A GENERALIZED
COST-EFFECTIVENESS MODEL
FOR THE EVALUATION
OF HEALTH PROGRAMS

A Research Report

By

GEORGE W. TORRANCE, B.A.Sc., M.B.A., Ph.D.
Associate Professor of Management Science

FACULTY OF BUSINESS
McMASTER UNIVERSITY

Research Series: No. 101.

A GENERALIZED COST-EFFECTIVENESS MODEL

FOR THE

EVALUATION OF HEALTH PROGRAMS

by

George W. Torrance, B.A.Sc., M.B.A., Ph.D.
Associate Professor of Management Science
Faculty of Business, McMaster University
Hamilton, Ontario, Canada

A research project funded by the
Ontario Department of Health:
Grant No. P. R. 118

November, 1970

ABSTRACT

This research is concerned with the optimal allocation of resources within the health service system. In particular it is concerned with methods for selecting, within specified constraints, the optimal sub-set of health service programs from a set of feasible programs.

Current approaches are reviewed and found inadequate. Cost-benefit analysis measures the economic, but not the health, consequences of a program. Cost-effectiveness analysis measures the health benefits in program-specific units, thus excluding any inter-program comparisons.

A new approach is proposed which generalizes the cost-effectiveness model by combining it with a new morbidity-mortality health index. The index for a particular health state is the subjective utility which society attaches to a day in that state. The index is standardized with zero for dead and one for healthy. The index-day can then be viewed as a universal unit of health, and the model structured to maximize these units, within specified constraints.

Two techniques are investigated for measuring the required subjective utilities: a time trade-off tech-

nique and a von Neumann-Morgenstern standard gamble approach. Both are applied in individual interviews with eleven general practitioners to measure the utilities of five different health states. Both prove highly reliable as measured by their internal consistency and each gives equivalent results, but the time trade-off technique is significantly easier to administer.

Two computational algorithms are investigated for analyzing a set of potential health programs to select the optimal sub-set: a cost-effectiveness ranking algorithm developed specifically for this project and a standard zero-one integer linear programming algorithm. The former proves superior for most applications: it is more efficient, it provides more useful information and it can handle larger problems. The latter proves more flexible for handling complicated problem structures. A computer program for the cost-effectiveness ranking algorithm is provided.

The new approach is tested by applying it to four different programs covering a broad spectrum of the health service field: two preventive screening programs, one for newborn (a screening program for the eradication of hemolytic disease of the newborn) and one for adults (a tuberculosis screening program); a treatment program for an acute condition (a coronary emergency rescue service); and a treatment program for a chronic condition (a kidney dialy-

sis and transplantation program). Data gathering is a time-consuming task and a plea is made for better quality data, particularly in the measurement of program health benefits. Otherwise, no outstanding difficulties are encountered and it is concluded that the approach is applicable to a wide variety of health programs -- perhaps all.

PREFACE

This research project grew out of joint discussions between the health community, represented by the Department of Clinical Epidemiology and Biostatistics, Faculty of Medicine, McMaster University; and the operations research community; represented by the author and various members of the Department of Industrial Engineering, State University of New York at Buffalo. The discussions revolved around the question: What significant problems of the health service system appear to be amenable to the operations research approach? Gradually a consensus emerged that one such major problem was the lack of a clear conceptual model for evaluating proposed changes (improvements?) to the health service system. This research provides such a model.

The project was funded by the Ontario Department of Health and conducted by the author with the advice and assistance of his colleagues as acknowledged below. The project also served as the basis for the author's doctoral dissertation in operations research.

