new beds there. The running costs, however, would be substantially increased, since each bed in the regional hospital costs an additional 4000 units per annum.
Solution No. 3

Proposal: the 1100 new beds will be distributed equally between the regional and the four intermediate hospitals (220 beds in each).

Analysis: to retain the same utilization factor in all the hospitals, annual admissions to the regional hospital = \(45\,525 \times (620/1900) = 14\,725\) approx. Annual admissions to any of the intermediate hospitals = 7700 approx.

The admission figures and transportation costs would be as shown in Table 25.

Running costs of the hospitals per annum = 1900 \(\times\) 9000 = 17 100 000 units.

Total operating costs per annum = 17.67 million units approx.

Additional capital expenses = 880 \(\times\) 5000 = 4.4 million units.

Utilization factor for all hospitals = 79\% approx.

Table 25. Admissions and transportation costs for solution no. 3

<table>
<thead>
<tr>
<th>From area or district:</th>
<th>Admissions to hospital:</th>
<th>Total admissions</th>
<th>Transportation costs in 1000 units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>V</td>
<td>X</td>
</tr>
<tr>
<td>Area  a</td>
<td>14 725</td>
<td>1725</td>
<td>2350</td>
</tr>
<tr>
<td>b</td>
<td>1000</td>
<td></td>
<td>1400</td>
</tr>
<tr>
<td>c</td>
<td>1400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>1400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>District 2</td>
<td>4975</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4900</td>
<td></td>
<td>4 900</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14 725</td>
<td>7700</td>
<td>7700</td>
</tr>
</tbody>
</table>

Solution No. 4

Proposal: strengthen the regional hospital by adding 500 new beds, construct 400 new beds in one of the intermediate hospitals, and only 66 beds in each of the three remaining hospitals.

Analysis: the annual admissions would be as follows: regional hospital = 21 600; strengthened intermediate hospital = 12 000; each of the three remaining hospitals = 3975. If the transportation costs shown in Table 23 are examined, it is obvious that hospital Y should be strengthened by the addition of 400 beds.

The admission figures and transportation costs would be as shown in Table 26.
Table 26. Admissions and transportation costs for solution no. 4

<table>
<thead>
<tr>
<th>From area:</th>
<th>Admissions to hospital:</th>
<th>Total admissions</th>
<th>Transportation costs in 1000 units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>V</td>
<td>X</td>
</tr>
<tr>
<td>a</td>
<td>21 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c</td>
<td></td>
<td></td>
<td>1 400</td>
</tr>
<tr>
<td>d</td>
<td></td>
<td></td>
<td>1 400</td>
</tr>
<tr>
<td>e</td>
<td></td>
<td>3 600</td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>375</td>
<td>375</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td></td>
<td></td>
<td>625</td>
</tr>
<tr>
<td>h</td>
<td></td>
<td></td>
<td>4 000</td>
</tr>
<tr>
<td>i</td>
<td></td>
<td></td>
<td>375</td>
</tr>
<tr>
<td>j</td>
<td></td>
<td></td>
<td>375</td>
</tr>
<tr>
<td>k</td>
<td></td>
<td></td>
<td>600</td>
</tr>
<tr>
<td>l</td>
<td></td>
<td></td>
<td>4 500</td>
</tr>
<tr>
<td>m</td>
<td></td>
<td></td>
<td>800</td>
</tr>
<tr>
<td>n</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td></td>
<td></td>
<td>125</td>
</tr>
<tr>
<td>q</td>
<td></td>
<td></td>
<td>800</td>
</tr>
<tr>
<td>Total</td>
<td>21 575</td>
<td>3975</td>
<td>4 000</td>
</tr>
</tbody>
</table>

Running costs of the hospitals per annum = 1400 × 10 000 + 500 × 6000 = 17 million units.
Total operating costs per annum including transportation = 17.39 million units approx.
Additional capital expenses = 700 × 5000 = 3.5 million units.
Utilization factor for all hospitals = 79% approx.

Comparison of the four solutions
The relevant results of the analysis of the four solutions can be summarized as shown in Table 27.

Table 27. Comparison of four solutions

<table>
<thead>
<tr>
<th>Solution No.</th>
<th>Total annual operating costs in 10^6 units</th>
<th>Additional capital necessary in 10^6 units</th>
<th>Balance of utilization factors of different hospitals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.27</td>
<td>0</td>
<td>Fairly well balanced</td>
</tr>
<tr>
<td>2</td>
<td>18.51</td>
<td>7.5</td>
<td>Unbalanced</td>
</tr>
<tr>
<td>3</td>
<td>17.67</td>
<td>4.4</td>
<td>Balanced</td>
</tr>
<tr>
<td>4</td>
<td>17.39</td>
<td>3.5</td>
<td>Balanced</td>
</tr>
</tbody>
</table>
It will be seen that solution No. 1 is superior to No. 2 while No. 4 is superior to No. 3. In other words, solution No. 1 is better than No. 2 for each of the three measures considered, and No. 4 is better than No. 3. Thus, Nos. 2 and 3 can be ignored in any further consideration.

In comparing solutions Nos. 1 and 4, it is clear that, at the cost of an additional initial investment of 3.5 million units, solution No. 4 achieves an annual saving of 0.88 million units. In order to compare the additional initial investment with the annual savings, the concept of “amortization period” is invoked. This is the number of years over which an initial investment is written off. Thus, an amortization period of 10 years denotes that an initial investment of 10 monetary units is equivalent to an annual expenditure of one unit. If the amortization period is greater than four years, solution No. 4 is better than No. 1. Since the amortization period is usually between 14 and 20 years, it would seem that solution No. 4 is the solution of choice.

LINEAR PROGRAMMING FORMULATION WHEN THE ALTERNATIVE STRATEGIES ARE NOT WELL DEFINED

As a first step, a model is devised on the assumption that no facilities exist. The problem then is where to build the five hospitals and how many beds should be provided in each. Operating costs, future demands, etc., are assumed to be defined.

Let the index i denote the class of patient, e.g., serious cases, convalescents, etc. (i.e., i = 1, ..., I); the index j, the area (i.e., one of 16); and index k, the location of a hospital (i.e., k = 1, ..., 5, since only five locations are considered feasible).

Then let:

\[ x_{ijk} = \text{the proposed number of patients belonging to the i'th class from the j'th area to be sent to hospital k.} \]

\[ r_{ij} = \text{the total number of patients in the i'th class from the j'th area. These numbers are assumed to be known.} \]

\[ b_{ik} = \text{the total number of beds to be provided in hospital k for i'th class patients.} \]

\[ t_i = \text{the average fraction of a year (i.e., the number of days expressed as a fraction of a year) that an i'th class patient spends in the hospital).} \]

\[ d_{jk} = \text{the cost of transporting a patient from the j'th area to hospital k.} \]

\[ c_{ik} = \text{the average annual cost of operating a bed in hospital k for i'th class patients.} \]

\[ e_{ik} = \text{the annual amortized expense of building a bed in hospital k} \]
for the \( i \)'th class patients. For instance, if it costs 30,000 units to provide a bed in a hospital for a specific type of patient and if the amortization period is 15 years, the annual amortized expense will be 2000 units.

\[ u = \text{the desirable utilization factor for all the hospitals.} \]

In linear programme form, the problem is to minimize the objective function:

\[
\sum_{i,j,k} d_{jk} x_{ijk} + \sum_{i,k} b_{ik} (c_{ik} + e_{ik})
\]

subject to the following three constraints:

1. \[
\sum_k x_{ijk} = r_{ij}
\]
2. \[
t_i \sum_j x_{ijk} \leq u b_{ik} \quad i = 1, \ldots, 1 \]
   \[
j = 1, \ldots, 16 \]
   \[
k = 1, \ldots, 5
\]
3. \[
x_{ijk} \geq 0
\]

In the objective function, the first term represents the total transportation costs, the second the total operating expense of the beds provided, including the amortized capital cost. The first set of constraints states the requirement that the total number of patients sent to different hospitals must equal the total demand for service, and the second set of constraints that the total demand made on a hospital must not exceed the hospital capacity, as modified by the utilization factor.

The next step is to extend the model to take account of the existing capacity of the hospitals. It is assumed that \( c_{ik} = e_k \) for all \( i \) (i.e., the cost of constructing a bed in a hospital does not depend on the class of the patients for whom it is intended), but that operating costs may vary according to the class of patients. Let \( s_k = \text{the number of existing beds in hospital } k \).

The new linear programme becomes:

Minimize:

\[
\sum_{i,j,k} d_{jk} x_{ijk} + \sum_{i,k} c_{ik} b_{ik} + \sum_k c_k \left( \sum_i b_{ik} - s_k \delta_k \right)
\]

subject to:

\[
\sum_k x_{ijk} = r_{ij}
\]
\[
t_i \sum_j x_{ijk} \leq u b_{ik}
\]
\[
\sum_i b_{ik} - s_k \geq \delta_k L
\]
\[
\sum_{i} b_{ik} - s_{k} \leq \delta_{ik} M \quad i = 1, ..., i \\
\quad \quad \quad j = 1, ..., 16 \\
\quad \quad \quad k = 1, ..., 5 \\
\]

\[x_{ik} \geq 0\]

\[\delta_{k} = 0 \text{ or } 1\]

The first two terms in the objective function need no explanation. The third term denotes that an expense of \( c_{k} \) is incurred per additional bed provided in hospital \( k \). The dummy variable \( \delta_{k} = 0 \), if no additional bed is constructed, and 1 otherwise. The first two sets of constraints need no comment. In the third and fourth sets, \( L \) and \( M \), both positive numbers, represent arbitrary lower and upper limits to the number of beds. For instance, \( L \) could be a small number, e.g., 0.5, and \( M \) could be a large number, e.g., 2000. The function of these two sets of constraints is to ensure that:

\[\delta_{k} = 0 \text{ if } \sum_{i} b_{ik} \leq s_{k},\]

and 1 otherwise. The problem is now a mixed integer programming problem, and is readily solved with the help of a computer.

The linear programming model is suggested only as a first step. The model would probably have to be considerably modified to represent any real situation adequately. When costs or future demand are uncertain, the relevant parameters can be varied to obtain alternative solutions (simulation). Finally, the planner accepts or modifies one of the solutions to take into account non-quantifiable factors.
CHAPTER 5

DISEASE CONTROL

The studies we present here are, in effect, instances of cost-effectiveness comparisons of alternative programmes for the control of three communicable diseases. Each in its own way is a demonstration of two important facts:

(1) the solution of this kind of problem involves a rather long sequence of steps that begins in the areas of epidemiology and health statistics and moves through cost estimates to implementation decisions;

(2) though the analytical methods employed are powerful tools for providing some of the essential information on which reasoned decisions can be based, there are usually many extraneous factors in the total situation that the administrator must take into account (this point is well brought out by the example of cholera control, see p. 147).

Our examples will be seen to comprise some or all of the following stages:

(1) the construction of an epidemiological model in flow-chart form;

(2) the elaboration of the parameters of epidemiological sub-groups of the population in the situation (states), and coefficients of daily (or other period) transfers from one sub-group to another;

(3) the construction of a mathematical model based on the quantified flowchart;

(4) the computation of future population states in the natural, or undisturbed, model;

(5) simulations of the consequences of alternative forms of intervention, e.g., immunization, improvement of sanitation;

(6) cost-benefit comparisons of alternative control programmes.

With respect to the mathematical modelling aspect and its cost-benefit implications, four points are worth emphasizing for the typhoid fever example (see p. 105):
(i) disease control benefits are likely to accrue over a period of years, thereby making the analysis quite sensitive to the discounting procedure employed;
(ii) some of the benefits may accrue to sectors other than the one under investigation; the improvement of environmental sanitation, for example, introduces benefits that extend far beyond the control of typhoid fever;
(iii) programme costs are often shared by several public and private agencies. Only the costs to government have been incorporated into the typhoid fever model, whereas for other purposes total costs to the community might be included;
(iv) the absolute differences between benefits and costs have been emphasized in the present model, whereas other analysts might wish to stress the ratio of benefits to costs, i.e., the benefits per dollar of costs incurred. The latter approach frequently produces conclusions that are quite different from those of the former.

Whilst it is true that the model-based conclusions could, in most instances, have been reached by less sophisticated reasoning, we are satisfied that the formalized approach is well worth while, in as much as it compels a re-examination of familiar problems with greater logical rigour — with the result that a deeper understanding of the variables and relationships involved is acquired.

**TYPHOID FEVER**

Typhoid fever is a public health problem primarily in endemic areas; accordingly, we have studied mathematical models for this disease in relation to endemic conditions.

The model has been constructed with a view to its possible use for forecasting trends of the natural course of infection and the effect of preventive measures — vaccination and sanitation — on such trends. For the sake of simplicity, stable endemic situations were taken as a basis for the model.

The effectiveness of antityphoid vaccines has been evaluated (Cvjetanović & Uemura, 1965) in controlled field trials in endemic areas. The degree of protection conferred by various vaccines, and methods of production and testing, have been established (WHO Expert Committee on Biological Standardization, 1967), as well as immunization schemes and dosages (Yugoslav Typhoid Commission, 1964; Typhoid Panel,

---

United Kingdom Department of Technical Co-operation, 1964; Hejfec et al., 1966; Cvetanović & Tapa, unpublished data).

The effect of sanitation has been demonstrated (WHO Expert Committee on Enteric Infections, 1964), although the available information does not give a clear idea of the exact quantitative effectiveness of each particular component of environmental sanitation.

We therefore believe that the essential information is available for the construction of the model, in spite of certain inadequacies that make it difficult to determine exactly each specific factor and parameter in the model. For example, the effect of mass immunization cannot be expressed in simple equations that take into account only the protective effect of the vaccine and the numbers of people immunized and not immunized. There are other factors that influence the outcome of vaccination programmes — e.g., the sources of infection and routes of transmission, the size of the challenge dose, and the degree of exposure of the population. Furthermore, transmission from the known sources of infection, sick persons or carriers, to other people depends on various characteristics of the population such as state of immunity, food habits, occupation, customs, and personal hygiene.

Environmental sanitation, like immunization, has a considerable effect on the control of typhoid fever. However, many factors, such as level of education and economic status, play a role, and make the effect of specific sanitation measures much more difficult to determine than that of immunization programmes. All these factors should be taken into consideration in constructing and, in particular, in applying mathematical models to specific population groups.

It is hoped that the mathematical model will be used for determining the probable results and relative benefits and costs of mass immunization and sanitation programmes. An attempt has therefore been made to construct a simple model that will enable health workers to plan and apply an effective typhoid fever control programme within the limits of their financial means and available facilities and resources.

**BASIC EPIDEMIOLOGICAL FACTORS**

For the construction of any mathematical model, it is necessary to establish some basic epidemiological factors and parameters as a point of departure.

*Natural history of typhoid fever*

The natural history of typhoid fever is known and will not be described here except in so far as it concerns the construction of the
model. Data on the natural history of the disease used in the construction of the model — i.e., incubation period, duration of illness, and relapse, morbidity, fatality, carrier, and other rates — were compiled from numerous studies in different countries. It was realized that the data obtained in one study frequently differ from the results of other studies. This is sometimes the result of differences in methods of investigation, laboratory techniques, and procedures of data collection and analysis, as well as of different environmental and other conditions. For the construction of the model, it was necessary to take some definite parameters as a starting-point.

Some of the prevailing opinions concerning these parameters (American Public Health Association, 1965) were critically appraised. Many of the parameters varied considerably, and it was necessary to come to some arbitrary compromises in order to arrive at definite numerical values to be used for the construction of the model.

Some of the basic values that were used are presented below:

- Incubation period: range, 7-21 days; mean, 14 days
- Duration of sickness: range, 14-35 days; mean, 28 days
- Duration of relapse: range, 7-28 days; mean, 18 days
- Frequency of relapses: 5% of cases
- Proportion of cases: symptomatic (typical, febrile), 20%; asymptomatic (and mild), 80%
- Case fatality rate: 1-10%; average, 3%
- Carrier rate: chronic — range, 2-5%; average, 3%; temporary (mean duration, 90 days) — range, 7-20%; average, 10%
- Incidence in endemic areas: 10-150 per 10,000 population

Infection was considered in the light of the complex host-parasite-environment relationships, and, as far as possible, from the quantitative point of view.

The host factor — number and immune status — was taken into account in constructing the model as this factor largely determines actual morbidity rates and levels of endemicity.

In some studies, a relationship has been demonstrated between age, sex, and socio-economic status and the typhoid morbidity rate; young age groups, females, and poor people being the most affected, while women, in particular, tended to be carriers for a longer period and were more difficult to cure. These and possibly other factors might be important in specific population groups but we have, for the sake of simplicity, omitted them in the construction of this model.

The parasite factor was also considered from the quantitative point of view and therefore the simple presence or absence of Salmonella typhi was not the only criterion for determining the risk of infection. The techniques used in some studies showed that carriers excrete regularly, rather than intermittently, a large and fairly constant number
of organisms (Merselis et al., 1964). It seems that persons living under poor hygienic conditions in the vicinity of carriers are at high risk and frequently contract the disease.

Studies carried out on healthy volunteers (Hornick & Woodward, 1967) have shown that the ID$_{50}$ is about $10^6$-$10^7$ organisms, and that the ID$_{50}$ is about $10^4$ organisms. However, people in natural conditions are usually infected with a lower dose (Cvjetanović, 1957; Hornick & Woodward, 1967). In most of the communities with endemic typhoid, the micro-organisms are spread widely by carriers and by convalescent and sick persons. Accordingly, infection may under favourable conditions be easily transmitted through contaminated food and water or on the hands. Infected persons and carriers are often found accidentally and Salmonella may be detected in the blood stream of apparently healthy persons (Watson, 1967). We have therefore considered that the parasite is more widely present than might be assumed from the incidence of clinical illness.

The morbidity rates in communities with different levels of endemicity of typhoid fever were determined from the available national statistical returns, but these data were critically appraised in the light of the many studies that have revealed much more infection than was indicated in health statistics reports.

For example, among 40 students in an army school stricken by a typhoid epidemic, 15 had Salmonella typhi in their faeces and/or blood, but only 2 had a febrile illness: 2 more had been subfebrile and in routine clinical and public health practice would never have been diagnosed as typhoid cases (Vojna Epidemiologija, 1966). The typical clinical illness, we believe, occurs in only a small proportion (perhaps 20 %) of those infected.

While many studies have revealed that the rate of temporary and chronic carriers after an illness varies, it is usually about 10 % for the former and about 3 % for the latter (AMES & ROBBINS, 1943; Vogelsang & Bøe, 1948). However, in the older age groups the chronic carrier rate has been as high as 10 % (AMES & ROBBINS, 1943), or even higher among those having typhoid concurrently with other conditions such as schistosomiasis (Saad El-Din Hathout et al., 1966) and cholelithiasis (Tynæs & Utz, 1962).

There are other factors that must be taken into account when constructing mathematical models. For instance, superimposed infections may change greatly the susceptibility and resistance of the host, and thus alter the natural history of the disease. Studies in Egypt (Saad El-Din Hathout et al., 1966) have shown that the carrier rate or the rate of urinary excretors of S. typhi among people infected with schistosomiasis is much higher, and the carrier state lasts longer, than among
otherwise healthy people. Moreover, the presence of urinary carriers in rural areas with much stagnant water and poor sanitation leads to extensive environmental contamination and to a high risk of infection. This fact has to be taken into account when our model is adapted for use in areas where schistosomiasis is a common disease.

The environment undoubtedly plays a role in the natural history of typhoid fever and it should not be neglected, since the risk of transmission of infection depends greatly on environmental conditions.

There may be a greater risk of infection in certain specific population groups — e.g., nurses and schoolchildren — owing to the environmental conditions to which they are exposed.

The transmission of typhoid fever varies under different climatic, socio-economic, and cultural conditions and determines, to a great extent, the level of endemicity and morbidity rates. The rapid decline of typhoid fever in the USA during the last few decades is primarily the result of rapid changes in environmental conditions and standards of personal hygiene (National Communicable Disease Center, 1967). We have taken these environmental factors into account in the construction of our model, and have considered them to be the most important and decisive factors determining the actual level of endemicity in a community.

*Effectiveness of vaccines and mass immunization*

The effectiveness of vaccines was calculated from the data obtained in various controlled field trials (Cvjetanović & Uemura, 1965. The degree of effective protection conferred by the vaccine was taken as being equal to that conferred by the most effective vaccines in the controlled trials. These were the acetone-dried and heat-phenol vaccines given in two doses; however, in endemic areas, similar results could be expected with only one dose (Typhoid Panel, United Kingdom Department of Technical Co-operation, 1964; Cvjetanović & Tapa, unpublished data).

In view of the field experience, it was considered that booster doses of an effective vaccine should be given about every 5 years, and this was applied in the model. For reasons of simplicity, these factors were applied to a homogeneous population.