The following people and institutions are thanked for the specific assistance they provided throughout the course of this research:

1. Dr. D.L. Sackett, Chairman, Department of Clinical Epidemiology and Biostatistics, Faculty of Medicine, McMaster University, who provided endless hours of consultation, discussion, reading and critiquing; all of which influenced, in a very major way, the direction and especially the relevance of the research.
2. Dr. W. H. Thomas, Chairman, Department of Industrial Engineering, State University of New York at Buffalo, who provided continuing consultation on the project with special emphasis on the operations research material.
3. Dr. W.P. Smith, Professor of Industrial Engineering; Dr. E.T. O'Neill, Assistant Dean, School of Information and Library Science; and, Dr. E. Calkins, Chairman, Department of Medicine, all from the State University of New York at Buffalo, for reading and critiquing the various versions of the manuscript.
4. The following three consultants for providing extensive assistance during the applications phase of the project: Dr. W.D. Wigle, Tuberculosis Prevention Branch, Ontario Department of Health, who consulted on the tuberculosis screening program; Dr. A. Zipursky, Chairman, Department of Pediatrics, McMaster University, who assisted with the program for the prevention of hemolytic disease of the newborn; and Dr. E.K.M. Smith, Associate Professor of Medicine, McMaster University, who provided information on the kidney dialysis and transplant program.

5. Mr. W.H. Harper and Dr. A.G. Shimizu for the development and provision of some required data. Eleven local general practitioners for volunteering their time for the health index measurement interview.

6. Messrs. A.R. Laughland and V. Vijayaraghavan for their valuable work as research assistants on this project.

7. The Health Services Research Seminar, Johns Hopkins University for a stimulating week during which the original outline for this research was formulated, and Drs. Kerr L. White, Charles D. Flagle, and Herbert E. Klarman for individual consultations at this seminar in which they encouraged, critiqued and improved this outline.

8. The Ontario Department of Health for providing financial support for this project through Research Grant No. P.R. 118.

9. Dean William J. Schlatter and my colleagues in the Faculty of Business for providing a working environment in which I could complete this project.

10. The Faculty of Business Research Committee for considering this report to be worthy of inclusion in their Research Series.

11. And finally, a special thanks goes to my family from whom I took so many hours that were rightfully theirs.

November, 1970 George W. Torrance

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Chapter

TABLE OF CONTENTS (continued)

Chapter

Appendices

TABLE OF CONTENTS (continued)

Appendices

II. continued...

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF ILLUSTRATIONS

INTRODUCTION

This research is concerned with the optimal allocation of resources within the health service system. The system is viewed as consisting of health programs and the problem is cast as one of selecting, within specified constraints, the optimal sub-set of health programs from a set of feasible programs. In particular, the following questions are addressed: given two or more health programs, how can they be evaluated and compared to determine which is best; how can they be ranked in a priority sequence; and how can the optimal sub-set be selected? These questions are necessary since, unfortunately, the economy cannot simultaneously support all possible programs at their maximum level: we cannot afford to provide all known health services to all the people all the time.

The research does not concern itself with the broader question of how much of society's total resources should be channelled into health activities. For example, the proposed method cannot be used to compare a health program with an education program. Rather it is only concerned with the optimal allocation of resources <u>within</u> the health service system, once a decision has been made on the total amount of resources which will be allocated <u>to</u> the system.

In this research the term health program or health service program will be used in its broadest possible context. In fact, any activity in the health service system will be defined as a program. It is immaterial whether or not this activity is deliberately sponsored by some organization or institution and labelled as one of their programs. It may be a large coordinated activity, often regarded as a program, like mass screening for tuberculosis; or a small one, not so regarded, like the addition of a nurse-practitioner to a clinic. It may be an existing program (activity), being evaluated for continued support, or a proposed program, being evaluated for implementation. It may be a program for communicable disease control, chronic disease treatment and rehabilitation, hospital services, ambulance services, mental health or accident prevention. Since any activity in the health service system can be viewed as a program, the program-orientation of the proposed method in no way restricts its applicability.

The research begins with a critical review of the existing approaches to the problem. None is found adequate and a new approach is proposed. It is developed in detail and tested by applying it to four different programs for the Province of Ontario covering a broad spectrum of the health service field: two preventive screening programs, one for newborn (a screening program for the prevention of hemolytic disease of the newborn) and one for adults (a tuberculosis screening program); a treatment program for an acute condi-

tion (a coronary emergency rescue service); and a treatment program for a chronic condition (a kidney dialysis and transplantation program).

CHAPTER I

REVIEW OF EXISTING APPROACHES

The problem addressed by this research has been previously tackled by three different scientific disciplines: economics, operations research, and the health sciences. Each has contributed its own perspective. The Economists have refined and applied cost-benefit analysis, which measures the economic consequences of a health program; and planning-programming-budgeting systems, which allocate resources to programs in a rational fashion. The Operations Researchers have applied cost-effectiveness models for program comparison, and linear programming models for systems optimization. The Health Scientists have stressed the definition of objectives for the health service system, and the related need for an outcome-oriented health index with which to measure progress towards the objective. These various approaches to the problem are critically reviewed in the following sections.

Economic Cost-Benefit Approach

Cost-benefit analysis

Cost-benefit analysis is the traditional theoretical model for evaluating alternative programs in the public sector. Basically it is a technique for enumerating and evaluating all the relevant costs and benefits of each program and then comparing them to decide which is "best".

An extensive survey of cost-benefit analysis was published by Prest and Turvey in 1965. In this article, they define the techniques as follows:

> Cost-benefit analysis is a practical way of assessing the desirability of projects, where it is important to take a long view (in the sense of looking at repercussions in the further, as well as the nearer future) and a wide view (in the sense of allowing for side-effects of many kinds on many persons, industries, regions, etc.) i.e., it implies the enumeration and evaluation of all the relevant costs and benefits (p. 683).

The usual objective in cost-benefit analysis is stated by Prest and Turvey as follows: "...the aim is to maximize the present value of all benefits less that of all costs, subject to specified constraints", (p. 686).

Specifically, the technique consists of identifying all the benefits that will accrue from the program and converting them into equivalent dollars in the year in which they will occur. This stream of benefit dollars is then discounted to its equivalent present value at the interest rate. Likewise, all costs of the program are identi-

fied, allocated to a specific year, and the cost stream is discounted to its present value at the same interest rate. Then, other things being equal, the program with the largest present value of benefits less costs is the best.

Of course, all the costs and all the benefits caused by the program must be included. This causes some difficulty, particularly on the benefit side, since many of the benefits of a health program are either difficult to measure, difficult to convert to dollars, or both. For example, consider benefits such as improved patient comfort without any change in prognosis, improved patient satisfaction with the health care system, improved working conditions for physicians, and reduction in the probability of a child becoming orphaned: it can readily be seen that these benefits are not only difficult to measure, but especially difficult to convert into dollars. In fact, most of the effort in cost-benefit analysis by researchers in health economics has been concerned with this specific problem: how do you attach a dollar value to the benefit of improved health? In cost-benefit analysis, as many benefits as possible are converted to monetary units, and the remainder, which cannot be expressed as dollars, are listed as "intangible benefits" and left to the decision-maker to include in his final deliberations.

In converting costs or benefits to dollar amounts, market prices are normally used. Furthermore, it is often unnecessary to adjust for anticipated future increases in

the market prices as pointed out by Prest and Turvey:

> ...it is generally agreed that adjustments need to be made to the expected prices of future inputs and outputs to allow for anticipated changes in relative prices of the items involved ...but not for expected changes in the general price level (1965, p. 691).

A continuing dilemma in cost-benefit analysis is how to determine the proper interest rate for discounting the future. Prest and Turvey conclude that:

> The truth of the matter is that, whatever one does, one is trying to unscramble an omelette and no one has yet invented a uniquely superior way of doing this (p. 700).

They recommend the selection of a rate in common usage for similar projects, followed by a sensitivity analysis on the problem to determine the effect of a range of discount rates on the final solution.