In constructing the model, we did not make adjustments for differences in the risk of infection and consequently in the expected morbidity rates between various population groups, including differences between those who did and those who did not volunteer to be immunized. It has been observed that, for various reasons, volunteers contract disease less readily and less often than those who do not volunteer for vaccination. In one controlled field trial, the typhoid
morbidity rate among volunteers belonging to the control group and receiving placebo was 13 per 1000, while in non-volunteers in the same community it was 26 per 1000 (Yugoslav Typhoid Commission, 1964). The ratio was thus 1:2. In the same study, the difference in morbidity rates between volunteers and non-volunteers was especially great among populations exposed to a heavy challenge dose in a waterborne outbreak, the morbidity rates being in the ratio of 1:11. This important fact should not be neglected as the immunization of a volunteering population tends to give results far below those that would be expected from the application of simple arithmetic.

For the above reasons, the “theoretical” effectiveness of typhoid vaccine, as determined in controlled field trials, differs from the “use” effectiveness in mass immunization campaigns. We have taken this into account and have made adjustments on the grounds of field experience (Yugoslav Typhoid Commission, 1964; Cvetanović, 1957) to compensate for the differences in vaccine effectiveness in the volunteers and the non-volunteers.

There are other possible reasons why the impact of immunization on the natural course of infection in the community may not in fact follow the straightforward calculations based on effectiveness determined in controlled field trials and expressed as a percentage reduction of the incidence rates. The possibility that vaccine is less effective for the prevention of inapparent infection and its spread than for the prevention of clinical illness has not been fully evaluated in any field trial and we still lack reliable information. We did not try to speculate or to make adjustments in our model to take this into account but this may become necessary if further research brings forth more clear-cut information.

Effectiveness of sanitation

Environmental sanitation — primarily the disposal of excreta, but also water chlorination, food control, etc. — when introduced and practised regularly considerably lowers the level of transmission of infection. The transmission rate or force of infection could easily be reduced to half its former level by the construction of privies and the provision of sufficient safe water (Schliessman et al., 1958; Wolf & van Zijl, 1969). Environmental sanitation appears to be the determining factor in the transmission of infection.

For the purpose of the model, the introduction of a specific sanitation programme could be considered simply as changing the force of infection. The construction of latrines would result in a diminished rate of transmission of infection from carriers — e.g., to 50% of its original value — which is supported by field observations.
Sanitation campaigns that are not followed by sustained efforts to maintain adequate sanitary practices may produce only temporary results. However, when sanitation is introduced together with health education and improvement of living standards, the effects tend to be cumulative, resulting in a steady reduction of typhoid morbidity rates owing to the decline in the force of transmission of infection.

CONSTRUCTION OF THE MODEL FOR TYPHOID FEVER ENDEMICITY

Structure of the model

The general population was divided into subgroups identifiable in the natural course of typhoid fever. The natural history and epidemiological evolution of the infection in the population depends essentially on changes in the various classes of individuals over a period of time. The structure and the class symbols adopted to simulate the dynamics of typhoid fever in the population¹ are illustrated in the flow chart (Fig. 17).

It is not easy to estimate the numerous rates of transition directly from available quantitative evidence. It was found more convenient to consider the rate of transition as the product of the rate of change from one stage of the disease to the other stages (or rate of exit) by a coefficient of transfer, which would represent the relative size of the class moving to any other subgroup.

Epidemiological parameters and daily rates of change

The epidemiological parameters involved in the present model are specified below. The numerical values of the corresponding daily rates of change are also indicated. They should, however, be considered as possible values only. Other simulations of typhoid fever dynamics could easily be worked out with different levels for these quantities.

An infected person may or may not become sick. In the present model it was assumed that the same dynamics of disease apply equally well to both types of infection with respect to the ability to transmit the infection to other persons and to maintain or lose resistance status. In the mathematical development, therefore, these two types of infection were treated, as far as possible, as one group, and for convenience the term “sickness” is used below also for asymptomatic infections.

Period of incubation. The mean duration was fixed at 14 days. The daily rate of exit is therefore $PI = 0.07143$ per person under incubation.

¹ The movement of births and deaths due to causes other than typhoid fever is not shown in the flow chart but was taken into consideration in the mathematical expression of the model.
Period of sickness. The mean duration was fixed at 28 days for both symptomatic and asymptomatic cases. In addition, it was assumed that 5% of affected persons would relapse for a mean period of 18 days. Hence the mean duration of the sickness period is \(0.95 \times 28 + 0.05 \times (28 + 18) = 28.9\) days per case. The daily rate of exit is therefore \(PS = 0.03460\) per case.

Temporary carriers. The mean duration was fixed at 90 days. The daily rate of exit is therefore \(PC = 0.01111\) per temporary carrier. The permanent carrier can exit only by death.
Table 28. Matrix of coefficients of transfer $R_{ij}$

<table>
<thead>
<tr>
<th>Class of origin $i$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>0.990</td>
<td>0.010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>0.040</td>
<td>0.950</td>
<td>0.010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>0.010</td>
<td></td>
<td>0.900</td>
<td>0.090</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>4</td>
<td>0.100</td>
<td></td>
<td></td>
<td>0.100</td>
<td></td>
<td>0.100</td>
<td></td>
<td>0.694</td>
<td></td>
<td></td>
<td>0.006</td>
</tr>
<tr>
<td>5</td>
<td>0.100</td>
<td></td>
<td></td>
<td></td>
<td>0.100</td>
<td></td>
<td>0.100</td>
<td></td>
<td>0.694</td>
<td></td>
<td>0.006</td>
</tr>
<tr>
<td>6</td>
<td>0.100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.300</td>
<td>0.600</td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.000</td>
</tr>
<tr>
<td>8</td>
<td>0.100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.900</td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>9</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.000</td>
</tr>
</tbody>
</table>

* Fatality rate is 0.03 of clinical cases. Assuming that 0.20 of cases $x_1$ and $x_2$ develop clinical symptoms, 0.006 of these cases are transferred to class $x_{10}$.

Resistants. The mean duration of short resistance was fixed at one year (365 days). The daily rate of exit is therefore $PR_i = 0.002740$ per short resistant. The mean duration of long resistance was fixed at 10 years. The daily rate of exit is therefore $PR_{x} = 0.0002740$ per long resistant.

Clinical or symptomatic cases. It was assumed that 20% of the persons passing through the sickness period are detected as typical acute clinical cases (symptomatic) (Vojna Epidemiologija, 1966). In this study, incidence rate refers to clinical cases only.

Mortality from typhoid. It was assumed that 3% of the clinical cases would die from typhoid fever. Therefore 0.6% of the daily exit of persons in the sickness period was allocated to typhoid deaths.

Natality and general mortality. For simplicity, a stable population was used in the model. The annual birth rate and crude death rate (all causes) were both fixed at the same level of 20 per thousand. The daily rates are therefore $PB = PD = 0.0000548$ per person in the community.

Force of infection. The risk of transfer of infection to a susceptible individual is proportional to the proportion of infectious persons in the population and to a factor $(RI)$ that is an expression of the force of infection. This factor is the resultant of the mean values of several para-

---

1 An actual example of a growing population is treated in the section entitled "Use of the model for the planning of preventive measures".
meters: frequency of contact, effective challenge dose, degree of susceptibility, etc.

In the present study, the factor $RI$ will be considered as the main variable determining the pattern of the epidemiological characteristics of the population. Four different values of $RI$ were successively entered in the model: 0.0018, 0.0020, 0.0025, and 0.0040 per susceptible and per infectious person per day.

**Infectiousness.** The infectious persons are: a small fraction of the persons incubating the disease, the majority of the sick, and all the carriers. The relative importance of each class was fixed as indicated in the matrix of coefficients of transfer (Table 28). The intensity of infectiousness was supposed to be constant for all persons in these classes.

**Coefficients of transfer**

All transfers from one epidemiological subgroup to another are represented in the flow chart (Fig. 17) by a set of coefficients $R_{ij}$, which express at each stage of the disease the fraction of individuals transferred from class $i$ to class $j$, out of all the individuals leaving class $i$.

The numerical values of the coefficients of transfer $R_{ij}$ were derived from available epidemiological evidence (see Table 28).

It is recognized that many of these coefficients can vary over a wide range and that for some of them the range of variation is not even known. It would not, however, be difficult to simulate typhoid fever dynamics with other values for the coefficients of transfer.

**Mathematical model**

The mathematical relationship between the 10 classes of individuals defined in Fig. 17 is expressed in the following system of 10 equations, where the differentials $dx_i$ are in fact finite daily increments, as all the rates were calculated on a daily basis:

\[
\begin{align*}
\frac{dx_1}{dx_{10}/x_1} &= -(x_5 + x_6 + x_7)(x_1/x_0)RI + (x_5 R_{1,1} + x_6 R_{5,1})PS + \\
&+ x_5 R_{5,0}PC + x_6 R_{5,1}PR + x_0 R_{6,1}PR + x_0 PB - x_1 (PD - \\
&- dx_{10}/x_1) \\
\frac{dx_2}{dx_{10}/x_2} &= R_{1,0}(x_3 + x_4 + x_5 + x_7)(x_3/x_1)RI + x_3 R_{3,3}PI - \\
&- x_3 (PL + PD - dx_{10}/x_1) \\
\frac{dx_3}{dx_{10}/x_3} &= R_{1,0}(x_2 + x_4 + x_5 + x_7)(x_4/x_1)RI + x_3 R_{3,3}PI - \\
&- x_4 (PL + PD - dx_{10}/x_1) \\
\frac{dx_4}{dx_{10}/x_4} &= (x_3 R_{4,3} + x_5 R_{4,1})PI + x_3 R_{5,3}PS - x_0 (PS + PD - dx_{10}/x_1) \\
\frac{dx_5}{dx_{10}/x_5} &= x_3 R_{5,3}PS - x_5 (PC + PD - dx_{10}/x_1) \\
\frac{dx_6}{dx_{10}/x_6} &= x_3 R_{4,3}PC - x_3 (PD - dx_{10}/x_1) \\
\frac{dx_7}{dx_{10}/x_7} &= (x_4 R_{4,3} + x_5 R_{5,3}PS + x_6 R_{6,3}PC - x_6 (PR + PD - dx_{10}/x_1)
\end{align*}
\]
\[ \begin{align*}
dx_3 &= x_6 R_{8,3} PR_1 - x_3 (PR_2 + PD - dx_{10}/x_5) \\
dx_{10} &= (x_3 R_{8,10} + x_8 R_{8,10})PS \\
\end{align*} \]

where \( x_i = \sum_{i=1}^{9} x_i \)

The annual number of cases is given by the formula:

\[ \Sigma [x_3 (R_{8,4} + R_{8,9}) + x_6 (R_{8,4} + R_{8,5}) 0.2 PI] \]

where the summation \( \Sigma \) is done over 365 days.

The annual number of typhoid fever deaths is simply given by the sum of \( dx_{10} \) over 365 days.

The above set of equations would constitute a system of differential equations if the daily rates were replaced by instantaneous rates of change. However, it was suspected that such a system could not be solved analytically with all mathematical rigour. On the other hand, the daily changes of the classes \( x_i \) are extremely small and can be calculated at high speed on the electronic computer. It was therefore decided to apply this technique in the simulation of typhoid fever dynamics.

In order to facilitate their interpretation, the numerical results of computer simulations actually produced will be presented here mainly in graphical form.

**APPLICATION OF THE MODEL TO EVALUATION OF THE EFFECT OF PREVENTIVE MEASURES**

**Stable Endemicity**

The first objective was to find the set of \( x_i \) values that would correspond to a stable endemic situation for a given value of the force of infection \( RI \); it was then possible to study clearly the effect of specific preventive measures imposed upon the stable endemicity.

Several preliminary trials showed that situations corresponding to existing levels of endemicity were obtained with the following four values of the parameter \( RI : 0.0018, 0.0020, 0.0025, \) and \( 0.0040 \). The percentage distribution of the population in the various epidemiological classes, when the stable situation is reached,\(^1\) are shown in Table 29 for the selected values of the force of infection.

It was found that the size of the epidemiological classes was almost linearly related to the reciprocal of the force of infection \( RI \). This fact

---

\(^1\) The mathematical problem consists of finding the set of values of \( x_i \) that simultaneously render null all the \( dx_i \). Asymptotic solutions were obtained with the computer by successive trials covering long periods.
Table 29. Stable percentage distribution in population classes for different levels of force of infection (RI). Birth rate and crude death rate are both equal to 20 per thousand population.

<table>
<thead>
<tr>
<th>Population class</th>
<th>0.0018</th>
<th>0.0020</th>
<th>0.0025</th>
<th>0.0040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susceptible</td>
<td>94.5</td>
<td>84.9</td>
<td>67.3</td>
<td>41.7</td>
</tr>
<tr>
<td>Incubating non-infectious</td>
<td>0.0244</td>
<td>0.0661</td>
<td>0.143</td>
<td>0.254</td>
</tr>
<tr>
<td>Incubating infectious</td>
<td>0.00122</td>
<td>0.00331</td>
<td>0.00716</td>
<td>0.0127</td>
</tr>
<tr>
<td>Sick infectious</td>
<td>0.0511</td>
<td>0.139</td>
<td>0.300</td>
<td>0.534</td>
</tr>
<tr>
<td>Sick non-infectious</td>
<td>0.00583</td>
<td>0.0158</td>
<td>0.0342</td>
<td>0.0609</td>
</tr>
<tr>
<td>Temporary carriers</td>
<td>0.0158</td>
<td>0.0430</td>
<td>0.0930</td>
<td>0.166</td>
</tr>
<tr>
<td>Permanent carriers</td>
<td>0.966</td>
<td>2.62</td>
<td>5.73</td>
<td>10.3</td>
</tr>
<tr>
<td>Short resistant</td>
<td>0.527</td>
<td>1.43</td>
<td>3.09</td>
<td>5.51</td>
</tr>
<tr>
<td>Long resistant</td>
<td>3.96</td>
<td>10.7</td>
<td>23.3</td>
<td>41.5</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Annual typhoid incidence rate&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.8</td>
<td>34.8</td>
<td>75.2</td>
<td>133.9</td>
</tr>
<tr>
<td>Annual typhoid death rate&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.3</td>
<td>11.7</td>
<td>25.3</td>
<td>45.1</td>
</tr>
</tbody>
</table>

<sup>a</sup> Per 10,000 population.
<sup>b</sup> Per 100,000 population.

facilitated the derivation of a stable situation from another already known stable situation. It is thought that a stable level of endemicity can establish itself only if the rate $RI$ remains above a certain critical value and that this value is a function of the birth and death rates. Further study in this direction might be fruitful.

**Immunization**

The mathematical model was then used to simulate the dynamic changes that would occur in the various epidemiological categories of the population under conditions of stable endemicity if mass immunization were carried out.

It was assumed that, by vaccination, a certain proportion of the susceptible persons was directly transferred to the short-resistant class. This proportion is measured by the efficacy of the immunization, which is itself the product of the immunization coverage and the effectiveness of the vaccine used. Ranges covering the more common values for these factors, as used for the computation of the resulting efficacy of the mass vaccination, are shown in Table 30.

The effects of different typical levels of efficacy of mass vaccination are analysed in the present study.
Table 30. Efficacy of vaccination against typhoid fever for various combinations of population coverage and vaccine effectiveness

<table>
<thead>
<tr>
<th>Population coverage</th>
<th>Effectiveness of vaccine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.60</td>
</tr>
<tr>
<td>0.60</td>
<td>0.36</td>
</tr>
<tr>
<td>0.80</td>
<td>0.48</td>
</tr>
<tr>
<td>1.00</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Single mass immunization. The effects of a single mass immunization on the annual incidence rate of typhoid fever as well as on the various epidemiological categories are shown in Fig. 18 for the two extreme levels of vaccination efficacy (36% and 90%). Separate graphs were drawn for each of the four levels of endemicity stability (see Table 29).

It is also interesting to observe the effect of periodic vaccinations on susceptible persons to the resistant class has an immediate effect on the incidence rate (per 10 000 population), the importance of the decrease being, of course, directly related to the efficacy of the mass immunization. It is, however, observed that after this spectacular drop the incidence rapidly rises and that, depending on the initial level of endemicity, between 50% and 90% of the gain is lost 10 years later. The speed of the loss is then considerably reduced and the curve tends slowly to the initial stability level. This fact is believed to be a consequence of the delayed repercussion of the mass vaccination on the carriers (see Fig. 18).

Periodic mass immunization. The results of seven successive mass immunizations carried out at intervals of 5 years are illustrated in Fig. 19 for the situation characterized by a low endemicity level ($R_I = 0.0018$) and a medium level of vaccination efficacy (60%).

Repeated vaccinations largely compensate for the rapid loss in the benefit observed on the incidence curve after each immunization, but it is noted that the additional gain decreases at each subsequent inoculation. Nevertheless, the long-term level, which is established when the vaccination programme is interrupted, is considerably affected by the number of successive vaccinations carried out. In the example illustrated in Fig. 19, the long-term gain on the incidence curve is, after seven inoculations, at least four times as large as after only one immunization.

It is also interesting to observe the effect of periodic vaccinations on the carriers. Slight decreases occur after successive vaccinations, but the

---

3 Computer runs were also produced for other levels of these parameters but are not reported here.
Fig. 18. Effect of a single mass vaccination on the dynamics of typhoid fever at different levels of endemicity and efficacy of vaccination: horizontal broken line — stability level; solid curve—efficacy of vaccination 90%; dashed curve — efficacy of vaccination 36%.
Fig. 18 (concluded)
Fig. 19. Comparison of the effects of single and periodical mass vaccination on the dynamics of typhoid fever; efficacy of vaccination, 60%; horizontal broken line — stability level for $R_I = 0.0018$; thick solid line — 1 vaccination; thin solid line — 7 periodic vaccinations.
movement is less and less accentuated, and after the last immunization
the curve sometimes shows a definite tendency to the re-establishment
of the original level.

*Improvements in sanitation*

Any improvement in sanitation — mainly the disposal of excreta, but
possibly also the provision of safe water, the adoption of hygienic habits,
etc. — would result in a decrease in the risk of infection, as measured
in this model by the force of infection $RI$ (Fig. 20).

The shift in time of the size of each epidemiological subgroup $x_i$ from
one stability level to another was simulated with the model.

The thick lines of Fig. 20 show the pattern of change of the annual
incidence rate (per 10,000 population), and of the percentages of
carriers and of susceptible and resistant persons, on the assumption that
a high force of infection ($RI = 0.0040$) is suddenly reduced, at the fifth
year, to a lower level ($RI = 0.0020$) as a consequence of the reduction
in the risk of transmission.

As seen in Fig. 20, the size of the various epidemiological classes
will ultimately pass from the initial stability level to the new, more
favourable, level of endemicity.

The 50% reduction in the force of infection causes an immediate
decrease in the annual incidence rate to about 50% of its original level,
followed by a temporary increase, most probably as a result of the
slower decrease in the reservoir of infection (see the trend of the per-
centage of carriers in Fig. 20). A long-term decrease is then observed,
bringing the incidence rate asymptotically to its new stability level.

*Combined effect of immunization and sanitation*

Fig. 20 also shows the additional gain on the incidence of the disease
that can be expected from combined mass immunization and sanitation
programmes with either single immunization or periodic vaccinations
at 5-year intervals. For the present illustration, the degree of immuniza-
tion efficacy was fixed at the medium value of 60% and the degree of
efficacy of sanitation at a value of force of infection 50% lower than
before the application of sanitary measures. Broadly speaking, the
results of combined measures are quite comparable in the long run with
those of improvements in sanitation alone. The main feature of interest
is perhaps that the long-term benefit of immunization is largely governed
by the permanent gain resulting from the favourable change in the
force of infection resulting from the improvement of sanitation. This
finding is of great importance for the long-term planning of control and,
possibly, eradication of typhoid fever.
Fig. 20. Effect of a change in the force of infection on the dynamics of typhoid fever with or without mass vaccination: thick solid line — no vaccination; thin solid line — 1 vaccination; broken line — 7 periodic vaccinations.
APPLICATION OF THE MODEL IN COST-BENEFIT EVALUATION

While the relative effectiveness of various preventive measures is of great practical interest to public health workers for both the planning and application of such measures, the costs and benefits must be taken into consideration in order to make the best use of available resources. We have therefore tried to apply our model to the evaluation of the relative merits of immunization and sanitation in the control of typhoid fever from the point of view of costs and benefits.

Determination of costs and benefits

Determination of the costs of vaccination and sanitation is not difficult. To the cost of the materials (vaccines, syringes, and needles; or latrines, water mains, etc.) was added the cost of transportation and manpower (professional and auxiliary). The benefits were calculated as the funds that would otherwise be spent on the treatment of typhoid cases, hospital and other expenses, as well as lost wages. We did not attempt to cost human lives in terms of money as some authors have done (Rice & Cooper, 1967). In view of this the actual benefits are always higher than can be presented by simple financial gains.

There were two main difficulties in the evaluation of costs and benefits, namely:

(1) The costs of immunization and treatment of cases, like other costs, differed greatly from country to country in view of the different stages of development of the medical services and the economy and the different socio-economic systems. In some countries, most of the cost of treatment was borne by individuals; in others, it was borne largely by the state (social or health insurance, for example). As the costs and benefits were differently distributed between individuals and state services, it was impossible to find a common international denominator and to express, in terms of one currency (e.g., US dollars) the costs and benefits that would be applicable generally.

(2) So far as sanitation is concerned, the benefits cannot be limited to its effect on typhoid alone. Sanitation affects other illnesses — enteric, parasitic, or skin infections — and leads to a rise in the standards of hygiene in general, and also brings (as in the case of water supplies) economic benefits.

We were therefore obliged to study each country or area separately, applying the same principles but taking into account specific conditions. The differences between the countries were so great that generalization was impossible.
We collected data on costs from several countries at various levels of development and with various socio-economic systems, and found that they can be roughly divided into several categories; for example:

(a) countries with a subsistence economy, the state being responsible for the provision of modest health services;

(b) countries with intermediate economic development, where the state has a limited financial responsibility for health matters and services;

(c) countries such as (b) in which the state has a greater financial responsibility for social and health matters and services;

(d) countries with a high degree of economic development, where the state has a limited responsibility for financing immunization and treatment of typhoid; and finally

(e) countries with a high degree of economic development where the state is largely (if not totally) responsible for providing free immunization, treatment, and wage compensation in case of illness.

Since typhoid fever is endemic and represents a problem in those countries with a lower level of development (a, b, c), we have limited our study to those categories.

Use of the model for long-term cost-benefit evaluation

Immunization and sanitation, even if envisaged as short-term programmes, have a long-lasting effect. The costs of initial investment are compensated over a long period of time. For practical reasons, a cost-benefit analysis should be considered on a long-term basis if one wishes to obtain meaningful information.

In view of the fact that conditions change with time, the cost-benefit analysis must be re-examined from time to time in the light of these changes and should become a continuous process in the planning and evaluation of public health programmes.

Use of the model for the planning of preventive measures

The model can be used for the planning of preventive measures in various countries and areas only if the necessary parameters, as described above, are known and if the relevant information is collected. Some of the parameters and information may be available from existing statistical returns and others may have to be collected in special surveys or studies designed for this purpose.

Once the data are available, they can be fed into the model and into the computer to predict the trend of typhoid for years to come, assuming that no special preventive measures are taken in the meantime. The
model can also be used to simulate the possible effect of the application of various immunization and/or sanitation programmes. On the grounds of costs and benefits, the merits of relevant preventive measures can be compared and those most suited to the goals envisaged and the resources can be selected.

In order to illustrate these uses of the model with an example, we shall take actual data on the epidemiological situation in a small, typical Pacific island with an initial population of about 150,000. The annual birth rate was taken as 35 per 1,000 inhabitants, and the annual death rate as 8 per 1,000 population. The annual natural incidence of typhoid fever cases was taken at the level of 7.2 per 10,000 inhabitants. These data correspond closely to the actual situation in Western Samoa and resemble that in some other islands.

The effect of one type of vaccine in two different immunization campaigns with vaccination repeated at 5-year intervals (A = 75% coverage, B = 50% coverage) on the population of this island is presented in Fig. 21. This shows how the incidence of typhoid would decline after immunization and indicates that higher coverage of the population with the same type of vaccine would give better results. The data thus obtained could be used for cost-benefit analysis. The cost of
immunization could be compared with the benefit derived from savings in the cost of treating the typhoid cases that would be prevented by immunization.

The effect of constructing privies is anticipated to produce a 50% drop in transmission owing to prevention of the spread of disease. Even if the effect of privy construction were smaller (e.g., 30%) it would still be considerable, as shown in Fig. 22, which presents the effect of a sanitation programme comprising construction of privies for the whole population over a 10-year period. The effect is long-lasting and produces a continuous decline in the incidence of typhoid owing to the gradual elimination of carrier-transmitted infection.

![Graph showing the effect of privy construction on typhoid incidence](image)

**Fig. 22.** Effect of privy construction on the annual incidence of typhoid fever. Effectiveness of privy construction: (A) = 50% on transmission by carriers; (B) = 30% on transmission by carriers.

Fig. 23 shows the effect of sanitation — namely, privy construction — on the incidence of typhoid when construction is accomplished over a period of 5 years and covers the whole population (case A). This is compared with privy construction over a 10-year period (case B). It is obvious that only a small additional long-term gain is achieved by early construction of all privies. This simulation (Fig. 23) shows, as does Fig. 22, that the endemicity level of typhoid in this community would, as a result of sanitation, begin to decline steadily and continuously. The same data can also be used for cost-benefit analysis.
Fig. 23. Effect of rate of privy construction on the annual incidence of typhoid fever.
Effectiveness of privy construction: 50% on transmission by carriers.

Fig. 24 compares the effect of privy construction alone with the cumulative effect of vaccination and privy construction combined, taking into account possible different levels of effectiveness of vaccination and sanitation. The effect of sanitation and vaccination is obviously greater, but a tendency to return to an earlier level of endemicity is obvious after immunization, whereas sanitation produces a definite and continuous downward trend in the endemicity level. It is therefore clear that sanitation would give a more permanent effect than immunization, although vaccination alone, or combined with sanitation, might, in the short run, be more effective for the control of typhoid fever.

In the present study, the numerical application of the cost-benefit calculation will be limited to three examples of single or combined activities drawn from the situations described above.

The cost factors have been determined from actual records available for the community and fixed as follows:

The estimated average cost of immunizing one person was taken as US$ 0.20, while the treatment of a typhoid fever case, including the cost of medical and paramedical personnel (but not lost wages), was estimated at US$ 100.00.

The average cost to the government of constructing a new, satisfactory privy or making sanitary an existing privy serving an average
Fig. 24. Effect of privy construction and mass vaccination at different levels of effectiveness on the annual incidence of typhoid fever. (A) = privy construction only — effectiveness, 50% on transmission by carriers; (B) = privy construction and vaccination — vaccination coverage, 75%; effectiveness, 80%; (C) = privy construction only — effectiveness, 30% on transmission by carriers; and (D) = privy construction and vaccination — vaccination coverage, 50%; effectiveness, 80%.
of six persons was estimated to be US$ 3.15. This represents the cost of the services of skilled manpower to aid and supervise construction or reconstruction of the privy. Other expenses of construction (unskilled labour and material) are readily borne by the population. The total cost of construction of a new, sanitary privy excluding unskilled manpower and superstructure was estimated to be US$ 5.00. Thus the government’s contribution represents over one half of the total cost of a new privy. The per caput cost of privy construction for the government is about $0.50 as compared with $0.20 for a single vaccination.

The costs and benefits are presented from the government’s point of view, the government being fully responsible for the cost of immunization and treatment of cases, while contributing only partly to the cost of privies; the population would provide, free of charge, the necessary material and manpower for construction of the privies.

The actual computer runs are presented graphically (Fig. 25), and only final values for a 30-year period are given in Table 31.

Example of costs and benefits of vaccination campaigns. In the first graph of Fig. 25 (left), the cost of vaccination and the saving on case treatment are cumulated over time for an immunization programme corresponding to the situation illustrated in Fig. 21 (line A). The cost of the first mass immunizations of 75% of the population would already be offset by savings on treatment in a 5-year period. After the third vaccination, owing to the decrease in case incidence, the difference between the cost of vaccination and the benefit on treatment is definitely positive and the balance is progressively augmented by the subsequent mass immunizations. One should not forget, however, that the incidence will slowly return to its initial level if vaccination activities are stopped.

Example of costs and benefits of privy construction. This example shows the cost of a programme for sanitation through the construction or improvement of privies. The parametric values and epidemiological effects of this programme were taken as described in Fig. 22 (line A). Furthermore, it was assumed that there was a necessity to rebuild or to make sanitary all the privies required by the population, the cost of material and manpower being borne by the population and the services of a sanitary inspector being provided by the government. The programme would cover a 10-year period and would then continue at a reduced rate to satisfy the needs of the annual population increase.

Fig. 25 (centre) shows that the savings resulting from the reduction

1 That is, vaccination at five-year intervals with an 80% effective vaccine of 75% of a community affected by a typhoid endemicity level of 7.2 per 10,000, the initial size of the population being about 150,000 and the natural annual growth 2.7%.
Fig. 25. Impact of different typhoid control programmes on the incidence of the disease and on the cumulative costs and benefits. (A) = incidence of typhoid case (per 10,000 population); (B) = cumulative costs; (C) = cumulative benefits.
in the number of typhoid fever cases grow slowly during the early years of the programme, and that the balance between the cost of privy construction and the benefit on case treatment starts to be positive only after 20 years. It should be observed that such a programme would ultimately lead to the eradication of the disease and thus provide an important and definite benefit (see Fig. 22). One should also take into account the beneficial effect of privies on other intestinal infections and the saving in lives and wages.

Example of costs and benefits of immunization and sanitation combined. The last example illustrates the impact of the combined strategy indicated for line B in Fig. 24. The cumulative cost of the five successive mass immunizations and the construction and improvement of privies (government contributions only) is presented in Fig. 25 (right), which also shows the corresponding benefits on case treatment expected from this programme. With the numerical values given to the parameters in this example, it is only after 25 years that the balance between cost and benefit begins to be positive, but in the meantime the disease would have been reduced to a considerably lower level than by any of the other control programmes.

The costs of vaccination and/or sanitation and the benefits obtained from savings on the treatment of prevented cases corresponding to the above three examples have been consolidated for a 30-year period in Table 31. In addition, the first line of the table shows the cost and benefit estimates corresponding to a single mass vaccination campaign with the same parametric values as in the first example of Fig. 25. The last two columns of this table show that the most favourable balance does not necessarily correspond to the greatest benefit as expressed in terms of saving on case treatment. In fact, as expected, the most substantial benefit results from combined immunization and sanitation, although the balance appears less satisfactory because the cost of this policy includes an expensive initial investment in privy construction.

It must be emphasized that these examples — limited by necessity to a single community in a developing country — considerably oversimplify the economic and financial treatment of the actual health problem and the strategy of control envisaged; for example, no allowance was made for interest on investments, for changes in absolute and relative costs of immunization, privy construction, and treatment that would occur in the lapse of time, or for numerous other factors.

In the preparation of control programmes numerous other possibilities arise in different communities and conditions. These could be analysed in a similar way. If, for example, the construction of privies proves unprofitable from a cost point of view for the government, when
Table 31. Summary of the costs and benefits expressed in US $ of various different typhoid control programmes over a 30-year period in a population and under conditions characteristic of a Pacific island

<table>
<thead>
<tr>
<th>Activity</th>
<th>Cumulative cost</th>
<th>Cumulative cost of treatment of typhoid cases</th>
<th>Balance between cost and benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vaccination</td>
<td>Construction of privies</td>
<td>Total cost</td>
</tr>
<tr>
<td>Vaccination, single</td>
<td>21 924</td>
<td>—</td>
<td>21 924</td>
</tr>
<tr>
<td>Vaccination, repeated(^b)</td>
<td>188 305</td>
<td>—</td>
<td>188 305</td>
</tr>
<tr>
<td>Privy construction</td>
<td>—</td>
<td>166 149</td>
<td>166 149</td>
</tr>
<tr>
<td>Vaccination(^c) and privy construction</td>
<td>145 632</td>
<td>166 149</td>
<td>311 781</td>
</tr>
</tbody>
</table>

\(^a\) The values shown when divided by 100 give the respective numbers of cases.

\(^b\) Six successive mass campaigns at five-yearly intervals.

\(^c\) Five successive mass campaigns at five-yearly intervals.
the government is responsible for the total or even half of the cost of construction, it may prove profitable if the population contributes 2/3 or 3/4 of the cost. When the proposed programmes, because of relatively high costs and low benefits, prove unacceptable to the health authorities, simulation would make it possible to explore alternative more beneficial approaches.

There are a number of economic and other factors not applied in the above examples that could be taken into account; for example, the secondary effects of control measures against typhoid fever, such as the effect of sanitation on the control of other enteric infections and intestinal parasites, or the effect of this control on the development of tourism.

The above examples of cost-effect and cost-benefit analysis showed that in a community resembling the population of Western Samoa, immunization and sanitation would give essentially the same results for about the same cost and that in selecting the most suitable control programme both would have to be considered in the light of local conditions.

A close inspection of local conditions in Western Samoa revealed, however, that the various districts of that country differ greatly in respect of incidence of typhoid fever and availability of water (necessary for the functioning of water-sealed latrines — the only satisfactory type of privy for these islands). Moreover, it was found that the cost of vaccination against typhoid fever could be significantly reduced if this antigen were combined with other vaccines (DPT) given to children. Such combined vaccination would cover only the younger age groups, as these are the only ones to receive DPT; however, it is precisely the very young age groups that are at highest risk of typhoid fever. Furthermore, in view of the serious financial limitations, the priorities in the control programme were determined, but the final analysis and plan of action demonstrated that the programme could be carried out all over the country without any appreciable increase of the Government's budget (but with continuing international assistance at the existing level).

In some districts with a water system, sanitation alone was shown to be the best long-term proposition for controlling typhoid fever, while in other areas, where incidence was very high and running water not available, vaccination was obviously of considerable benefit for a certain period of time until a water supply system and sanitary privies could be built.

It could be argued that such planning was possible earlier even without the help of a model. While there is probably some truth in this, there is no doubt that the model made it easier to prepare a sound pro-
gramme. The above plan for typhoid control at present forms a part of the national health programme.

OTHER USES OF THE MODEL

So far, the examples have shown how the model can be used to simulate the effects of preventive measures and to analyse their costs and benefits, and how it can assist in the planning and evaluation of typhoid fever control programmes.

The model has other uses, such as the prediction of future trends of typhoid fever and the requirements in material and manpower for specific control projects.

We used the model in this way by applying recent typhoid fever morbidity data from certain countries and simulating present trends. Comparing data obtained through the model with actual incidence in the countries studied, we observed a regularity and parallelism in the declining trend. However, in Great Britain, the natural decline was recently much slower than the model had predicted. On checking this discrepancy it was found that the majority of the recent cases of typhoid fever in Great Britain were imported or occurred among immigrants. The trend towards eradication of the disease shown by the model was therefore not borne out by fact. However, eradication would still be possible if cases and carriers were no longer imported into the country.

This theoretical exercise demonstrates how the model could be used to explore the possibilities of eradicating typhoid fever in a country and to determine the factors to be taken into account should eradication be the aim of the health authorities.

DISCUSSION

The typhoid fever model that has been developed represents a simplified natural epidemiological process. Nevertheless, it could be used in its present form for drawing up long-term public health programmes concerning, in particular, the use of both vaccines and sanitation for control. Whenever this model is applied to an actual population, it is necessary to keep in mind the factors (mentioned in the introductory paragraphs of this article and in the section on epidemiological factors) that have not been included in the model. These factors differ from population to population. They should first be evaluated and then, if necessary, introduced according to their relative merits and importance.

Knowledge of the number of carriers in a population is helpful in determining the dynamics of typhoid fever and will differ by age groups
according to the past incidence in these population groups. When most carriers are aged it should be expected, if other factors do not change, that they will be eliminated by death, and that a somewhat more favourable level of endemicity will be established. However, it should be mentioned that many elderly carriers represent a particular risk for the population since their standard of personal hygiene tends to deteriorate and they thus become a dangerous source of infection.

An increase of population under favourable environmental conditions should also lead to an improvement, particularly if the new generation is immunized. Where unfavourable conditions exist, an increase of population may lead to a deterioration, owing to overcrowding and general lowering of standards of living, sanitation, and personal hygiene. The growth of population should therefore be considered in the light of other pertinent epidemiological factors.

There are numerous other factors that may also have an important impact on the incidence of typhoid fever — e.g., natural calamities, superimposed infections such as schistosomiasis, and changes in food habits and standards of hygiene. It is the task of epidemiologists and public health workers to evaluate these factors critically and to use the mathematical model creatively in practice.

A few other factors should also be kept in mind, such as timing of the immunization campaign and selective protection of groups at high risk. The effect of mass immunization, as shown by the model, is of only a temporary nature. However, if it is repeated at the proper intervals and on sufficiently large portions of the population, immunization will lead to a definite decline in the endemic level of the disease. It must be realized, however, that while a more potent vaccine and a greater number of immunized persons signify a lower incidence of disease, they also mean an increased number of susceptible and a decreased number of resistant persons in the population. In practice, this means that once an immunization campaign has started it is important that it should continue if the gains made are not to be lost, since the carriers not eliminated by immunization represent a constant danger of further spread of infection. The effect of mass immunization campaigns should not be over-estimated as is often the case. Immunization campaigns have only temporary effects and, in addition, have other limitations as mentioned above.

The effect of sanitation is more spectacular and permanent. However, it is difficult to determine with certainty the degree of effectiveness in practice of any one of numerous sanitary measures or of their combinations: the effectiveness may be affected by additional health education and by changes in the standard of living.

A combined immunization and sanitation programme, while not
much more effective than sanitation alone, is indicated, in particular, in cases of disaster when disruption of the normal sanitary installations and measures occurs and maximum protection is required.

We have limited ourselves, in this instance, primarily to evaluation of the effect of immunization and/or sanitation programmes on the natural course of typhoid in an endemic community, but other preventive measures could also be evaluated by use of the same model. The model could also be used to evaluate the relative costs and benefits of immunization and/or other measures such as sanitation, treatment and isolation of cases, and treatment of carriers in various economic and epidemiological circumstances and at different levels of endemicity.

The effect of employing vaccines with increased potency or the effect of immunization of increased numbers of people in the campaigns can also be investigated. Finally, the model could be used for operational research in the evaluation of various public health programmes in terms of their costs and benefits, thus ensuring that the programmes set up give the best results possible with the financial means available.

No attempt has been made at this stage to determine the optimum use of funds for typhoid control in a wider public health programme, since it is difficult to evaluate all the economic and other consequences of an effective typhoid control or eradication programme. This would involve a complex study of balanced economic and health development and detailed cost-benefit analysis of numerous interrelated activities in the field of health and other spheres.

REFERENCES

American Public Health Association (1965) Control of Communicable Diseases in Man, 10th ed., New York
Cvjetanović, B. (1957) Vrijednost Cijepiva Protiv Tribužnog Tifusa, Zagreb, pp. 25-26
Saad El-Din Hathout et al. (1966) Amer. J. trop. Med., 15, 156-161
Schlessman, D. J. et al. (1958) Publ. Hlth Monogr., No. 54
Typhoid Panel, United Kingdom Department of Technical Co-operation (1964) Bull. Wild Hlth Org., 30, 631-634
Vogelsang, Th. M. & Bee, M. D. (1948) J. Hyg., 46, 252
TUBERCULOSIS

The methodology described in this example is based on the principles of operations research as applied to public health planning. The sequence of steps comprises:

1. formulation of the problem (including the definition of the objective);
2. collection of the information necessary to enable the problem to be expressed in quantitative terms;
3. construction of a model to represent the system under study;
4. derivation of model-based solutions and programme efficiency forecasts;
5. a test run of the "optimal" solution; plan of action;
6. evaluation and feedback; and
7. application at the national level.

Formulation of the problem

Tuberculosis is both a communicable disease and a source of human suffering. Tuberculosis control implies the application of available medical technology in a given situation so as to interfere actively with the epidemiological dynamics of the disease, commonly by attempting to "break the chain of transmission". The control measures comprise case-finding, chemotherapy, BCG vaccination of the uninfected, and chemoprophylaxis for certain categories of the infected. The health planner's objective is to make the optimal use of the preventive and curative means at his disposal so as to reduce the incidence of the disease progressively. In operations research terms, this is a problem of resource allocation under constraints.

The concept of the epidemiological effectiveness of the measures taken rests on a definition of the "disease problem", which must be represented symbolically and quantified. It has been suggested that the tuberculosis problem in a community should be represented as the

1 Based on an unpublished WHO document. For further details and references see WHO/TB/Technical Guide 67.2.
cumulative sum of the man-years of active infectious disease that will be experienced by the community.

If this definition is adopted, there is no theoretical difficulty in measuring the effectiveness of control measures in terms of problem reduction.

Represented graphically (see Fig. 26), the objective is to maximize the problem reduction (ΔP), within certain limits imposed by the epidemiological, administrative, economic and sociological constraints described below.