Measuring the benefits

The application of cost-benefit analysis to health programs has evolved through three distinct phases which, for convenience in this paper have been labelled: (1) the national income approach, (2) the productive resources approach, and (3) the consumption benefit approach.

1. National income approach

The original approach was structured around the question: what are the monetary benefits, to the economy as a whole, from the proposed program as measured by changes in national income and wealth? Or, more specifically: if

we spend money on this particular health program, we should save money two ways; first by a reduction in money spent on the illness, and second, by an increase in the future national income because the population is healthier. This approach was used by Fein (1958) in a study on the economics of mental illness and by Mushkin (1962) in a survey paper on health economics.

A major criticism toward this approach centers around the housewife. Since she doesn't contribute to the official national income figures, programs to cure housewives would receive an inordinately low priority.

2. Productive resources approach

By 1965, the housewife issue was settled in her favor. As Prest and Turvey pointed out in that year one cannot ignore the value of a housewife. "What is really at issue, therefore, is how to measure their value, not whether to measure it" (1965, p. 722). The choice, they state, is between the opportunity cost (what she could earn if she were not a housewife) and the replacement cost (the market price of her services). Prest and Turvey refuse to take sides.

Other researchers, however, have selected the replacement cost as the appropriate measure of the value of a housewife. Weisbrod (1961), in a study to determine the economic benefits to society through the elimination of

three specific diseases - cancer, tuberculosis and poliomyelitis, established a formula to give the replacement cost of a housewife as a function of her age. In two different papers in 1965, Klarman used the average earnings of a full-time domestic worker to represent the replacement value of a housewife (1965b, p. 380; 1965c, p. 700). Finally, in 1966 the stamp of approval was given to this method by Dorothy Rice in a very thorough report published by the U.S. Public Health Service (Rice, 1966, p. 14).

3. Consumption benefit approach

The productive resources approach measures the monetary impact on society of specific health programs. Recently, however, economists have recognized the philosophical issues which are buried in this traditional earnings-oriented cost-benefit approach. For example, consider the following statements by prominent health economists:

> A pervasive problem in economic calculations is the tendency to measure and report what is readily measurable; and that is not necessarily relevant or most important. The less tangible losses, such as pain and grief, are not measured. This is tantamount to valuing them at zero (Klarman, 1965c, p. 700).

> The satisfactions purchased in health care are not exclusively, probably not even primarily, economic. There are humanitarian values, religious values respecting human life, social values and personal values such as sheer comfort and relief from pain and anxiety. Perhaps one day social science may be able to impute acceptable quantitative values to such intangibles and place them in a common or comparable scale with economic values. The objective deserves the attempt (Somers and Somers, 1967, p. 27).

> Are programs to be evaluated primarily on the basis of "investment" criteria? Is the "worth" of an individual his productive contribution? Is the measurement technique representative of our social values? If not, how can other values -- for example, equity and distributional considerations -- be built in? The technique, after all, says that A is worth more than B because he would earn more than B. But while this may be true under certain conditions, dare we adopt policies that are based on such considerations? The state exists to serve man -- not man to serve the state. It is true that the use of average income figures does avoid some of the problems -- we do not say that we should help rich white children who are likely to earn higher incomes rather than help poor Negro children. But the philosophic issues do exist. Are men worth more than women, are whites worth more than Negroes? Is the discounting procedure that says 5-year-olds are worth more than one-year-olds appropriate? (Fein, 1967a, p. 49).

> Another problem is that translation of benefits into dollars puts a higher value on one age group than on another...The concern is whether one age group should be "saved" before another solely because of its greater productivity. The choice between such programs seems cold and calculating if based on an economic value placed on human life,... (Rice, 1969, p. 99.)

One approach to accounting for some of these non-monetary benefits of health programs is by using the "consumption benefit" concept. The consumption benefit is defined as the "intangible or psychic costs of disease, such as pain and grief (Rice, 1966, p. 15)". It can also be viewed as the amount of money people would pay to avoid the disease in cases where there are no monetary consequences to getting the disease. The existence of a positive consumption benefit is illustrated by health programs to help retired people, people permanently unemployable from

chronic disabilities, and people suffering from terminal diseases.