Fig. 26. Problem reduction in tuberculosis control

1) The service must be permanent (epidemiological requirement)

The epidemiological situation and the available control measures are such that there is no reasonable expectation of reducing the problem rapidly. Even if an existing infectious pool could be reduced substantially by an energetic one-time treatment programme, there is evidence that the infectious pool would again be almost as great a few years later, since new infectious cases develop as a result of the “break-down” of earlier infection. Likewise, mass BCG vaccination over a short period cannot be expected to have a radical effect on the infectious pool in the short run. The services to be established must therefore have the character of permanent programmes, not of emergency campaigns.

2) The service must be integrated into the general health services (administrative requirement)

In most developing countries, the strengthening of general health services has a high priority. The development of specialized tuber-
c ulosis services diverts funds and manpower from this priority objective. Furthermore, although basic health units may require the support of a specialized referral service, one of the duties of general health services is to deal with tuberculosis. The specialized services should be restricted to areas where specialization is essential on technical grounds, and should not make use of basic health units as a field arm. This consideration influences many aspects of planning.

In particular, tuberculosis control can be developed so that it both supports and promotes the development of existing general health services, and it is both economically and socially desirable that it should be developed in this way.

(3) The service must be nationally applicable (economic requirement)

Any plan should be formulated for the nation as a whole, and should be based on a realistic assessment of existing and future resources, including both money and manpower. The essential considerations to be borne in mind are that: (a) BCG vaccination is a cheap control measure; (b) diagnosis by microscopy is highly efficient; (c) much of the infectious case-load can be dealt with by ambulatory treatment provided by general health units; and (d) specialized tuberculosis services at the peripheral level are not required for these control methods. A national plan based on these considerations is within the means of most developing countries.

(4) Development consonance (sociological requirement)

Closely related to national applicability is the principle that service development must be in consonance with the economy and with social development.

The question facing the public health administrator is therefore: “with the available resources in money and manpower, what kind of control measures and how much of each kind should be applied, by whom and to whom, in order to reduce the problem of tuberculosis as much as possible?” The objective is sometimes qualified further by specifying a time limit, such as “before 1990”. According to the definition of the tuberculosis problem adopted, there is no conflict, in the planning process, between alleviating suffering (regarded by the economist as a kind of short-term consumption) and control of the disease (considered to be a long-term investment).

Collection of information

Quantifiable information is required for the formulation of the programme and a plan of action, and for selection of the test area,
efficiency forecasts and demarcation of fields for further studies.

Such information includes general demographic and administrative data, specific data on the epidemiology and sociology of tuberculosis, and operational data on the health infrastructure. These are obtained partly from existing sources and partly from surveys in a test (pilot) area.

The information required for formulating a programme, the method of selecting a test area, and the design of a population survey and of an inventory of health services, are all based on familiar statistical and survey methods.

Construction of a model

Descriptive models of the epidemiological course of tuberculosis must be distinguished from decision models, in which additional "intervention parameters" enable more or less explicit tuberculosis control programmes to be simulated and so contribute to the choice of optimal strategies for attaining defined objectives. It is with the latter category that we are concerned here.

It should, however, be understood that model-processing contributes only one element, though an important one, to the actual planning and programming of tuberculosis control. Model-based conclusions can, for instance, commonly identify an optimal programme that could be carried out under specified conditions — such as a suitable combination of vaccination and treatment of infectious cases — but they do not indicate where and how vaccinations and treatment should be given.

Four examples of general mathematical models, as applied to tuberculosis control, are discussed below. Three other models are also considered, namely the problem reduction model, the activity effectiveness model, and the comprehensive operational model.

Example 1. A mathematical model for the economical allocation of resources for tuberculosis control, developed by ReVelle et al.,1 has for its starting point a descriptive model of tuberculosis epidemiology, expressed in terms of a system of differential equations. The planning period is divided into one-year intervals, and equations are written for the rate of change of numbers in the various categories during the i'th year. The descriptive model is then converted into an optimization model by introducing: (a) a specified pattern of active case reduction; and (b) data that enable the combinations of control measures that can produce this pattern, at least cost, to be identified.

Example 2. A linear programming decision model for tuberculosis

---

control uses, as "inputs", estimates of the demands on medical staff, financial and other resources for each of the tasks involved in tuberculosis control. Constraints that limit the choice of alternatives are specified. Some constraints embody restrictions on the money and other resources required for health activities, such as staff time, bed-days, etc. Others embody epidemiological restrictions, such as the maximum number of subjects eligible for a particular health activity. "Outputs" are the health and other benefits to the individual and the community, namely, the quantity of benefit that results from a unit of health activity. Economic benefits are considered separately. A weighting system is introduced to enable the various benefits to be expressed in terms of the same scale of utility. The solution is given in the form of the optimal combination of activities in specified circumstances. A FORTRAN computer program enables the unit inputs and outputs to be computed from the basic observed data, and the Simplex method for solving linear programming problems is used. The results of test runs have been presented.\(^8\)

**Example 3.** Another type of model suggested for this purpose is the "simulation model", which represents the performance of various types of health services in respect of different population groups. This type of model expresses the operational efficiency of services in terms of the work that could be done during a certain period of time and the probable coverage that could be achieved in various areas, without regard to cost.

One such model\(^3\) involves five sub-systems, defined by the following parameters: the individual's state of health, the type of health services available, awareness of chest symptoms, the participation of the public in case-finding programmes, diagnostic techniques and treatment regimens, and the organization available. On the basis of this model, operational forecasts of case-finding and treatment can be made and then tested in the field.

**Example 4.** A similar model has been suggested for estimating the operational effectiveness of BCG vaccination programmes.\(^4\) It takes into account the demographic dynamics of the population, and such operational parameters as daily output of work per vaccinator, daily coverage of the population, number of working days, number and type of vac-

---

\(^1\) Developed by the Tuberculosis Unit, WHO, and Professor M. S. Feldstein, Harvard School of Economics, Cambridge, Mass., USA.


cinators (mass campaign, integrated). If it is assumed that, within a reasonably narrow range of variation in the coverage, the unit cost of vaccination remains constant, the problem is solved in terms of the maximum cumulative coverage at some point of time (the "planning horizon").

Example 5 (problem reduction model). This is based on the epidemiological forecast shown in Fig. 27, where the vertical scale shows the prevalence of infectious tuberculosis, and the horizontal scale, time in years. The different curves represent projected prevalence rates resulting from the application of different control programmes in a population with known demographic and epidemiological characteristics. The simulated programmes comprise BCG vaccination of the susceptible (non-infected) population at age 15, and the detection and treatment of infectious cases of tuberculosis. A constant 80% BCG vaccination coverage of susceptibles at age 15 and an initial protection of 80%, which decreases at the rate of 1% per annum, are assumed. In the programme represented by the uppermost curve (T0), successful treatment of cases is nil. This constitutes a standard against which the results of other programmes can be compared. Successive curves then show the effect of successful treatment of 5% (T1), 10% (T2), 33% (T3), and 66% (T4) of cases.

Fig. 27. Epidemiological forecast of prevalence of infectious tuberculosis
The area below any curve and delimited by the ordinates corresponding to one year and to any subsequent year is taken as a measure of the "tuberculosis problem". Thus, for example, if the areas under the two upper curves are compared, it is possible to estimate the problem reduction to be expected from 5% successful treatment combined with an 80% vaccination coverage, and so on. Other vaccination coverage levels could, of course, be similarly represented. Alternative programmes that achieve the same problem reduction by different combinations of vaccination and treatment coverage are regarded as epidemiologically equivalent, though their operational contents differ. Forecasts of this kind point to the conclusion that the same problem reduction might be achieved in different ways. Alternatively, given different programmes, they enable one to decide which of them could be expected to reduce the problem most, or which is the minimal programme that could be expected to reduce the problem to some particular extent. This kind of epidemiological model also provides one possible basis for optimization.

**Example 6 (activity effectiveness model).** This is based on the data shown in Table 32, where the 60 activities listed in the first column are possible components of a tuberculosis control programme, such as direct BCG vaccination; conventional vaccination of non-reactors to the tuberculin test; case-finding by microscopy and by culture, with or without X-ray screening; treatment with various regimens and according to various administrative patterns (ambulatory, institutional, self-administered, supervised administration, etc.). The activities are age-specific, and as such differ in clinical and epidemiological content. The second column shows the output per unit of activity, in "years of healthy living" gained by patients and by persons who are protected against tuberculosis. The third column shows the benefit expected from spending 100 monetary units (US cents) on the given activity. It can be seen that activity 22 (diagnosis by microscopy) gives the highest output-input ratio, followed by activity 37 (a regimen of isoniazid/thiacetazone by self-administration to cases of infectious tuberculosis in the age-groups 15-44 and 45-64 years). Activity 1 (direct vaccination of children in the age-group 0-14 years) comes third in decreasing order of output-input ratio. Next comes activity 52 (the same as 27, but applied in the age-group 65+). Whilst the choice of a programme will also depend on other factors or constraints, this kind of approach can provide a basis for an optimal programme, where the amount of money available for tuberculosis control is limited.

**Example 7 (comprehensive operational model).** An operational forecast of programme performance during three months is shown in Table 33; this is based on epidemiological estimates of prevalence, as follows:
Table 32. Expected output of tuberculosis control activities\(^1\)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Output per unit activity</th>
<th>Output per 100 monetary units (US cents)</th>
<th>Activity</th>
<th>Output per unit activity</th>
<th>Output per 100 monetary units (US cents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1300</td>
<td>1.867</td>
<td>31</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>0.1300</td>
<td>0.840</td>
<td>32</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>—</td>
<td>—</td>
<td>33</td>
<td>22.9131</td>
<td>0.532</td>
</tr>
<tr>
<td>4</td>
<td>—</td>
<td>—</td>
<td>34</td>
<td>22.9131</td>
<td>0.575</td>
</tr>
<tr>
<td>5</td>
<td>0.1300</td>
<td>0.321</td>
<td>35</td>
<td>22.9131</td>
<td>0.628</td>
</tr>
<tr>
<td>6</td>
<td>0.1300</td>
<td>0.296</td>
<td>36</td>
<td>22.9131</td>
<td>0.628</td>
</tr>
<tr>
<td>7</td>
<td>—</td>
<td>—</td>
<td>37</td>
<td>22.9131</td>
<td>3.340</td>
</tr>
<tr>
<td>8</td>
<td>—</td>
<td>—</td>
<td>38</td>
<td>22.9131</td>
<td>2.035</td>
</tr>
<tr>
<td>9</td>
<td>16.4322</td>
<td>0.843</td>
<td>39</td>
<td>22.9131</td>
<td>1.207</td>
</tr>
<tr>
<td>10</td>
<td>16.4322</td>
<td>0.833</td>
<td>40</td>
<td>22.9131</td>
<td>1.162</td>
</tr>
<tr>
<td>11</td>
<td>16.4322</td>
<td>—</td>
<td>41</td>
<td>22.9131</td>
<td>0.115</td>
</tr>
<tr>
<td>12</td>
<td>16.4322</td>
<td>—</td>
<td>42</td>
<td>22.9131</td>
<td>0.115</td>
</tr>
<tr>
<td>13</td>
<td>16.4322</td>
<td>—</td>
<td>43</td>
<td>22.9131</td>
<td>0.123</td>
</tr>
<tr>
<td>14</td>
<td>16.4322</td>
<td>—</td>
<td>44</td>
<td>22.9131</td>
<td>0.122</td>
</tr>
<tr>
<td>15</td>
<td>0.0859</td>
<td>0.019</td>
<td>45</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>16</td>
<td>0.0981</td>
<td>1.409</td>
<td>46</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>17</td>
<td>0.0981</td>
<td>0.634</td>
<td>47</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>18</td>
<td>0.0981</td>
<td>0.331</td>
<td>48</td>
<td>8.7050</td>
<td>0.202</td>
</tr>
<tr>
<td>19</td>
<td>0.0981</td>
<td>0.325</td>
<td>49</td>
<td>8.7050</td>
<td>0.218</td>
</tr>
<tr>
<td>20</td>
<td>23.4062</td>
<td>0.641</td>
<td>50</td>
<td>8.7050</td>
<td>0.239</td>
</tr>
<tr>
<td>21</td>
<td>23.4062</td>
<td>0.642</td>
<td>51</td>
<td>8.7050</td>
<td>0.239</td>
</tr>
<tr>
<td>22</td>
<td>23.4062</td>
<td>3.412</td>
<td>52</td>
<td>8.7050</td>
<td>1.269</td>
</tr>
<tr>
<td>23</td>
<td>23.4062</td>
<td>2.897</td>
<td>53</td>
<td>8.7050</td>
<td>1.077</td>
</tr>
<tr>
<td>24</td>
<td>23.4062</td>
<td>1.201</td>
<td>54</td>
<td>8.7050</td>
<td>0.459</td>
</tr>
<tr>
<td>25</td>
<td>23.4062</td>
<td>1.187</td>
<td>55</td>
<td>8.7050</td>
<td>0.442</td>
</tr>
<tr>
<td>26</td>
<td>23.4062</td>
<td>0.117</td>
<td>56</td>
<td>8.7050</td>
<td>0.044</td>
</tr>
<tr>
<td>27</td>
<td>23.4062</td>
<td>0.117</td>
<td>57</td>
<td>8.7050</td>
<td>0.044</td>
</tr>
<tr>
<td>28</td>
<td>23.4062</td>
<td>0.125</td>
<td>58</td>
<td>8.7050</td>
<td>0.047</td>
</tr>
<tr>
<td>29</td>
<td>23.4062</td>
<td>0.124</td>
<td>59</td>
<td>8.7050</td>
<td>0.046</td>
</tr>
<tr>
<td>30</td>
<td>—</td>
<td>—</td>
<td>60</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

\(^1\) For details, see document WHO/TB/Techn. Information/67.55.

1. sociological estimates of awareness of symptoms and motivation for consulting various types of health institution (collected in a sociological sampling enquiry);

2. an inventory of the available health institutions, with particular reference to the feasibility of operating simplified case-finding, referral, and treatment procedures;

3. the behaviour pattern of patients receiving intensive self-administered treatment, as observed in similar institutions in the country; and
<table>
<thead>
<tr>
<th>Classification and code no. of health unit</th>
<th>Hospitals</th>
<th>Health centres</th>
<th>Health sub-centres and dispensaries</th>
<th>Grand total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. completed primary examination</td>
<td>600</td>
<td>268</td>
<td>260</td>
<td>928</td>
</tr>
<tr>
<td>No. positive smear</td>
<td>26.4</td>
<td>12.2</td>
<td>12.5</td>
<td>41.2</td>
</tr>
<tr>
<td>No. completed secondary examination</td>
<td>91.7</td>
<td>41.0</td>
<td>12.7</td>
<td>43.2</td>
</tr>
<tr>
<td>No. positive culture</td>
<td>1.59</td>
<td>2.02</td>
<td>0.86</td>
<td>3.41</td>
</tr>
<tr>
<td>No. positive X-ray only</td>
<td>0.49</td>
<td>2.44</td>
<td>7.93</td>
<td>25.06</td>
</tr>
<tr>
<td>No. completed child examination</td>
<td>22.4</td>
<td>0.99</td>
<td>45.1</td>
<td>71.5</td>
</tr>
<tr>
<td>No. positive X-ray</td>
<td>11.10</td>
<td>4.45</td>
<td>15.5</td>
<td>21.06</td>
</tr>
<tr>
<td>No. diagnoses based on clinical examination only</td>
<td>2.22</td>
<td>0.89</td>
<td>3.31</td>
<td>6.40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Excellence of methods:</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. eligible for treatment</td>
<td>26.3</td>
<td>14.8</td>
<td>13.4</td>
<td>54.6</td>
</tr>
<tr>
<td>No. x-ray treatment</td>
<td>18.8</td>
<td>7.68</td>
<td>26.6</td>
<td>53.0</td>
</tr>
<tr>
<td>No. x-ray collection</td>
<td>15.0</td>
<td>6.13</td>
<td>15.2</td>
<td>36.4</td>
</tr>
<tr>
<td>No. x-ray collection for diagnosis</td>
<td>13.0</td>
<td>5.93</td>
<td>16.5</td>
<td>45.4</td>
</tr>
<tr>
<td>No. x-ray collection for diagnosis</td>
<td>10.5</td>
<td>4.48</td>
<td>10.7</td>
<td>25.6</td>
</tr>
<tr>
<td>No. x-ray collection for diagnosis</td>
<td>7.54</td>
<td>3.01</td>
<td>8.4</td>
<td>18.9</td>
</tr>
<tr>
<td>No. x-ray collection for diagnosis</td>
<td>7.75</td>
<td>3.17</td>
<td>8.4</td>
<td>19.3</td>
</tr>
<tr>
<td>No. x-ray collection for diagnosis</td>
<td>7.55</td>
<td>3.18</td>
<td>8.4</td>
<td>19.3</td>
</tr>
<tr>
<td>No. x-ray collection for diagnosis</td>
<td>1.96</td>
<td>0.80</td>
<td>2.3</td>
<td>4.21</td>
</tr>
<tr>
<td>No. x-ray collection for diagnosis</td>
<td>1.96</td>
<td>0.80</td>
<td>2.3</td>
<td>4.21</td>
</tr>
<tr>
<td>No. of patients with tuberculosis</td>
<td>2.28</td>
<td>0.99</td>
<td>2.5</td>
<td>5.76</td>
</tr>
<tr>
<td>No. of patients with tuberculosis</td>
<td>2.28</td>
<td>0.99</td>
<td>2.5</td>
<td>5.76</td>
</tr>
<tr>
<td>No. of patients with tuberculosis</td>
<td>2.28</td>
<td>0.99</td>
<td>2.5</td>
<td>5.76</td>
</tr>
<tr>
<td>No. of patients with tuberculosis</td>
<td>2.28</td>
<td>0.99</td>
<td>2.5</td>
<td>5.76</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment of patients:</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients with tuberculosis</td>
<td>2.28</td>
<td>0.99</td>
<td>2.5</td>
<td>5.76</td>
</tr>
<tr>
<td>No. of patients with tuberculosis</td>
<td>2.28</td>
<td>0.99</td>
<td>2.5</td>
<td>5.76</td>
</tr>
<tr>
<td>No. of patients with tuberculosis</td>
<td>2.28</td>
<td>0.99</td>
<td>2.5</td>
<td>5.76</td>
</tr>
<tr>
<td>No. of patients with tuberculosis</td>
<td>2.28</td>
<td>0.99</td>
<td>2.5</td>
<td>5.76</td>
</tr>
</tbody>
</table>

| Grand total                           |          |               |                                    |            |
(4) the expected effectiveness of case-finding and treatment under local conditions, extrapolated from clinical trials.

It will be seen that the forecast covers the amount of work expected from various health units, as well as the quality of the work and the potential epidemiological yield of the programme. It should be emphasized that these figures do not represent targets but estimates of what can be done.

The epidemiological impact, the priority ranking of possible alternative activities, and the operational implications, as estimated by the three types of forecast, correspond to three stages of the planning process:

(1) conception;
(2) decision; and
(3) operation.

For the purpose of decision-making, all three types of forecast are needed.

Model-based solutions and programme efficiency forecasts

Several computer models are now available for providing forecasts of the efficiency of simulated tuberculosis control programmes in terms of output, cost, coverage of BCG vaccination, chemotherapy, etc.

Epidemiological models are of particular interest to the epidemiologist, resource allocation models to the public health administrator and operational models to the programme director or field team-leader.

Test run of the optimal solution; plan of action

Of the various alternatives simulated, the programme selected will be the one that conforms to the objective of maximal problem reduction in the given circumstances. The allocation of resources to the different programme components, and the expected outputs and coverages in the field, are specified as part of the solution.

The test run consists in the implementation of the optimal programme in the test area on which operational forecasts were based. Implementation involves, inter alia, preparing work instructions and technical manuals, training staff, providing supplies, and obtaining administrative clearance.

All procedures, whether teaching methods or basic techniques, are standardized and simplified so that implementation, as far as possible, is in accordance with the computed optimal solution.

Evaluation and feedback

The test run provides the means of comparing observed values of output quality, work-loads and cost with forecast values. The accuracy
of the forecasts is thus assessed by comparison with operational results; estimates of operational parameters, such as output per vaccinator-day, public participation in a diagnostic programme, and default rates, can then be modified appropriately. Revised forecasts are then made on the new basis, which may in turn lead to the selection of new solutions by means of a new set of simulations. As a rule, only marginal adjustments of programmes are needed.

Application at national level

The countrywide application of a tuberculosis programme need not be delayed while the test run is in progress. The two can proceed concurrently, with the test run one step ahead. Technical and other improvements indicated by the test run can be incorporated into the national programme as it proceeds. Furthermore, many education and training facilities required for the national programme can be linked to the test run.

The first step towards formulating an epidemiological model was taken by WHO in 1959. Four years later, a workable model was put into the computer. By 1966, a formal decision model was in service, and in 1968 operational forecasts were made in the field. Although many gaps remain to be filled, the progress already made is promising.

CHOLERA

The following is an attempt to consider certain public health aspects of the problems that are produced by outbreaks of cholera in endemic and non-endemic areas; it is intended primarily to enable public health administrators in developing countries to make decisions as to the control of such outbreaks.

On the basis of the data available from several communities in South-East Asia, synthetic population groups have been used as models, and the possible consequences of an outbreak in such model communities studied.

Requirements for treatment and control

Hospital treatment. The costs of rehydration fluid, drugs, and medical care for the effective treatment of a hospitalized patient in endemic and non-endemic areas are listed in Tables 34 and 35, respectively. The costs of treatment are given separately for endemic areas because, as

---

1 Based on: Public health aspects of cholera and its control in non-endemic and endemic areas by B. Cvetjanov; (unpublished paper presented at the WHO Inter-Regional Seminar on the Organization of Cholera Control Programmes, Manila, October 1970).
Table 34. Cost of hospital facilities, drugs and manpower required for treatment of a cholera case in well-established treatment centres in an endemic area (Calcutta)

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment with rehydration fluid (parenteral) only</th>
<th>Treatment with rehydration fluid (parenteral) and antibiotics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Cost (Rs)</td>
</tr>
<tr>
<td>Total hospital stay (days)</td>
<td>9</td>
<td>135.00</td>
</tr>
<tr>
<td>Fluid needed (litres)</td>
<td>18</td>
<td>92.00</td>
</tr>
<tr>
<td>Drugs needed (tetracycline) (dose)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Physician's time (hours)</td>
<td>12</td>
<td>48.00</td>
</tr>
<tr>
<td>Nurse and auxiliary time (hours)</td>
<td>20</td>
<td>40.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost</td>
<td></td>
<td>315.00</td>
</tr>
</tbody>
</table>

* $ 41 approx.

b $ 20 approx.

Table 35. Cost of hospital facilities, drugs and manpower required for treatment of a cholera case in a non-endemic area

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment with rehydration fluid (parenteral) only</th>
<th>Treatment with rehydration fluid (parenteral) and antibiotics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Cost ($)</td>
</tr>
<tr>
<td>Total hospital stay (days)</td>
<td>9</td>
<td>18</td>
</tr>
<tr>
<td>Fluid needed (litres)</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>Drugs needed (tetracycline) (dose)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Physician's time (hours)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Nurse and auxiliary time (hours)</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
</tr>
</tbody>
</table>

a result of the long experience of cholera and the low wages prevailing, treatment will be considerably cheaper in such areas than in non-endemic areas with a higher standard of living. In spite of differences in the cost of treatment in various countries, however, the variation in
treatment and in average cost is not very great, since the clinical course of a hospitalized cholera patient is more or less the same everywhere.

The costs shown in Tables 34 and 35 apply to an average case of cholera; mild cases will cost less, and severely ill cases more. Average costs in any given hospital may vary according to the relative proportions of severe and mild cases of cholera treated in that hospital.

The tables permit the estimation of the supplies and manpower needed, depending on the expected number of patients. If pyrogen-free rehydration fluid for parenteral use is lacking, oral fluid can be given. The cost of oral fluid is negligible, but its administration requires double the nurse time given in the tables, if not more. The total duration of hospital stay is essentially the same, and thus the total cost is also more or less identical, or perhaps somewhat lower. However, in view of its other advantages, such as suitability for use under difficult field conditions in the absence of parenteral rehydration fluid, oral rehydration may be preferred.

Transport. The outcome of treatment will depend not only on the availability of hospital beds, drugs and manpower, but also on that of transport.

A patient hospitalized within three hours of the onset of symptoms is saved; the case fatality rate of those hospitalized between three and six hours after onset is 10%, while for those hospitalized more than six hours after onset, the rate is 30%.

Quick transport is thus an essential requirement. Available ambulances will not be sufficient, even if round-the-clock working is introduced. In order to avoid delay, one fully staffed ambulance (in good repair!) working 24 hours a day is needed for every five admissions per day. This means that, in most places, additional vehicles must be made available. At least 50% of these vehicles, particularly those used for transporting severe cases from distant areas, must be equipped for intravenous fluid administration during transportation. In most cases, transportation difficulties can be solved if assistance is provided by the armed forces.

The costs shown in Tables 34 and 35 do not include an allowance for transport, but this can easily be estimated: for each patient, about two hours of auxiliary and transport staff time, and transport over a distance of 10 km in a small city or 20 km in a large city, can be taken as normal.

Hospital beds. The beds needed will comprise:

(a) special beds in infectious diseases wards with specialized facilities;
(b) in the absence of such special beds, hospital beds of any kind;
(c) improvised beds. Cholera treatment requires a special cholera cot, which can be easily improvised, provided the necessary material is available (e.g., plastic sheets).

Much can be improvised if social organization exists and is functioning well. The effect of panic should not be overlooked, because this could greatly hamper the use of the resources available (hospital beds, transport, etc.).

Rehydration fluid. This will not always be available. Fatality rates of 30% in some hospitals indicate that possibly only 10-20%, if any, of the necessary rehydration fluid is given. Fatality rates of 1-3% indicate that virtually all the necessary fluid is given. This is on the assumption that the necessary staff are transferred from other tasks, that all available beds are used, and that the necessary care is provided.

Possible effect of a cholera outbreak on a non-immunized population in a developing country

In our hypothetical examples, we have considered the following situations with regard to the supplies needed for treatment:

(a) all the fluid needed, but no drugs, are available;
(b) all the fluid and drugs needed are available;
(c) only 50% of the fluid needed, but no drugs, are available;
(d) only 50% of the fluid needed and 50% of the drugs are available.

Effect on a city of 5 million population. Of the city population, approximately 10,000 would develop the disease within three months, which gives a morbidity rate of 2:1000. If it is assumed that stocks of rehydration fluid and antibiotics are sufficient to treat 50% of the clinical cases, the fatality rate for this group would be 2%. Partial treatment would be available for a further 3000, for whom the fatality rate would be 30%, and no treatment at all for the remaining 2000, for whom the fatality rate would be 50%. The number of deaths in the three groups would thus be as shown in Table 36, and the total number of deaths would be 1700. Hospitalization and transportation problems would be manageable though with certain difficulties.

Effect on a city of 500,000 population. Of the city population, approximately 1000 would develop the disease within three months. Medical resources, hospitals and staff will be proportionately scarcer in the smaller city than in the larger, so that the situation will be correspondingly more difficult.
Table 36. Number of deaths from cholera in a city of 5 million population (no immunization)

<table>
<thead>
<tr>
<th>Type of treatment</th>
<th>No. of patients</th>
<th>No. of deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full</td>
<td>5000</td>
<td>100</td>
</tr>
<tr>
<td>Partial</td>
<td>3000</td>
<td>600</td>
</tr>
<tr>
<td>None</td>
<td>2000</td>
<td>1000</td>
</tr>
</tbody>
</table>

Effect on a rural population of five million. The morbidity will be the same as or higher than in the cities, but it will be impossible to make satisfactory arrangements for hospitalization and treatment, and external assistance from a neighbouring city (or cities) will be needed to meet those demands that are out of proportion to the facilities available.

Possible effect of a cholera outbreak on a partially immunized population in a developing country

The same populations as above, with the same facilities, will be considered here. However, it is assumed that the population is 50-75% immunized. In view of the effectiveness of vaccine at the present time, (about 50%), the total number of cases should diminish by about 20-30%, respectively. Accordingly, rehydration fluid and drugs will be available, at least partially, for all. As a result, there will be fewer deaths, thanks to better treatment in less crowded infectious wards.

A comparison of the effects of an outbreak in an immunized and a non-immunized population is given in Table 37.

Table 37. Possible effect of a cholera outbreak in an immunized and a non-immunized population

<table>
<thead>
<tr>
<th>Population of city</th>
<th>50%</th>
<th>75%</th>
<th>No. of cases</th>
<th>No. of deaths</th>
<th>No. of cases</th>
<th>No. of deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5000 000</td>
<td>800</td>
<td>700</td>
<td>7000</td>
<td>500</td>
<td>10 000</td>
</tr>
<tr>
<td></td>
<td>500 000</td>
<td>80</td>
<td>80</td>
<td>700</td>
<td>58</td>
<td>1 000</td>
</tr>
</tbody>
</table>
It can be seen from Table 37 that, although vaccine is not very effective, a mass immunization campaign in developing countries with a scarcity of supplies, if applied at the right time, would reduce the fatality rate by more than 50%. If full treatment facilities were available to every patient, however the effect of the mass immunization of even 75% of the population would be a negligible decrease of the fatality rate, possibly by between 10 and 15%. Thus, in countries with little equipment and the highest incidence of cholera, the relative benefit from the immunization campaign will be greater.

Cost-benefit aspects of immunization campaigns

The per caput cost of immunization against cholera is approximately US$ 0.10-0.20, whereas the treatment of one case of cholera costs approximately US$ 40-70 in non-endemic areas and US$ 20-40 in endemic areas; the average cost is possibly US$ 25. This means that the prevention of one cholera case represents a saving in money that could be used for the immunization of 200 to 700 people, depending on the cost immunization in the country concerned.

The cost-benefit analysis of an immunization programme, for 50% coverage of the population, a cost of US$ 0.1 per caput, and different levels of incidence, is given in Table 38. This shows that, when the incidence is eight per 1000, there is neither a loss nor a gain as a result of the programme, as compared with the cost of treatment of a non-immunized population.

Where the incidence is low and the cost of treatment high, quick detection, prompt transport and good treatment would appear to be more profitable, financially speaking.

It is unnecessary to consider the value of the human lives saved; this does not need any economic justification. In addition, benefits are derived from saved wages and higher production; these can be calculated separately in each case.

It should be pointed out that, in view of the effectiveness of treatment and the relative ineffectiveness of the vaccine, there is little reason for all the emphasis to be placed on immunization and for treatment, which is a valuable life-saving tool, to be disregarded.

The timing of mass inoculation campaigns

Epidemics of cholera follow certain patterns that can be expressed in mathematical terms. An epidemiological model of such epidemics has been worked out, making it possible to simulate the effect of immunization carried out at various times and with varying coverage.
Table 38. Cost-benefit analysis of an immunization programme at different levels of incidence

<table>
<thead>
<tr>
<th>Incidence per 1000</th>
<th>Immunized population</th>
<th>Non-immunized population</th>
<th>Difference between total cost (immunized population) and cost of treatment (non-immunized population)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost of immunization</td>
<td>Cost of treatment</td>
<td>Total cost</td>
</tr>
<tr>
<td>1</td>
<td>9 375</td>
<td>34 375</td>
<td>12 500</td>
</tr>
<tr>
<td>2</td>
<td>18 750</td>
<td>43 750</td>
<td>25 000</td>
</tr>
<tr>
<td>3</td>
<td>28 125</td>
<td>53 125</td>
<td>37 500</td>
</tr>
<tr>
<td>4</td>
<td>37 500</td>
<td>62 500</td>
<td>50 000</td>
</tr>
<tr>
<td>5</td>
<td>46 875</td>
<td>71 875</td>
<td>62 500</td>
</tr>
<tr>
<td>6</td>
<td>56 250</td>
<td>81 250</td>
<td>75 000</td>
</tr>
<tr>
<td>7</td>
<td>65 625</td>
<td>90 625</td>
<td>87 500</td>
</tr>
<tr>
<td>8</td>
<td>75 000</td>
<td>100 000</td>
<td>100 000</td>
</tr>
<tr>
<td>9</td>
<td>84 375</td>
<td>109 375</td>
<td>112 500</td>
</tr>
<tr>
<td>10</td>
<td>93 750</td>
<td>118 750</td>
<td>125 000</td>
</tr>
<tr>
<td>11</td>
<td>103 125</td>
<td>128 125</td>
<td>137 500</td>
</tr>
<tr>
<td>12</td>
<td>112 500</td>
<td>137 500</td>
<td>150 000</td>
</tr>
<tr>
<td>13</td>
<td>121 875</td>
<td>146 875</td>
<td>162 500</td>
</tr>
<tr>
<td>14</td>
<td>131 250</td>
<td>156 250</td>
<td>175 000</td>
</tr>
<tr>
<td>15</td>
<td>140 625</td>
<td>165 625</td>
<td>187 500</td>
</tr>
</tbody>
</table>

1 Population: 500 000; immunization coverage: 50%; effectiveness of vaccine: 50%; cost of treatment: $2.25 per case; immunization cost: $0.1 per person.

It has been shown that early application of mass immunization curbs the outbreak effectively, while later immunization has little if any effect.

The benefit from immunization can be greatly enhanced if it is carried out at the proper time.

CONCLUSIONS

In making policy decisions concerning the control of cholera, public health administrators could effectively use available data (even when these are not complete). The available resources can be put to better use if plans are made on the basis of a cost-effectiveness and cost-benefit analysis of immunization and of all other control and treatment activities.
CHAPTER 6

HEALTH MANPOWER REQUIREMENTS

Staffing a health service is clearly not only a question of numbers. Quality is vital as well as quantity. The right appointments and postings have to be made. The education and training of health personnel, prior experience, professional opportunities, career structures, selection procedure, etc., are no less important in the solution of the total problem than personnel sufficient in numbers to man the service. We shall concern ourselves here only with the numerical aspect of the problem of forecasting manpower requirements. We would stress, however, that although the exercise involves nothing more than straightforward though somewhat tedious arithmetic, real problems always involve a great many contingent unquantifiable factors that also have to be taken into account.

Three broad approaches to estimating future manpower requirements have been described:

1. methods based on criteria for personnel/population ratios;
2. economic methods, such as health-expenditure trends and population-income levels and trends;
3. methods based on defined “need”, as ascertained professionally from health statistics and surveys.

We shall restrict ourselves here to the last-mentioned approach, considering in the main, for purposes of illustration, the number of doctors required for personal health care services.

In the broadest terms, the interdependent factors on which health-manpower-planning depends are as follows:

1. present levels of “need” and health manpower;
2. present and future population size and structure;
3. present and future morbidity;

---

(4) present and future organizational structure and functioning of the health services.

All of these contain an element of uncertainty.

ESTIMATION OF PRESENT MANPOWER REQUIREMENTS (BASELINE)

The volume of morbidity is ascertained for individual diseases by age, sex, and social and occupational groups, covering a full calendar year (in order to allow for the influence of seasonal fluctuations), from:

(a) data on attendances for qualified medical care on the patient's initiative in the course of a year; and

(b) data from the multiphasic screening of the population to detect early and preclinical forms of chronic disease requiring medical care. (In the USSR, surveys were carried out in five towns with a total population of 1,500,000).

In the course of studying the general morbidity (from both acute and chronic diseases), data are collected on the frequency and make-up of hospital admissions (by specialties), and of out-patient attendances (by disease groups and the more commonly encountered diagnostic entities).

These data make it possible to establish the amount of out-patient and in-patient curative care required by various population groups. At the same time, the amount of preventive work by doctors and other health staff is also ascertained, based on the frequency of various medical examinations of healthy persons, and the degree to which doctors from the various specialties participate in such examinations.

The ambiguities of need and demand, discussed earlier (see page 29), are evaded rather than resolved by introducing the neutral term "requirements", but on the assumption that the volume of disease requiring treatment and the related consumption of health manpower can be ascertained from existing statistics and professionally conducted surveys, present health manpower requirements can be readily computed.

As an illustration, consider the number of doctors \(X_k\) required for the medical care of patients suffering from a particular disease or disability \(D_i\). In addition, let:

\[
N_i = \text{the number of cases of } D_i \text{ in the male quinquennial age-group } A_i;
\]

\[
T_k = \text{the average number of doctor-hours consumed per year in the medical care of a case;}
\]

\[
H = \text{the average number of hours per annum worked by a clinical practitioner.}
\]
The value of $X_i$ for the medical care of disease $D_i$ in the existing male population with existing doctor utilization is then:

$$X_i = \sum A_j \left( \frac{N_i T_k}{H} \right)$$

and the total number of doctors required for male medical care becomes $\sum X_i$.

The number of doctors required for female care is computed similarly.

To obtain an estimate of the total number of doctors needed at present for all purposes, the medical personnel requirements for personal health care other than the care of the sick (e.g., prophylaxis, mother and child care) and for administration, environmental services, laboratory services, occupational health, teaching, research, the armed forces, etc., must be included. The estimated requirements (in practice broken down by specialty) and the present morbidity status of the population, related to its size and demographic characteristics, thus provide a baseline for projections and future planning.

**ESTIMATION OF FUTURE REQUIREMENTS**

Assuming that the number of doctor-hours devoted per annum to medical care and the doctor-time consumed for each disease category remain unchanged, future requirements are forecast by introducing adjustments for expected changes in the age and sex structure and size of the population and in disease incidence (or prevalence). Thus, for the age-group $A_j$, the number of doctors required at year $Y_e$ becomes:

$$X_i \times \left( \frac{P_j(Y_e)}{P_j(Y_o)} \right) \times \left( \frac{N_i(Y_e)}{N_i(Y_o)} \right)$$

where the second term is the ratio of the projected population aged $A_j$ at year $Y_e$ to the baseline population at year $Y_o$, and the third term is the ratio of the expected number of cases at $Y_e$ to the baseline number at $Y_o$. Global requirements can be computed by summing overall age and sex groups and disease categories, and the global "norm" thus obtained can be adjusted so as to allow for local variations in age and sex structure, occupational factors, and morbidity patterns, for regional or other geographical sub-populations.

**RECRUITMENT (EDUCATIONAL) REQUIREMENTS**

The estimation of the number of entrants (or medical school places) to be provided year by year involves, in addition to the factors
considered above, what has been referred to as the demography of the profession, and also certain educational factors. Account must therefore be taken of:

(a) the age and sex structure of the profession, age at entry and retirement or withdrawal, wastage rates from retirement, death, emigration, etc., geographical distribution, plurality of appointments, part-time service, and continuing employment after pensionable or normal retirement age has been reached; and

(b) the age and educational level of entrants, student wastage and the time required for general and specialized medical education.

All these factors are likely to vary in unforeseeable ways for remote target dates, and in many countries complete and accurate information about many items is lacking. It follows that forecasts and plans must be both flexible and subject to continuing revision.

AREAS OF NUMERICAL UNCERTAINTY AND CONJECTURE

The adjustments to computed estimates of future manpower requirements made necessary by non-quantifiable factors are outside the scope of this publication. It will suffice to stress the necessity of a systems approach, in addition to projection methods, in any realistic forecasting and planning, and to list some of the areas of uncertainty involved. These include:

A. Demographic, morbidity and demand trends

(1) The well-known uncertainty of long-range demographic projections.

(2) The implied assumption that the baseline need/demand, other things being equal, remains constant.

There is, in reality, a cohort effect, or a change in population preference, e.g., the present generation of old people accept illness and disability, without demanding medical care, to a greater extent than is likely in future generations.

(3) Statistically projected disease trends may be invalidated by advances in biomedical science and changing socio-economic circumstances, e.g., in the opinion of many experts it is not unreasonable to expect that, in 20 years' time:

(a) the common communicable diseases of childhood will have virtually disappeared;

(b) tuberculosis will no longer be a major public health problem;

(c) except in Africa, malaria will have been brought under control to such an extent that it will have become the responsibility of the general public health services;
(d) severe protein-calorie deficiency will be rare;
(e) cancer may well be largely controllable by chemical or immunological methods;
(f) hypertensive disease will constitute a smaller and less severe problem;
(g) kidney disease is likely to be much rarer;
(h) improved control of the main psychotic disorders is likely.

B. Services, organization and utilization

(1) Care in the community will probably continue to increase and hospitalization to diminish correspondingly.
(2) Hospital utilization will continue to improve, and further reductions in the average duration of in-patient stay are likely.
(3) Although a reduction in the length of the doctor’s working week is likely, the labour/output ratio will increase because of:
   (a) the further development of health centres, group practice and medical teamwork;
   (b) an increased use of auxiliary personnel;
   (c) the transfer of some work now performed by doctors to nurses, dieticians, etc.;
(4) Doctors are tending to continue working, at least to some extent, after the formal age of retirement.
(5) Increased specialization and a further splitting up into subspecialties is virtually certain.
(6) Technical advances, especially the widespread use of EDP, will influence the organizational structure of services increasingly.

FORECASTING HEALTH MANPOWER REQUIREMENTS IN THE USSR

The method previously described has been used to work out standard levels of curative and prophylactic care, and on this basis to estimate the number of medical staff that will be needed in the USSR in the next few years.

Investigations in the USSR have shown that demographic factors have a great influence on the level and structure of general morbidity, and on indices of hospital admissions and out-patient care.