The only published research which could be discovered in which the consumption benefit was actually measured was that by the health economist, Herbert Klarman. He has used the analagous disease approach in which he identifies a disease with similar pain and discomfort but with no possible economic benefit; and then the money spent on this case is clearly consumption spending, and can be used as an estimate of the consumption benefit for the disease under study. The problem with this method is illustrated when Klarman suggests that an analagous disease for the late complications of syphilis is terminal cancer upon which we spend an average of $2,000 per case, and this then is the consumption benefit for both terminal cancer and late syphilis (Klarman, 1965b). This suggests that a retired person or a person with a guaranteed income, for example, from investments, would only be willing to spend up to $2,000 to avoid terminal cancer. If the price were $2,001, he would choose terminal cancer rather than pay it. This appears unreasonable. It would seem that in this case, the analagous disease method does not measure the consumption benefit at all, but merely measures the amount of services we decide (or are able) to supply before the patient dies. In fact, this can really be viewed as only a lower bound on the consumption benefit.

For the early stages of syphilis Klarman uses, as the analagous disease, psoriasis which has an average expenditure of $50 per episode. Once again, the implication is that a person would only spend up to $50 to avoid early syphilis. While this may be more reasonable it still seems somewhat questionable.

An alternative approach to measuring the consumption benefit would be to use utility measuring techniques like those employed in this research but applied to the consumption benefit. This would have the advantage of measuring the item of interest directly rather than merely establishing a lower bound indirectly (by analogy) but, on the other hand, this approach would have all the difficulties inherent in any subjective measurement technique. It is suggested that this would be a worthwhile research undertaking for another project.

Measuring the costs

There is substantial consistency among Health Economists concerning the measurement of costs for health programs.[1] Market prices are used as the measure of cost,

[1]For example see Mushkin, 1962; Klarman, 1965a, 1965b, 1965c and 1966; Rice, 1966 and 1967a; Fuchs, 1966 and Robertson, 1967.

where available, and they need not be adjusted for general price level changes.[1] A health program incurs program costs and reduces illness costs.

Program costs are the costs of establishing and operating the health program. They will be incurred as long as the program exists but, of course, no longer.

Illness costs are the costs of ill health. There are two types: direct costs and indirect costs. The direct costs of illness are the costs of the required health care. A health program which improves the health of the people will cause a reduction in direct costs since fewer people will be ill. Furthermore, this reduction will often continue long after the program costs have been stopped.[2]

Indirect costs of illness are "the loss of output to the economy" (Rice, 1966, p. 13). They are calculated using the following assumptions:

1. The indirect cost is the lost future earnings of those individuals who would have worked had they not been ill or prematurely dead.
2. It is assumed that cured patients would participate in the labor force at the same rate as well people of

---

[1] See p. 6 above or Prest and Turvey, 1965, p. 691.

[2] The tuberculosis screening program analyzed in this project provides a good example of this phenomenon.

the same age and sex would participate if there were full employment.

3. Housewives are assumed to earn the same as domestic workers.

Applications

Cost-benefit analysis is a widely discussed technique for evaluating health programs. Despite this, there is a shortage of thoroughly-documented applications in the literature. (On the other hand, there is certainly no shortage of sweeping articles discussing the general cost-benefit technique as applied to health programs.)

The published applications include a study on the economics of mental illness (Fein, 1958) and determinations of the economic benefits which would accrue to society through the elimination of a number of specific diseases -- cancer, tuberculosis and poliomyelitis (Weisbrod, 1961); syphilis (Klarman, 1965b) and heart disease (Klarman, 1965c).

Cost-Effectiveness Approach

Edward S. Quade, of the RAND Corporation, a prominent writer on cost-effectiveness, defines the technique as follows:

> Broadly defined (perhaps too broadly), it is any analytic study designed to assist a decision-maker in identifying a preferred choice among possible alternatives (1967, p. 1).