Substantial differences exist in the indices of the prevalence of particular diseases, as between the sexes and people of various ages,

---

1 Bogatyrev, I. D., ed. (1967) Zaboloursnosti gorodskogo naselenija i normativy lechebo-profilakticeskoi pomoshki (Morbidity of urban populations and standards of curative and prophylactic care), Moscow, Meditsina.
e.g., acute diseases (influenza, sore throat, catarrh of the upper respiratory tract, etc.) are more frequently encountered in children and adolescents, while chronic diseases (diseases of the cardiovascular system and malignant neoplasms) are more common among the elderly; diseases of the kidneys and urinary tract, thyroid diseases and appendicitis are more frequent among women than among men, but men suffer more frequently from gastric and duodenal ulcers, gastritis and hernia, and are more often injured in accidents.

These features of morbidity, and of hospital admissions and attendances at out-patient and polyclinic establishments, for the different age- and sex-groups of the population, have a great influence on the level of medical staffing requirements, and particularly on structure by specialty. For this reason, demographic features must be studied in detail and assume particular importance in long-term forecasts of medical staff requirements. General trends, such as a continuous increase in the proportion of old people in the population and a reduction in the birth-rate, must be taken into account when studying the problem of medical staffing.

The forecasting of general morbidity is a complex problem. Two main factors are acting in opposite directions. The improvement in the general cultural level of the population and living conditions is bringing about a reduction in the morbidity due to certain diseases, while the increase in the proportion of old people — potential sufferers from chronic diseases — is contributing to an increase in morbidity indices. The frequency of chronic diseases, for which effective treatment and prevention are not yet available, can be forecast accurately.

To forecast the future frequency of communicable diseases and diseases dependent on environmental conditions, it is obviously necessary to take into account the feasibility of controlling these diseases and the tendencies towards a decline in the rate of decrease in the morbidity from these causes.

Research work on this problem in the USSR includes a wide range of investigations, drawing on various medical specialists, statisticians and economists. The huge volume of work involved, both at the data-collection stage and at the stage of statistical processing, requires the use of modern computers and other auxiliary technical devices. Sampling methods are widely used, and require the establishment of special centres in various economic, geographical and climatic zones of the country.

Before work in such centres begins, a number of organizational measures are needed to ensure completeness of ascertainment, high standards of medical care, and the provision of modern technical equipment.
Methods of dealing with many of the problems involved have already been developed and tested in the USSR, but the solution of the problem as a whole will still require considerable expenditure and time.
A given demand for services does not imply a direct demand for specific numbers of certain categories of manpower. Service requirements can be expressed in terms of manpower needs only after agreement has been reached as to the role of each member of the health team in the provision of various forms of care. Since such agreement is frequently lacking at present, studies aimed at determining the current job content of various categories of health workers are of great interest.

Such studies seem most often to have been concerned with nursing activities in the hospital setting. Two approaches have been used. In the first, the workers have been asked to keep a record of their activities so that summaries could be made of the time distribution among various categories of effort. The second type of study has been observational. Either a non-participant observer has followed the worker and compiled a continuous account of the activities performed, or he has sampled and classified the activities at randomly selected points in time.

Our principal concern here is to examine techniques for analysing activity time distributions, although the technique employed is obviously related to the source of the data. In our discussion we shall rely heavily upon the reports of two studies: the work of Feyerherrm\(^1\) in Kansas, and that of Wolfe & Young\(^2\) in Maryland. In the former study, the patient census and nursing complement were considered as given, so that the aim was to predict variations in nursing activity patterns under different conditions of staff need and availability. The study by Wolfe & Young, in contrast, was designed to utilize the information on patient requirements in order to vary staff levels optimally.

CHANGE IN ACTIVITY PATTERNS WITH CHANGE IN PATIENT MIX

Feyerherrm divided nursing activities into five categories:

1. physical — all activities inside a patient’s room, plus preparations for treatments and procedure;


— 161 —
(2) delivery — all activities in a labour or delivery room;
(3) clerical — charting, writing and reading notes, preparing requisitions, and other paper work;
(4) oral communications — telephone and face-to-face conversations, including shift change;
(5) standby — lunch breaks, errands, and inactivity.

Since nurses are on duty for eight hours or 480 minutes per day, the total time, $T_t$, must amount to $480N$, where $N$ is the number of staff nurses on duty. If the time spent in the $i$th category of activity is $T_i$, we have the following relationship:

$$T_t = 480N = T_1 + T_2 + T_3 + T_4 + T_5$$

where the subscripts refer to the five categories of nursing activities just listed. A corresponding relationship exists for the time of nursing aides.

With respect to patients, three levels of direct care were recognized, based on the assistance required in ambulation, feeding, and bathing, namely:

- $M$ — minimal care
- $I$ — intermediate care
- $H$ — high care.

Thus, the total number of patients, $P_t$, is:

$$P_t = P_M + P_I + P_H$$

Work sampling techniques of data collection were employed. Ten sets of observations were made on each of the seven days of the week. The 70 days sampled were scattered over a nine-month period, and 32 observations per nurse were collected on each day included. The distribution of activities sampled on a given day provided values of $T_i$. The 70 sets of $T_i$ values were treated as observations of dependent variables in multiple regression equations in which the numbers of nurses and patients served as the independent variables. The approach was employed independently in several units of the hospital investigated. The equations that resulted from the study of the medical unit are reproduced below; there is no equation for $T_2$, since delivery activity was not performed in this unit:

$Physical activities$

$$T_1 = -102 + 158N + 2P_I + 13P_H$$
Clerical activities
\[ T_3 = 6 + 72N + 5P_t + 1P_H \]

Oral communications activities
\[ T_4 = 109 + 154N - 5P_t - 8P_H \]

Standby activities
\[ T_5 = -13 + 96N - 2P_t - 6P_H \]

If, for example, two staff nurses are on duty in a medical unit in which 20 patients, including four in a high-care status, are receiving treatment, we can predict the following pattern from these equations:

\[ T_1 = 306 \text{ min} = 15 \text{ min per patient} = 153 \text{ min per nurse} \]
\[ T_3 = 254 \text{ min} = 13 \text{ min per patient} = 127 \text{ min per nurse} \]
\[ T_4 = 285 \text{ min} = 14 \text{ min per patient} = 142 \text{ min per nurse} \]
\[ T_5 = 115 \text{ min} = 6 \text{ min per patient} = 58 \text{ min per nurse.} \]

The equations indicate further that an increase in the number of patients without a corresponding increase in the nursing complement is likely to lead to increased physical and clerical activity, but to reduced communications and standby time. If the minimal amount of time necessary for oral communications and the maximal amount of permissible standby time can be defined, these equations can be used to determine acceptable levels of staffing for specified numbers and types of patients.

PATIENT MIX AS DETERMINANT OF STAFFING REQUIREMENTS

Wolfe & Young exercised great care in spelling out the criteria whereby patients were to be classified as requiring minimal, intermediate, or high care. (McEwin in Australia has gone even further by identifying seven direct-care categories).

On the basis of work sampling, Wolfe & Young found that the average minimal-care patient requires 30 min of direct care per day, compared with 60 min for intermediate care patients and 140 min for those in the high-care category. The total amount of direct care \( T_d \) to be provided in a given hospital ward can therefore be estimated as follows:

\[ T_d = 30P_m + 60P_i + 140P_H \]

Analysis of other nursing activities, such as paper-work, communications, errands, etc., revealed that patterns varied little with the number of patients to be looked after. It was found possible simply to add a lump sum of 20 hours, or 1200 min, to the daily staffing needs of each
ward to account for all non-direct care needs. Thus the total time ($T_t$) was estimated from the equation:

$$T_t = 1200 + T_d$$
$$= 1200 + 30P_M + 60P_I + 140P_H.$$  

In a ward providing care for 11 minimal, 5 intermediate, and 4 high-care patients, for example, a total of 2390 min of nursing time would be required, of which direct care accounts for 1190 min. If each nurse is to contribute 480 min, approximately five nurses should be assigned to the ward. Questions as to the distribution of the total time among shifts and among categories of personnel, such as registered nurses and aides, are not covered by these calculations.

The work sampling revealed a certain variation in the direct-care needs of individual patients, even within a specified care category. The standard deviation for minimal-care patients was about 10 min, that for intermediate-care patients about 15 min, and that for high-care patients about 25 min. If it is assumed that the time requirements are approximately normally distributed and statistically independent, we can estimate the maximal as well as the expected amount of direct care required for a given patient mix.

As a basis for this calculation, we must estimate the total variance ($V_t$) of need as the sum of the variances applicable to individual patients. This is given by:

$$V_t = P_MV_M + P_IV_I + P_HV_H$$

The variances $V_M$, $V_I$, and $V_H$, applicable to the three care categories, are simply the squares of the standard deviations noted above. In the example quoted, therefore, we have:

$$V_t = 11 \times 10^2 + 5 \times 15^2 + 4 \times 25^2$$
$$= 4725$$

The standard deviation of the total direct care required is therefore 69. If we consider as "maximal" the level of direct-care need that has only one chance in ten of being exceeded, we must add 1.28 standard deviations (according to normal probability tables) to the expected need for such care of 1190 min. Therefore:

$$T_d = 1190 + 1.28 \times 69$$
$$= 1190 + 88$$
$$= 1278\text{ min}$$

A conservative approach to staffing would thus provide a personnel reserve of 88 min of direct care, in addition to the expected need.
CHAPTER 8

TRAINING FOR HEALTH ADMINISTRATION AND HEALTH PRACTICE RESEARCH

Key posts in health administration cannot be adequately filled by persons without special training, however gifted they may be. The efficient operation of health services now demands not only an extensive knowledge of medicine and the biomedical sciences, but also a range of managerial and research skills that in-service experience cannot wholly provide. For this reason, formal training of some sort in management science, including the use of mathematical techniques, is now recognized as a necessary part of the education of senior health personnel in all countries. Moreover, as the planning and management of health care services relies greatly on systematic epidemiological and operational enquiries, research methodology and procedures must also be covered by training programmes.

Our primary concern in this publication is with the training of specialists in health administration and health practice research, but modern requirements also demand a radical revision of a wide range of training programmes for many other categories of personnel. Managerial and research competence are needed not only at higher administrative but also at operational levels. In the organized health care services of today, general practitioners and clinical-pathological specialists have managerial functions as directors of teams that include, in addition to medical colleagues and workers in allied professions, specialists recruited from disciplines other than medicine. Health centres, laboratories, and the whole range of diagnostic and therapeutic units in hospitals and elsewhere have to be managed at both executive and administrative levels, and both their management and related organizational research usually involves a partnership between operational personnel and specialist research workers. This situation has obvious implications both for medical education as a whole and for education and training in allied fields.

The relationship between training and health practice research has three main aspects:
(1) the preparation of health administrators ("community physicians") skilled in scientific management and planning procedures;
(2) the preparation of personnel for the pursuit and support of research, involving:
   (a) the training of specialist research workers
   (b) the teaching of research methods as an integral part of public health training;
   (c) ensuring that all health workers appreciate the importance of research;
   (d) the incorporation of research into service activities;
(3) the preparation of teachers to give effect to training programmes.

To satisfy the above requirements it is clear that many existing curricula will have to be revised and the range of many existing training provisions extended. Matters for special consideration include:

(1) the revision of general postgraduate public health training;
(2) the revision of existing advanced courses, and in many schools the provision of additional courses in areas such as national health planning, hospital administration, research methodology, electronic data processing, advanced administration and management;
(3) provision for continuing education in public health and allied subjects;
(4) ad hoc short courses for senior health administrators;
(5) formal in-service training;
(6) fellowship and exchange arrangements for special studies abroad;
(7) appropriate training for social scientists and other non-medical specialists for participation in multidisciplinary research in the health field;
(8) provision for the training of senior academic personnel;
(9) some revision of undergraduate medical education.

Many kinds of training institutions are involved — schools of public health, research institutions, university departments, schools and other institutions responsible for the training of personnel in allied professions and a range of non-medical scientists, health services staff colleges and undergraduate medical schools.

THE BASIC POSTGRADUATE PUBLIC HEALTH CURRICULUM

During the 50 years in which schools of public health have prepared students for specialized careers in health services, their programmes have needed frequent revision to keep them in line with prevailing concepts of public health and the progressive broadening of the health officer's function.
By 1965, traditional programmes, based almost exclusively on environmental hygiene, the control of communicable diseases, vital statistics and public health law, had been superseded everywhere by programmes in which social welfare, the control of non-communicable diseases and health services administration were also represented. In many schools, a comprehensive socio-medical programme had been established. It was already apparent, however, that the evolution of organized health care services and developments in planning and managerial practices demanded yet another radical review of public health training and, by 1970, a range of advanced courses, including in particular hospital administration, were offered by most schools of public health to doctors who had already obtained a basic public health qualification. In some places, health officers were being encouraged to attend courses in business administration offered by universities and other institutions. By this time, basic postgraduate programmes in public health were, as a rule, based on the behavioural as well as the biomedical sciences, and were tending to become more obviously interdisciplinary in character. Notwithstanding these developments, however, by 1971, only about one public health school in three had introduced managerial science and research methodology into their programmes at the relatively high level required for senior health administration.¹

To elaborate a little, most postgraduate public health courses now include all or most of the following topics as “core” subjects:

(a) the behavioural sciences (sociology, political science, anthropology, psychology);
(b) economics;
(c) demography;
(d) statistical methods and theory;
(e) principles of epidemiology;
(f) health statistics (including vital statistics) — disease patterns;
(g) the organizational structure of the health services and other social services;
(h) public health law and legislative procedures.

The basic courses in sociology and economics deal with those aspects of these subjects that are related to health and health services, and include such topics as:

Sociology (and political science)

Kinds of leadership. Forms of government.
Characteristics of urban, rural and industrial communities.

Social and cultural consequences of progress and rapid change.
Urbanization and industrialization.
Socio-economic casualties.
The sociology of handicapped and aging population groups.
Social aspects of family planning.

Economics

Principles and terminology. Economic systems.
Macro-economic variables. Private and public sectors of the economy.
Determinants of economic growth.
Principles of accountancy and budgeting.
Capital function. Financial management.
The health-economics relationship. Cost benefit.
Health insurance and other methods of payment for health care.

In the 40 or so schools in which modern managerial training has been introduced, the following subjects are also presented, with varying depth and completeness as part of the “core” or obligatory curriculum.

(1) service administration, management and evaluation;
   (a) general principles;
   (b) quantitative methods and approaches — models, operations research, systems analysis, the multidisciplinary approach, decision-making, policy formulation and priorities;
(2) the scientific method; health survey and other health research methods;
(3) health planning — forecasting methods; patterns of disease and health services; health manpower planning; norms and normatives; the demand/need problem; hospital systems planning; comprehensive (socio-economic) planning; the health planning process; regional, sectoral and project planning; the vertical and the horizontal approaches (mass campaigns); health planning and educational planning relationships;
(4) computer technology, EDP applications and simulation techniques;
(5) information and communications theory.

In a number of schools, some of these subjects are also offered as electives in the basic course and are also often offered at advanced levels.
CONTINUING EDUCATION; HEALTH SERVICES STAFF COLLEGES

The continuing education needed by health workers for both administrative and research purposes can conveniently be shared between training in academic institutions and formal and informal in-service training. Whilst it can be assumed that newly appointed personnel are already acquainted with administrative principles and the general organization of health and allied services, their academic training does not and cannot familiarize them with the special features of the service they have joined. After appointment, they have to acquire knowledge of the details of the organizational structure, budgetary methods, staff gradings, appointment- and decision-making procedures, etc., of the service they have joined. Hitherto, it has commonly been assumed that competence in these matters could be picked up in the course of work, without special in-service training provisions, but it is now widely recognized that this informal and uncontrolled method is no longer adequate. Health services staff colleges have been established in some countries — and are contemplated in many more — to supplement the academic basis of professional training. The staff college, or its equivalent, also provides a means of offering reorientation and refresher courses at intervals for established staff at all levels. Such courses are needed increasingly because the structure and functions of services have to be substantially changed from time to time to meet changing demands and attitudes. Schools of public health and other training institutions can contribute, especially by providing advanced specialist courses and reorientation training in research methodology. They can also offer short courses designed to acquaint senior administrators with research methods and activities. Research undertaken within health services, often in collaboration with schools of public health and other institutions, also provides an opportunity for practical work as a part of the continuing education of staff at all levels, as well as having an operational function.

HEALTH PRACTICE RESEARCH TRAINING FOR CLINICAL TEACHERS AND PRACTITIONERS

A common impediment to providing field assignments for medical students is the small importance attached to this form of training by faculty clinicians, with the result that students are either denied the opportunity of participating in field work or regard it as foreign to their primary professional studies. In addition, research work in the field invariably needs the collaboration of clinical practitioners and other health personnel on the ground. It is therefore essential to in-
introduce survey and organizational research methods into the post-
graduate training of clinical and allied specialists, and to encourage
multidisciplinary research projects, in which clinicians participate, in
field training areas.

TRAINING OF NON-MEDICAL RESEARCH WORKERS

Since health practice research is essentially multidisciplinary in
character, social scientists and others who intend to become members
of health practice research teams must be introduced to social medicine
in their training. Furthermore, attractive career opportunities should
be offered by health authorities and universities in order to induce
social scientists and other non-medical researchers to take up appoint-
ments in health services and training institutions, and to encourage
them to participate in health practice research.

UNDERGRADUATE TRAINING

Although considerable progress has been made in recent years, the
most serious deficiencies in undergraduate medical education are still
probably in the area of public health subjects and research methods.
Most medical students become reasonably competent in clinical dia-
gnosis and case management, but are not always well prepared for
medical practice in the world of today because their training pays in-
sufficient attention to prevention, the behavioural sciences, statistics,
the scientific method, and the organizational aspects of health care
services.

The heavy load imposed by existing undergraduate curricula is a
strong argument against introducing new subjects unless they are clearly
necessary as part of a liberal medical education or as an indispensable
foundation for later studies. Management science does not fall into
either of these categories, and it is probably sufficient for the under-
graduate, at some stage, to be made aware of the logistics and manage-
rial aspects of health care practice, and of the broad character of
managerial and planning procedures, the technical aspects and the
acquisition of skills in their use being deferred until later. The same
cannot, however, be said of studies that help the student to become
research minded, or of those that enable him to see medicine in the
perspective of community problems and needs. Such studies are an
essential part of the scientific-humanistic education to which he is
committed. The medical student should therefore be exposed more
than has hitherto been usual, to the fundamental concepts of social
science, and to research methods and their applications in the bio-
medical and behavioural sciences and health care practice. He needs also, as part of an integrated programme, to be exposed to a range of extramural disciplines in relation especially to the community aspects of health care. The same, it should be added, applies to students of the allied medical professions. A formal exposition of the scientific method in the pre-medical or pre-clinical years is probably indispensable for most students, and ways must be found to incorporate rigorous scientific thinking into all appropriate aspects of medical education. In some schools, students are introduced to research principles and skills by senior faculty members, and are systematically exposed to current research in health care, epidemiology and social medicine in the course of regular field assignments. Such an approach, however, is by no means universal.

RESEARCH TRAINING METHODS

"One of the important tasks of the school of public health is the teaching of scientific methods". Furthermore, "it is advisable to develop, in every student, an interest in research and skill in the investigation of public health problems."\(^1\)

These objectives are achieved by a combination of lectures, discussions, seminars, situation studies and other familiar teaching methods and the engagement of students in active research projects. There are, then, two main components of training for research, namely formal courses in basic disciplines and research experience under supervision. It is, indeed, often said that the only way to learn about research is to do it.

The current research work of teachers, which is in any event indispensable for maintaining a high academic standard of teaching, is a useful source of teaching examples. Pilot and demonstration areas, which are used for many of the field research projects conducted by schools of public health, can also serve as training areas in health practice research both for students and health administrators. Much of the research work that forms an integral part of public health training requires collaboration between the school and other institutions, as well as support from specialists, such as social scientists, mathematicians, planners and communications experts, who are not, in most schools, full-time staff members. Data processing facilities, including EDP, either within the school or accessible to it, are now regarded as virtually indispensable for teaching purposes, as they are for the actual conduct of a wide range of research projects.

LEVELS OF PRESENTATION

The depth at which a subject is presented will vary with the professional group involved and its professional maturity. The level of treatment required for a particular professional group also varies from subject to subject; from this point of view, subjects fall into three categories:

1. subjects in which the student needs to acquire a specialist knowledge, and skill in the use of the corresponding methods;
2. subjects of which he requires sufficient understanding to interpret the work of specialists; it is not expected, however, that he will be skilled in the methods they employ;
3. subjects in which he requires only a background knowledge, together with sufficient information as to the nature of the methods and techniques that might be used in the solution of his own particular problems.

In the broadest terms, if health personnel are to have adequate management and research competence for present-day needs, training programmes for health administrators, practising doctors, social scientists and others should satisfy certain minimal conditions. They should therefore ensure that such personnel have:

(a) a thorough knowledge of the scientific method;
(b) a sufficient competence in mathematics (including statistical methods);
(c) a sufficient awareness of the competence available in cognate disciplines, and an attitude of mind that encourages competent and willing interdisciplinary collaboration.

They should also make the student explicitly aware of contemporary lines of scientific progress and social evolution, and direct his attention to the kind of society and services that might be expected in the foreseeable future.

Programmes that satisfy these conditions will be based more on scientific and sociological principles than has been usual in the past, and demand a greater competence in mathematics than has hitherto been common.

MATHEMATICS IN TRAINING PROGRAMMES

The minimal mathematics now needed for medical studies is more than nine out of ten entrants to the profession, as a rule, possess. The student whose mathematics does not go beyond elementary algebra and plane geometry is not only ill-equipped to understand the statistical and
other quantitative methods that are an essential part of social medicine
courses, but is also severely handicapped in many areas of clinical and
pre-clinical studies, e.g., physics, biochemistry, psychology, pharma-
cology, and the quantified and instrumented aspects of diagnosis and
treatment. He also lacks an essential tool for understanding and using
the scientific method throughout the entire domain of medicine. The
mathematics now required includes the elements of probability theory,
summation methods, linear, quadratic and exponential functions, the
differential calculus and (perhaps) matrix algebra. This is not to say
that the medical student or doctor should be a mathematician, but
only that he should be sufficiently familiar with mathematical notation
and methods to be able to think numeratively, to express relationships
in mathematical terms, and to construct simple mathematical models.
Modern methods of teaching mathematics in high schools and colleges
should enable most pupils to reach the required standard without adding
greatly to their burdens, and it is not unreasonable to expect that future
entrants to medicine will have sufficient mathematical ability for their
needs. Short revision courses in elementary mathematics, which are
offered in some schools of public health, and the re-introduction to
related mathematics that accompanies biostatistical courses in some
undergraduate schools are not, as everyone who has tried them is aware,
wholly effective ways of remediying earlier educational deficiencies.
Until such time as adequate mathematical competence can be assumed,
they are, however, the best that can be done. Such courses are likely to
be needed for some time to come in most places in conjunction with
postgraduate and advanced training in health practice research, manage-
ment science, statistics, and epidemiology.

IMPEDEMENTS TO THE DEVELOPMENT OF TRAINING IN RESEARCH
AND MANAGEMENT SCIENCES

The rapid expansion of training needed to satisfy present-day re-
quirements is not at present feasible in many countries because of the
absence or inadequacies of institutions offering the necessary post-
graduate and advanced specialist training.

There is an almost universal shortage of teachers who are able to
present research methodology at advanced levels or to deal adequately
with the interdisciplinary aspects of health practice and research. There
are as yet no textbooks on these subjects, few standard models that
teachers can use, and the adaptation of industrial and other applications
of the newer analytical and managerial techniques for use in the health
field is at an early stage. The task of remediying these deficiencies is
beyond the competence of all but a few persons anywhere in the world.
One reason for the relatively slow adoption of scientific management methods in health services is that, with few exceptions, senior administrators rarely have a research background that satisfies present requirements; progress will inevitably be especially protracted in countries where there is little awareness at governmental level of the need for, and the potentialities of, systematic research in the health practice field. In otherwise favourable circumstances, moreover, teaching institutions often do not have adequate field facilities under their own control, and the necessary close relationship between training and research programmes and the development of health services has not been achieved. Collaboration between academic and executive health departments is often poor, and the same applies to that between schools of public health and other research institutions, university departments, laboratories and departments in control of statistical services and EDP, who must frequently work together in the planning and execution of large-scale projects.

Many obstacles must clearly be surmounted before health practice research can become a generally accepted part of both academic curricula and health administration, but this is not an argument for delaying the appropriate revision and expansion of training programmes. Managerial practices based on analytical techniques, such as EDP, are here to stay and will become routine in the health services of most countries well within the professional lifetime of the present generation of postgraduate students.

EXAMPLES OF RECENT CURRICULUM DEVELOPMENTS

We give here brief accounts of recently revised programmes of basic postgraduate public health training in two schools in the United Kingdom, a reference to the training of public health administrators and health practice research workers in the USSR, and a short note on existing programmes in the Johns Hopkins School of Public Health, Baltimore. We do not thereby intend to imply that these are either the only, or the best illustrations of recent developments. They happen to be personally known to us, and are probably reasonably representative of current trends.

London School of Hygiene and Tropical Medicine

In 1969, an entirely new academic course was introduced to provide training for doctors intending to follow careers in either health administration and community health care or in teaching and research in
social medicine. The course extends over two academic years and leads to the degree of Master of Science in the Faculty of Medicine of the University of London. Candidates are required to attend a full-time course of studies in the School for one year, followed by a year of attachment to an academic or service unit approved by the University. The course includes the study of statistics and epidemiology, social and behavioural sciences, and the principles of management and medical administration. It aims to integrate the biological, social, and practical aspects of major problems in hygiene, preventive medicine and medical care. During the second year, the student gains experience in applying the relevant range of skills derived from epidemiology, operations research and behavioural science to policy, planning, management and the evaluation of health services. The former annual courses leading to a DPH are no longer offered. The School also offers a wide variety of advanced courses, including a 12-week course in medical services administration, mainly for medical graduates who are senior health administrators.

The Usher Institute for Public Health, Edinburgh

This Institute now offers a one-year course leading to a diploma in social medicine; this replaces earlier diploma courses in public health and medical services administration. The new programme is designed as an introduction to the whole field of social and community medicine, and is intended for doctors embarking on a career in medical administration. It is recognized that many of the young doctors pursuing such courses will require further training — perhaps in a health services staff college — as they are promoted to posts of greater responsibility. The basic course, which aims to provide only the foundation needed by a medical administrator, consists of the following two parts.

Part I is devoted to the community, the distribution of disease within it, and the agencies responsible for controlling disease. It includes: sociology; host-agent and environment interactions; health care provisions; health services organization; demography, statistical theory, health statistics and the principles of epidemiology. This provides a foundation for Part II.

Part II deals with the techniques used in solving health problems, and the applications of these techniques, and includes:

(a) the control of communicable and non-communicable diseases;
(b) organizational theory, economics and finance;
(c) systems design, operations research, research and evaluation methods, decision tree theory, simulation methods, etc.
Class and individual projects are essential aspects of the training given, and there are opportunities for more advanced study in specialized fields.

*The training of public health administrators and health practice research workers in the USSR*

The Central Institute for Advanced Medical Studies (CIAMS), founded in 1930 to promote the further education and training of highly-qualified specialists, has five faculties, namely surgery, therapeutics, paediatrics, sanitation and hygiene, and the basic sciences. It trains research workers and teachers for medical schools (*aspirantura*) and clinical medical specialists (*ordinatura*). Each faculty is separately housed and has access to the appropriate facilities of research institutes belonging to the Academy of Medical Sciences of the USSR. Departments of the Faculty of Sanitation and Hygiene are conveniently situated for maintaining close ties with the Moscow City Sanitation and Epidemiological Station.

Besides doctors from the USSR, those from other countries are admitted to advanced studies. International courses offered by the Institute include public health administration (in Russian and English), epidemiology of infectious diseases (in English), and public health planning (in Russian).

The Institute's research activities, which are closely linked with its academic work, are a part of the national medical research programmes.

The courses offered include advanced training for public health and hospital administrators in social medicine and the organization of public health services, intended to prepare high-level workers in the fields of administration (management), research or teaching.

The course for public health administrators extends over a single academic year, consists of 900 study hours, and leads to a diploma, the M.Sc. in social medicine. It includes lectures, seminars on selected questions, the practical solution of problems in public health management, practical periods, discussions, reports to conferences, and the writing of a course (diploma) paper on an investigation of some aspect of social medicine or public health organization.

Field work is conducted in the laboratories and clinics of the Central Institute for Advanced Medical Studies, and in therapeutic, preventive and research institutes in Moscow. It also includes a study of the organization of medical establishments in Leningrad, Kiev, an oblast in the Ukraine, and in a selected country.
The curriculum comprises:

**Medical sociology and the theory of public health**

- Man's health, his physical and spiritual development and welfare.
- The philosophical and sociological concepts of health, disease, public health and welfare.
- The interrelationships between social and biological laws in the development of man and his health.
- The influence of social trends on the development of public health.
- Problems of health and reproduction in the nineteenth and twentieth centuries. Types of reproduction and pathology in the population and the factors determining them.
- The main types of public health organization system.
- Modern trends in medical sociology.
- The role of the public in improving the environment, working and living conditions.

**Vital and health statistics**

- Methods of investigation, sources of information, methods of processing statistical data, the use of computers.
- Vital and health statistics, statistics in sociological investigations.
- Statistics for assessing the operation and efficiency of the health services.

**Epidemiology**

- Epidemiological methods and principles.
- Sources of information: programme of investigations (with special reference to the medical services).
- Epidemiology of non-infectious diseases.
- Epidemiology of infectious diseases.
- Experimental epidemiology — field trials and active research.

**Principles of public health management and the efficient organization of labour**

- The fundamentals of management.
- Organization, methods and techniques.
- Systems of public health management in various countries.
- Legislation and planning, health economics and finance.
- Principles and factors in the efficient organization of labour in the public health services.
- Ways of introducing efficient forms of labour organization into public health establishments.
Organization of in-patient and out-patient care

Present-day hospital care: principles of organization.
Organization of child care.
Organization of care for women.
Organization of rural health care.

Design and construction of medical establishments

Modern architecture, methods and principles of siting hospitals and other curative and preventive establishments.
Engineering and technical equipment in hospitals.

Medical education and science

Medical education, specialization, advanced training of medical personnel and workers in allied professions.
Fundamentals of coordinating and planning research work.

Information about modern medical problems (selected topics from theoretical and experimental medicine)

Modern aspects of clinical medicine.
Doctors who complete the International Course for Public Health Administrators and are awarded a specialist diploma in social medicine, are given opportunities to carry out research in social medicine and public health administration. The aspirantura, research work, and preparation of a dissertation for the title of candidate of medical sciences, provide the basis for the training of research and teaching staff.

All schools of public health in the USSR — at present 13 in number — work closely with extramural scientific workers. These workers receive instruction partly on the spot and partly in the schools. Most of the health personnel in field demonstration centres are scientific co-workers in this sense. Many are awarded scientific grades, receive grants from the graduate schools and often act as extramural teachers.

A proposed curriculum for the training of postgraduate students in the general methodology of medical research^1 includes the following topics:

(a) classification of medical research;
(b) selection and definition of a problem for research

^1 G. Karkovic, The teaching of the general methodology of medical research for the postgraduate student, lecture at the First General Assembly of the Association of Institutions for Advanced Training in Public Health in Europe, Zagreb, 7-11 October 1968.

(e) collection of information, work on bibliography;
(d) formulation of a research target for a certain problem;
(e) design of experiments and of research work generally; how to prepare a research project;
(f) methods of carrying out experiments and collecting data;
(g) principles of scientific analysis of data;
(h) methods of presentation of the results;
(i) preparation and editing of scientific papers;
(j) general concepts and logical basis of research work (summary);
(k) ethics of research work.

The Johns Hopkins School of Public Health, Baltimore

This School provides the opportunity both for postgraduate professional training and for advanced academic development in various areas of research. In the past, the professional programmes have attracted mostly physicians pursuing the MPH or DPH degrees. Recent years, however, have witnessed an increasing enrollment of dentists, nurses, midwives, social scientists, economists and other non-health professionals interested in the field of community health. In 1970, a Master of Health Sciences degree was approved as a somewhat more specialized avenue of professional development than the MPH. The various departments of the School also offer research programmes leading to the M.Sc., D.Sc., or Ph.D. degree. Although these programmes are directed toward individual areas of training and research, each D.Sc. candidate is required to complete a year of course work in three departments other than that corresponding to his major field of interest. Perhaps the most fundamental principle underlying all the programmes at Johns Hopkins is that the training of public health professionals must be broadly based.

A further feature of the Johns Hopkins programmes is their concern with the widely different public health needs of different parts of the world. Both staff and curriculum in chronic disease epidemiology and medical care practices have been strengthened substantially in recent years in response to developments in the USA and other developed countries. In parallel with this growth, the departments of international health, population dynamics, and pathology have increased the depth and range of their involvement during the same period, and about one-third of the student body comes from developing countries overseas.

Yet another feature of interest is the increasingly multidisciplinary nature of the curriculum. In addition to the department of behavioural sciences, divisions of health economics and operations research have recently been organized to complement the traditional public health
disciplines. Staff members in each of the new disciplines usually hold joint appointments in corresponding departments in the School of Arts and Sciences or the School of Engineering. Thus a useful channel of communication is maintained with, for example, the Department of Political Economy, yet the courses in economics are specifically School of Public Health courses, and are thereby assured a genuine public health orientation.

The historical development of operations research at Johns Hopkins is of particular interest. The discipline first emerged within the Department of Industrial Engineering during the 1950s. Then, about a decade ago, an operations research group was organized at the Johns Hopkins Medical Institutions to study hospital and other health care services. Finally, within the last five years, an operations research sub-group in health has been developed to give special attention to developing countries, where health problems tend to be different, data are inadequate, and competence in the use of sophisticated mathematical techniques is sometimes lacking.

About ten years ago, a two-month course in national health planning was introduced by the Department of International Health. The class was made up partly of MPH candidates with special interests in health planning and partly of senior health administrators from overseas who had come for the course only for purposes of further education. As a result of increasing general interest in health planning, the programme became interdepartmental in 1967 under the joint sponsorship of the Departments of International Health, Public Health Administration, and Medical Care and Hospitals. At that time, additional courses in demography, decision theory, operations research, and behavioural sciences were incorporated into the programme, and it became possible for doctoral candidates to prepare theses on some aspect of health planning or health practice research. The course remained, however, suitable for purposes of further education, and its duration was not changed.

The development of the programme in health planning was paralleled by that in operations research designed for M.Sc. and D.Sc. candidates. As indicated above, the operations research programme has become increasingly international in character; in addition, it has been coupled with two major field research projects involving several countries. Of these, the first is a WHO-sponsored international collaborative study of comparative patterns of health services utilization, the second a systems analysis of health care delivery in three rural settings in developing countries. Now that both the health planning and operations research programmes are well established and international in character, attention has shifted to the effective integration of the two. It is felt that macro-planning uncovers specific problems, such as the need for new
categories of health workers, that lend themselves to the operations research approach. Likewise, the results of health practice research need to be incorporated into the planning process.

Administratively, the trend towards programme integration is reflected in the fact that the director of the programme in health planning is a member of the advisory group for curriculum development in operations research; similarly, the director of operations research is a member of the advisory group in health planning.

A further consequence of the same trend is the expansion of the two-month course in health planning into a four-month course. The additional two-month period precedes the planning course as such, and is devoted to the teaching of health practice research methods. Emphasis is placed on the use of quantitative techniques that can be used where data and computer facilities are minimal. The format and content of this part of the course draws heavily upon the methodology developed as a result of the systems analysis of health services mentioned above.

SUMMARY AND CONCLUSIONS

It is too early to judge whether the managerial, research-oriented type of basic postgraduate curriculum will be adopted universally. In countries where environmental hygiene and the control of communicable diseases are still subjects of paramount importance, for instance, it might not be expedient to give greater prominence to managerial science in basic public health training. Specialist courses for health administrators might, for some time, at all events, continue to be a more satisfactory arrangement.

It is, however, generally recognized that, in all countries, the top-level health administrator is ill-equipped unless at some stage he has had systematic training in modern management and research methods in a multidisciplinary setting. Whilst academic training alone cannot, of course, provide adequate preparation for senior posts in health administration, such training makes it possible to profit more surely from in-service experience and to acquire managerial competence in a shorter time. It also provides a basis of theory that is invaluable in dealing with the unfamiliar problems that arise in new situations resulting from changing disease manifestations, technological and social advances, and the further development of organized health care services.
ANNEX

CERTAIN PRACTICAL CONSIDERATIONS
IN HEALTH PRACTICE RESEARCH

Identification of problems for investigation

Health workers become aware of problems requiring investigation:

(i) in the day-to-day issues that arise in running services;
(ii) from the spontaneous expression of dissatisfaction by public groups;
(iii) from anomalies or inadequacies disclosed by formal enquiries;
(iv) as a result of evaluation studies; or
(v) from management and other deficiencies that appear in the course of health planning experience.

The number of questions arising in these ways is virtually unlimited, so that the choice of problems for investigation is a highly selective process, based on a variety of considerations — general principles, the spectrum of facts, insight into local priorities, feasibility, and the expected usefulness of the results balanced against the cost and labour of obtaining them. The next step is to draw up a list of the data required to answer the questions selected, and to decide how much of the data it is feasible to obtain and how the information should be collated. Only when these steps have been taken can a viable project be structured with any confidence. In all these matters, administrators and research workers must understand each other and work in harness. They have to reach agreement on both objectives and means. The administrator should realise that research does not always produce cut and dried results; the research worker should be aware of administrative constraints. Both should recognize that research is a slow business, that information on which administrative decisions can be based has to be built up laboriously over a long period of time, and that questions of a general character are rarely answerable by research methods. They must be broken down into simple components to become “research-able”.

— 182 —
Project design

The many decisions that have to be taken about project design include those concerned with:

1. The broad character of the investigation proposed, i.e., whether the project is to be based on:
   (a) descriptions of naturally occurring situations that may occasionally have the character of naturally occurring experiments;
   (b) a deliberate search for areas in which experimentation is feasible without changing the basic components of the existing situation; or
   (c) the manipulation of variables, as in controlled field studies, where relevant factors can be altered and the ensuing consequences studied.

2. The choice between case studies, the study of total populations, and sample studies, and that between longitudinal (cohort) studies and studies relating to a short cross-section of time. (It is especially difficult to ensure that samples are representative in countries where there is insufficient statistical information to define stratification.)

3. The choice of method in relation to the degree of precision required (see also p. 185).

4. Particularly in manpower studies, whether to use a macro- or a micro-approach. Thus, for example, the macro-approach, while providing information over a wider range of situations, introduces many more variables than studies at local levels. Also, studies at State, district or even village level are in some instances a better basis for planning than country-wide studies.

5. In interdisciplinary projects, account must be taken of the fact that each discipline has its own background of theory and preferred methods of collecting and analysing data; the project has therefore to be conceived and conducted within the framework of the theories of the disciplines involved.

6. The selection of the best practicable sources of data and of the ways of obtaining them.

Sources of data and project design

The main sources of primary data, which may be used singly or in combination in health practice research, are:

(a) documentary sources — existing statistical and other records, which may be either of a historical nature or routinely compiled. Although data collected at the local level for routine purposes can be used to some extent in research, they are often of limited value for this purpose, and almost always have to be supplemented by data obtained from specifically designed enquiries;
(b) interviewing and questionnaire techniques, whether free, open-ended or fully structured, e.g., censuses, self-recording and diary methods, population attitudes. (Sociology has an important contribution to make in some of these methods because it is within this field that interview techniques have been specially developed); (c) observational methods, ranging from the descriptive approach of the anthropologist to specific, quantified time-and-motion studies; (d) standardized testing procedures, e.g., physical and psychological tests.

Other methodological considerations

Relatively simple studies can often provide useful baselines for use in identifying, measuring and changing the main influences at work in complex situations. Furthermore, as administrators and policy-makers frequently have to act without waiting for the results of extended research and trials, simple studies often have to provide a sufficient basis for immediate policy decisions. The research process may stop here but, in addition to yielding practical results, this first stage of research usually suggests hypotheses and operational adjustments that can be tested in natural experimental situations, controlled trials, or by comparing one system with another. It may thus be a point of departure for a second stage, consisting of more elaborate and more sophisticated investigations focused on specific hypotheses. Whether these two stages proceed simultaneously or in sequence, they set in motion processes that end in policy validation, programme indications, the simplification of management tools, and the further refinement of research methods. Seen in this way, the research continuum, as represented in Fig. 28, consists of three stages.

University departments and national planning bodies are usually especially interested in testing methods, defining norms, devising indices and defining their range of application. In executive health departments, in contrast, the main concern is usually with specific problems. These practical researches may make methodological advances incidentally, but this is not the primary purpose. Conversely, investigations primarily of an academic character often have an immediate practical value. In particular, stages II and III of the continuum, as represented in Fig. 28, can be the means of identifying simple but reliable indices, simplifying the records and procedures used in routine administration, and developing methods that can be used in almost any health department. The establishment of norms, control procedures and monitoring systems is a common end product of the more sophisticated thinking and processing.

The choice of subjects for investigation and their relative priorities
clearly depend to a large extent on the prevailing health situation, the level of development of services, the information bases and resources available, and the cultural and socio-economic circumstances of a particular country. Not uncommonly, countries where operations research is most needed are least equipped to carry it out. Methods suitable for developed countries usually have to be modified for use in developing countries. For most practical purposes, however, relatively crude data and simple methods are both adequate and within the capacity of almost every health administration. The problem of selecting the method to be employed is best approached pragmatically, and often involves the development of a method that is suitable for the particular purpose, or alternatively the modification of a well-tried general method.