Unfortunately, this definition is also suitable for cost-benefit analysis, systems analysis, operations analysis, and operations research. What then is the distinctive characteristic, if any, of cost-effectiveness analysis? The answer is provided by William A. Niskanen (1967, p. 18) who differentiates the following three techniques according to the units used to measure the inputs (costs) and outputs (benefits).

Technique	Inputs	Outputs
Classical operations analysis	units	units
Cost-effectiveness analysis	dollars	units
Cost-benefit analysis	dollars	dollars

Here, units refer to problem-specific measures. For example, in operations analysis the inputs might be measured in nursing-hours and the outputs in patients processed. Generally, in cost-effectiveness analysis, the output units are related to outcomes or end-results: lives saved, life-years added, disability-days prevented. Cost-benefit analysis

is differentiated from cost-effectiveness analysis through the use of dollars to measure the output.

One common misconception which should be clarified at this point concerns whether cost-effectiveness analysis is a narrower or a broader approach than cost-benefit analysis. Sometimes cost-effectiveness is defined extremely broadly, for example:

> ...a systematic approach to helping a decision-maker choose a course of action by investigating his full problem, searching out objectives and alternatives, and comparing them in the light of their consequences, using an appropriate framework -- insofar as possible analytic -- to bring expert judgment and intuition to bear on the problem (Quade and Boucher, 1968, p. 2),

and other times it is described as a narrow technique:

> Cost/benefit studies are designed to measure all costs and all benefits...The identification of all costs and all benefits appeared so overwhelming that our initial efforts have emphasized the narrower approach; i.e., cost/effectiveness analysis (Kissick, 1969, p. 39).

The truth of the matter is that neither technique is inherently narrow or broad. Both can and have been applied to very broad problems: for example, multiple benefits are handled in cost-benefit analysis by converting them all to dollars and summing, and in cost-effectiveness analysis by using an effectiveness vector with an appropriate decision criterion. And, of course, both techniques can and have been applied very narrowly.

Generally, cost-effectiveness analysis has been applied to health matters in situations where the program

inputs can be readily measured in dollars (the cost) but the program outputs are more appropriately stated in terms of the health improvement created (the effectiveness); for example, cases discovered, lives saved, life-years gained, disability-days reduced. Three typical cost-effectiveness analyses of health programs are summarized below.

1. A cost-effectiveness application to chronic kidney disease was published by Gottschalk as part of a study committee report in 1967, and by Klarman, Francis and Rosenthal as a journal article in 1968. Two alternatives were being compared for the treatment of chronic kidney disease: dialysis (assuming 50 per cent at home and 50 per cent at a kidney centre) and transplantation (assuming that transplantation failures would revert to dialysis). The cost was the dialysis or transplantation cost converted to its present value at a six per cent annual discount rate. The output was measured in quality-adjusted life-years gained, where a life-year gained by transplantation was considered to be 25 per cent better than a life-year gained on dialysis. This reflected the superior quality of life which the transplant patient was felt to enjoy relative to the dialysis patient. The alternative with the minimum cost per life-year gained was selected as best. Note that this is the same as the alternative with the maximum effectiveness-cost ratio.

2. In 1968, McCaffree published a cost-effectiveness study in mental health. Three different methods of treating mentally ill patients were compared. The cost of each method was determined as the cost of the health care (direct costs) plus the value of the earnings lost due to the mental illness (indirect costs). The effectiveness of each method was measured as disability-days saved, where a disability-day was any day of substandard or stopped performance.
3. In 1969, Leslie Lipworth reported a cost-effectiveness study to compare two hypothetical national screening programs for bacteriuria. The health care costs (direct costs) only, were used as the cost of each program. The number of lives saved was used as the measure of a program's effectiveness.