In general, “best” methods both in data collection and in analysis have to be worked out in relation to the resources available rather than the other way round. The choice should take into account all relevant circumstances — the character of the investigation (i.e., whether a field enquiry or a highly conceptualized study, the degree of precision required, the quality of the data likely to be available, the feasibility of using sophisticated techniques, and the appropriateness of, and justification for the use of such methods, in terms of cost. The use of highly sophisticated methods of processing data that are inaccurate, unreliable or incomplete is not only incongruous but can also be misleading by
creating a false impression of precision. Careful consideration should therefore be given to the kind and level of research that requires the use of sophisticated analytical techniques. Surveys of medical care needs and health service utilization, for instance, fail more commonly because of imprecise definitions of terms and objectives, inaccuracies and incompleteness of records, shortages of adequately trained staff, and difficulties in sustaining the necessary effort over long periods of time, than because specialized techniques are not available. Generally speaking, methods of handling data are more advanced than methods of collecting them.

It is important also, when employing mathematical techniques, to recognize that the data of health practice research are rarely exclusively numerical in character. For example, indices of health-care and fertility often have a hidden non-numerical content because they are derived partly from non-quantifiable variables, such as human attitudes and behaviour, and socio-economic circumstances.

The importance of feasibility trials and pilot runs in field projects cannot be over-emphasized. Unless full-scale enquiries are preceded by trials of alternative methods followed by pilot or test runs, a great deal of effort can be made to little or no purpose. Pilot runs are necessary not only for testing the feasibility of survey procedures, but also, in many instances, for providing information that enables amendments and adjustments to be made before such procedures are widely applied, and before resources are committed to a full-scale enquiry.

Provision for evaluation and feedback should be a normal feature of field enquiries and, as far as possible, evaluation at both pilot and operational stages should be related to the undisturbed system under scrutiny. In health practice research as a whole, the comparison of achievements with stated objectives has not hitherto been given the priority it merits.

The importance of human relations in surveys is self-evident. The cooperation of the population to be studied and adequate follow-up are obviously essential if a high level of response is to be secured. The information required should be obtained at the least cost to the population in time, effort, and exposure to stress, and with due safeguarding of privacy. When interviewing techniques are used, special attention has to be given to the quality and form of personal contacts so as to avoid, as far as possible, the introduction of prejudice and bias into the records.

Interdisciplinary collaboration may either involve multidisciplinary teams working on specific projects (concurrent investigations) or further work by teams representing other disciplines on problems disclosed by investigations undertaken initially by a team representing a single discipline (sequential investigations). In order to obtain an overall view
of a problem, different approaches have somehow to be brought together. There are many ways of doing this. The use of display techniques — sometimes referred to as contextual map making — that record decisions, progress and predictions, is one way of keeping a multidisciplinary group informed on the state of the project. The map serves as a group memory, and gives everyone concerned a clear picture of the relations involved. Conferences are also used to give structure and unity to a research programme as a whole. After meeting as a body, participants are commonly divided into working groups, each dealing with a particular aspect of a problem, that meet either concurrently or in a succession of sub-conferences, each concerned with a particular aspect of the problem. A core group, one or two of whose members are also members of each of the working groups, is a common integrating device.

Technical and evaluation reports intended for the guidance of policy-making bodies should, as far as possible, be presented in plain terms that are easily understood, even if the conclusions they contain were reached by the use of highly sophisticated methods.
Survey of specific approaches to research, with special attention to nursing.

Ackoff, R. L. et al. (1962) *Scientific method optimizing applied research decisions*, New York, Wiley
Comprehensive, scholarly discussion of the scientific method in applied research, with chapters on modelling, measurement, sampling, estimation, hypothesis testing, and implementation, among other topics. Not health oriented.


Exemplifies the fitting of data to mathematical models in an attempt to understand more fully the phenomena of interest.

Presentation of a manpower model, along with a rather detailed description of health manpower prospects in the USA.

Churchman, C. W. et al. (1957) *Introduction to operations research*, New York, Wiley
Classic textbook on operations research methodology. Not health oriented.

Proceeds from the construction of a mathematical model to a consideration of cost-effectiveness and cost-benefit analysis.

Description of relatively simple epidemic models.

Very detailed and complex mathematical analysis of size, character, and cost of hospital operation, based upon extensive data from the United Kingdom.
BIBLIOGRAPHY

Feldstein, M. S. (1967) An aggregate planning model of the health care sector, Med. Care, 5, 369-381
Comprehensive and complex model of the health care sector.

One of the few practical guides directly applicable to the health field in general and to mental health in particular. Excellent simplified review of operations research problem areas and techniques, with a useful section on the conduct of operations research studies.

Kalu, P. I. (1962) On the methodology of scientific research in public health protection organization, Sante publ. (Buc.), 5, 259-269
General description of applications in certain areas of methodology in the USSR.

Review of research activities in medical care in the United Kingdom. Considerable methodology at unsophisticated level.

Simplified method for the costing of alternative approaches to leprosy and tuberculosis care.

Non-technical discussion of the subject. Not health oriented.

Useful conceptual model of strategies for attacking a community problem within a social science framework.

Description of a complex tuberculosis model, with an illustration of its use.

MEASUREMENT

Description of four observational techniques: continuous, zone, log, and intermittent work sampling. Findings from application of fourth are discussed.

Good example of quantification and analysis of an intangible, namely satisfaction.

Grube, E. F. (1967) Here is how work measurement works, Mod. Hosp., 108, (5), 118-121
Illustrates use of time measurement and work sampling techniques in hospital setting.

A general guide to the conduct of social research, both descriptive and explanatory. Includes a discussion of the utilization of survey findings.


Provides a good general account of the U.S. National Health Survey.


Concise, simplified review of objectives, design, and conduct of sample surveys. Includes discussion of fruitful areas of application in public health, but does not deal with statistical techniques of analysis.

**COMPUTERS**


Review of studies in which use has been made of mathematics and computers.


A good general account of computer logic, design and application.


Review of information systems.


Relation of mathematical models and computers in medicine.


Review of the developing role of computers in medicine.


Recent review of the nature and role of computers.


A system of compiling individual patient statistics is discussed in terms of its potential and its inadequacies as a hospital management information system.


Organization of computerized information systems for use in health administration.
Summary of computer processing of health statistics.

**SIMULATION**

Fetter, R. B. & Thompson, J. D. (1965) *The simulation of hospital systems, Ops Res.,* 13, 689-711
An extensive review of simulation in varied hospital settings.

Outlines mathematical model and computer program for simulation of patient flow through a progressive patient care system in order to determine optimal allocation of beds.

Kennedy, F. D. et al. (1968) *The development of a simulation model of a community health service system, Research Triangle Park,* North Carolina, Research Triangle Institute (4 vols)
Presentation of conceptual model of entire health service system, followed by detailed listing of items to be measured, selected sources of data, and events to be simulated. Computer flow charts of simulation models included.

Detailed consideration of a computerized analysis of a wide range of parameters associated with refuse collection. The paper describes the computer logic, and discusses findings and implications.

Report on the use of a particular model to simulate reproductive history in a hypothetical population.

Lists various forms of pest control models, difficulties associated with their use, and the benefits of computer simulations. Contains appendix giving computer logic in considerable detail.

**MATHEMATICAL PROGRAMMING**

Bristoe, J. D. (1967) *An introduction to linear programming,* Boston, Heath
An elementary introduction to the mathematics of inequality relations, polygonal convex sets, and matrix algebra, applied to linear programming.

Discussion in French of WHO work with tuberculosis control models. English summary.

Presentation of two tuberculosis control models, including a linear programming model designed to identify specified number of active cases at minimum cost.


A measure of locational efficiency is derived for a given urban area on the basis of the value and frequency of seven sources of hospital input.


**QUEUEING**


Study of factors affecting, and relationship between, physician idle time and patient waiting time.


Detailed description of the sampling procedure, variables selected, and results of a survey of outpatients.


Illustration of queuing and another statistical technique applied to surgery schedules.


Development of queuing model of unscheduled hospital admissions for purpose of establishing optimal decision procedure for elective admissions.

**MISCELLANEOUS**

Government of Canada (1969) *Planning programming budgeting guide*

Addressed to broad issues of planning and administration with special reference to PPBS. In English and French. Not especially oriented towards health.


Discusses methods and results of measuring use and cost of facilities and services, as well as efficiency of health personnel utilization in Bucharest.


Survey of studies in the field.


General review of the approach, with its assumptions and limitations, as applied to intersectoral economic analysis. Not highly technical, but requires a good understanding of basic economics terminology.
Consideration of: (1) differential reactions of public to health programmes; and (2) communication barriers between health providers and consumers, as well as the role of behavioural sciences in their removal.

Presents tables of discounted lifetime earnings for the USA in 1964, by age, sex, race, and education. Includes discussion of the considerations involved in the calculations.

Rockwell, T. H. et al. (1962) Inventory analysis as applied to hospital whole blood supply and demand, *J. industr. Engng.*, 13, 109-114
Joint analysis of problem of shortage and wastage of whole blood.

Smalley, H. E. & Freeman, J. R. (1966) *Hospital industrial engineering; A guide to the improvement of hospital management systems*, New York, Reinhold
Extensive review of industrial engineering and operations research at the hospital level. Discussion of applications to medication control, activity study, admissions variability, outpatient queueing, and menu planning via linear programming.

Comprehensive consideration of issues involved in screening.
<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Authors</th>
<th>Pages</th>
<th>Price</th>
<th>Swiss Francs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>PSYCHIATRIC SERVICES AND ARCHITECTURE.</td>
<td>A. Baker, R. Llewelyn Davies &amp; P. Sivadon</td>
<td>59</td>
<td>0.60</td>
<td>2.00</td>
</tr>
<tr>
<td>2.</td>
<td>EPIDEMIOLOGICAL METHODS IN THE STUDY OF MENTAL DISORDERS.</td>
<td>D. D. Reid</td>
<td>79</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>3.</td>
<td>HEALTH SERVICES IN THE USSR. Report Prepared by the Participants in a Study Tour Organized by the World Health Organization</td>
<td></td>
<td>58</td>
<td>0.60</td>
<td>2.00</td>
</tr>
<tr>
<td>4.</td>
<td>ASPECTS OF PUBLIC HEALTH NURSING.</td>
<td>Various authors</td>
<td>185</td>
<td>1.75</td>
<td>5.00</td>
</tr>
<tr>
<td>5.</td>
<td>TRENDS IN JUVENILE DELINQUENCY.</td>
<td>T. C. N. Gibbens</td>
<td>56</td>
<td>0.60</td>
<td>2.00</td>
</tr>
<tr>
<td>6.</td>
<td>IONIZING RADIATION AND HEALTH.</td>
<td>Bo Lindell &amp; R. Lowry Dobson</td>
<td>81</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>7.</td>
<td>BASIC NURSING EDUCATION PROGRAMMES. A GUIDE TO THEIR PLANNING.</td>
<td>Katharine Lyman</td>
<td>81</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>8.</td>
<td>THE ROLE OF IMMUNIZATION IN COMMUNICABLE DISEASE CONTROL.</td>
<td>Various authors</td>
<td>118</td>
<td>1.25</td>
<td>4.00</td>
</tr>
<tr>
<td>9.</td>
<td>TEACHING OF PSYCHIATRY AND MENTAL HEALTH.</td>
<td>Various authors</td>
<td>186</td>
<td>2.00</td>
<td>6.00</td>
</tr>
<tr>
<td>11.</td>
<td>MATERNAL AND CHILD HEALTH IN THE USSR. Report Prepared by the Participants in a Study Tour Organized by the World Health Organization</td>
<td></td>
<td>71</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>12.</td>
<td>ROAD TRAFFIC ACCIDENTS. Epidemiology, Control and Prevention.</td>
<td>L. G. Norman</td>
<td>110</td>
<td>1.25</td>
<td>4.00</td>
</tr>
<tr>
<td>13.</td>
<td>ASPECTS OF WATER POLLUTION CONTROL.</td>
<td>Various authors</td>
<td>165</td>
<td>1.25</td>
<td>4.00</td>
</tr>
<tr>
<td>14.</td>
<td>DEPRIVATION OF MATERNAL CARE. A Reassessment of its Effects.</td>
<td>Various authors</td>
<td>165</td>
<td>2.00</td>
<td>6.00</td>
</tr>
<tr>
<td>15.</td>
<td>EPIDEMIOLOGY OF AIR POLLUTION. Report on a Symposium.</td>
<td>P. J. Lawther, A. E. Martin &amp; E. T. Wilkins</td>
<td>32</td>
<td>0.30</td>
<td>1.00</td>
</tr>
<tr>
<td>16.</td>
<td>THE SCOPE OF EPIDEMIOLOGY IN PSYCHIATRY.</td>
<td>Tsung-Yi Lin &amp; C. C. Standley</td>
<td>76</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>No.</td>
<td>Title</td>
<td>Authors/Editors</td>
<td>Pages</td>
<td>Price</td>
<td>Currency</td>
</tr>
<tr>
<td>-----</td>
<td>-----------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>-------</td>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>18</td>
<td>MEDICINE AND PUBLIC HEALTH IN THE ARCTIC AND ANTARCTIC. Selected Papers from a Conference.</td>
<td>Various authors (1963)</td>
<td>169</td>
<td>60</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.00</td>
</tr>
<tr>
<td>19</td>
<td>HEALTH EDUCATION IN THE USSR. Report Prepared by the Participants in a Study Tour Organized by the World Health Organization (1963)</td>
<td>69 pages</td>
<td></td>
<td>30</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.00</td>
</tr>
<tr>
<td>22</td>
<td>THE NURSE IN MENTAL HEALTH PRACTICE. Report on a Technical Conference.</td>
<td>Audrey L. John, Maria O. Leite-Ribeiro &amp; Donald Buckle (1963)</td>
<td>212</td>
<td>70</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.00</td>
</tr>
<tr>
<td>23</td>
<td>URBAN WATER SUPPLY CONDITIONS AND NEEDS IN SEVENTY-FIVE DEVELOPING COUNTRIES.</td>
<td>Bernd H. Dieterich &amp; John M. Henderson (1963)</td>
<td>92</td>
<td>30</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.00</td>
</tr>
<tr>
<td>24</td>
<td>CARE OF CHILDREN IN DAY CENTRES.</td>
<td>Various authors (1964)</td>
<td>189</td>
<td>70</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.00</td>
</tr>
<tr>
<td>25</td>
<td>HOUSING PROGRAMMES: THE ROLE OF PUBLIC HEALTH AGENCIES.</td>
<td>Various authors (1964)</td>
<td>187</td>
<td>80</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.00</td>
</tr>
<tr>
<td>26</td>
<td>DOMESTIC ACCIDENTS.</td>
<td>E. Maurice Backett (1965)</td>
<td>138</td>
<td>60</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.00</td>
</tr>
<tr>
<td>27</td>
<td>TRENDS IN THE STUDY OF MORBIDITY AND MORTALITY.</td>
<td>Various authors (1965)</td>
<td>196</td>
<td>80</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.00</td>
</tr>
<tr>
<td>28</td>
<td>ASPECTS OF FAMILY MENTAL HEALTH IN EUROPE.</td>
<td>Various authors (1965)</td>
<td>123</td>
<td>50</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.00</td>
</tr>
<tr>
<td>29</td>
<td>MASS CAMPAIGNS AND GENERAL HEALTH SERVICES.</td>
<td>C. L. Gonzalez (1965)</td>
<td>87</td>
<td>40</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
</tr>
<tr>
<td>30</td>
<td>NOISE. An Occupational Hazard and Public Nuisance.</td>
<td>Alan Bell (1966)</td>
<td>131</td>
<td>60</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.00</td>
</tr>
<tr>
<td>31</td>
<td>A GUIDE FOR STAFFING A HOSPITAL NURSING SERVICE.</td>
<td>Marguerite Paetznick (1966)</td>
<td>93</td>
<td>40</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
</tr>
<tr>
<td>32</td>
<td>AN INTERNATIONAL STUDY OF HEALTH EXPENDITURE AND ITS RELEVANCE FOR HEALTH PLANNING.</td>
<td>Brian Abel-Smith (1965)</td>
<td>127</td>
<td>60</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.00</td>
</tr>
<tr>
<td>33</td>
<td>THE PHYSIOLOGICAL BASIS OF HEALTH STANDARDS FOR DWELLINGS.</td>
<td>M. S. Goromonov (1968)</td>
<td>99</td>
<td>50</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.00</td>
</tr>
<tr>
<td>No.</td>
<td>Title</td>
<td>Author(s)</td>
<td>Year(s)</td>
<td>Pages</td>
<td>Price</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------------------------------------------------------</td>
<td>-----------------------------</td>
<td>---------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>34</td>
<td>PRINCIPLES AND PRACTICE OF SCREENING FOR DISEASE</td>
<td>J. M. G. Wilson &amp; G. Jungner</td>
<td>1968</td>
<td>163</td>
<td>70</td>
</tr>
<tr>
<td>35</td>
<td>PREVENTION OF SUICIDE</td>
<td></td>
<td>1968</td>
<td>84</td>
<td>40</td>
</tr>
<tr>
<td>36</td>
<td>A REVIEW OF THE NATURE AND USES OF EXAMINATIONS IN MEDICAL EDUCATION</td>
<td>J. Charvat,</td>
<td>1968</td>
<td>74</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. McGuire &amp; V. Parsons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>THE ASSESSMENT OF BIOLOGICAL AGE IN MAN</td>
<td>F. Bourlière</td>
<td>1970</td>
<td>67</td>
<td>50</td>
</tr>
<tr>
<td>38</td>
<td>PROBLEMS IN COMMUNITY WASTES MANAGEMENT</td>
<td>H. M. Ellis, W. E. Gilbertson, O. Jaug, D. A. Okun, H. I. Szuval &amp; J. Summer</td>
<td>1969</td>
<td>81</td>
<td>60</td>
</tr>
<tr>
<td>39</td>
<td>POSTGRADUATE EDUCATION FOR MEDICAL PERSONNEL IN THE USSR</td>
<td></td>
<td>1970</td>
<td>52</td>
<td>40</td>
</tr>
<tr>
<td>40</td>
<td>PRINCIPLES AND PRACTICE OF CHOLERA CONTROL</td>
<td>Various authors</td>
<td>1970</td>
<td>139</td>
<td>80</td>
</tr>
<tr>
<td>41</td>
<td>MENTAL HEALTH OF ADOLESCENTS AND YOUNG PERSONS</td>
<td>A. R. May, J. H. Kain &amp; B. Cronholm</td>
<td>1971</td>
<td>72</td>
<td>50</td>
</tr>
<tr>
<td>42</td>
<td>THE PREVENTION OF PERINATAL MORBIDITY AND MORTALITY</td>
<td></td>
<td>1972</td>
<td>97</td>
<td>60</td>
</tr>
<tr>
<td>43</td>
<td>PRINCIPLES OF HEALTH PLANNING IN THE USSR</td>
<td>G. A. Popov</td>
<td>1971</td>
<td>172</td>
<td>90</td>
</tr>
<tr>
<td>44</td>
<td>PLANNING AND PROGRAMMING FOR NURSING SERVICES</td>
<td></td>
<td>1971</td>
<td>123</td>
<td>70</td>
</tr>
<tr>
<td>45</td>
<td>MASS HEALTH EXAMINATIONS</td>
<td></td>
<td>1971</td>
<td>99</td>
<td>60</td>
</tr>
<tr>
<td>46</td>
<td>APPROACHES TO NATIONAL HEALTH PLANNING</td>
<td>H. E. Hilleboe, A. Barkhaus &amp; W. C. Thomas, Jr</td>
<td>1972</td>
<td>108</td>
<td>70</td>
</tr>
<tr>
<td>47</td>
<td>ASPECTS OF MEDICAL EDUCATION IN DEVELOPING COUNTRIES</td>
<td>Various authors</td>
<td>1972</td>
<td>113</td>
<td>80</td>
</tr>
<tr>
<td>48</td>
<td>EVALUATION OF COMMUNITY HEALTH CENTRES</td>
<td>Milton I. Roemer</td>
<td>1972</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td>49</td>
<td>INTERRELATIONSHIPS BETWEEN HEALTH PROGRAMMES AND SOCIO-ECONOMIC DEVELOPMENT</td>
<td></td>
<td>1973</td>
<td>54</td>
<td>50</td>
</tr>
<tr>
<td>50</td>
<td>HOSPITAL LEGISLATION AND HOSPITAL SYSTEMS</td>
<td>R. F. Bridgman &amp; M. I. Roemer</td>
<td>1973</td>
<td>236</td>
<td></td>
</tr>
</tbody>
</table>