Linear Programming Approach

Linear programming is a mathematical technique for optimally allocating scarce resources (dollars, physician time, hospital beds, etc.) to competing ends (alternative health services and programs) when the problem can be approximated by linear relationships. Recently there have been a number of applications of this technique in the health field and these will be reviewed below.

Linear programming is not, however, an alternative technique to cost-benefit or cost-effectiveness analysis.

In reality it is just a particular modelling and calculation method applied within the framework of either cost-benefit or cost-effectiveness analysis. This will be more clearly displayed through the examples below.

An extensive linear programming model for tuberculosis control was published by Piot and Sundaresan of the World Health Organization in 1967. The study developed a complex epidemiological model of the disease; defined possible approaches for control of the disease; designed a systems model which would predict the health impact, costs and resources connected with each possible alternative solution to the problem; and programmed the whole analysis for computer solution. The model used the following objective function:

Maximize Z = PV (present value) of health benefits + PV of economic benefits, where:

PV of health benefits = the present value (at 4%) of healthy life-years added, where all healthy-years-added are considered equal whether they come from the elimination of a temporary disability or a premature death. That is, this optimization process considered it equally "good" to eliminate a year of temporary disability or to eliminate a year of premature death.

PV of economic benefits = the present value (at 4%) of the increased earnings due to the program.

This economic benefit is the indirect cost reduction explained earlier. However, the direct cost reduction (reduced sanitoria costs, drug costs, etc.), which is also a legitimate economic benefit, was disregarded in this study. Then, in order to add dollars to economic benefit to years of health benefit, the economic benefit was converted to years by dividing by the minimum annual subsistence wage.

This is essentially a cost-benefit format with the conflicting objectives (cost and health) converted to a common unit of years, so they can be added, rather than the conventional unit of dollars. However, the identical results could have been obtained in the conventional cost-benefit manner by converting the health benefits to dollars by multiplying by the subsistence wage.

A second linear programming approach to tuberculosis control was published in 1967 and again in 1969 by ReVelle, Lynn and Feldman. Again, the greater part of the study is spent developing a sophisticated epidemiological model and casting the problem into a linear programming format. In this study, the objective function is established to minimize costs with a desired health objective (20 year active case reduction) as a constraint. This is basically a cost-effectiveness model: the problem is to determine the minimum method of achieving a specified health objective.

At the 1969 Fall Meeting of the Operations Research Society of America, Naddor, Shuman and Young presented a linear programming planning model for regional health services. Like the last example cited, this is also basically a cost-effectiveness format. The objective is to minimize the total cost to society (both the direct and indirect costs) subject to a constraint on the level of health provided.

In summary, then, linear programming is a useful model for either cost-benefit or cost-effectiveness analyses when the number of alternatives is large and, of course, when a linear model of the system can be developed.

Planning-Programming-Budgeting Systems

On August 25, 1965 at a meeting of the Cabinet, the President of the United States, Lyndon B. Johnson, announced that the Planning-Programming-Budgeting System (PPBS), which had until then been restricted to the Department of Defense, would be extended on a government-wide basis. As might be expected, this created a flurry of interest in PPBS and articles began to appear explaining the technique and how it could be applied to the health service field.

First, what is PPBS? A typical definition is provided by Hatry:

> PPB systems are aimed at helping management make better decisions on the allocation of resources among alternative ways to attain government objectives. Its essence is the development and presentation of relevant information as to the full implications -- the costs and benefits -- of the major alternative courses of action (1967, p. 1).

From this definition one could obtain the impression that PPBS is an additional way to analyze alternative health programs and set priorities, and that this new technique would compete with cost-benefit and cost-effectiveness analyses. In fact, it turns out that PPBS doesn't compete at all, but complements the other techniques. PPBS establishes the administrative framework such that all health activities must be assigned to individual health programs; all health programs must have clearly defined objectives (benefits), and all such benefits must be justified in relation to their costs. This justification is performed by either cost-benefit or cost-effectiveness analyses.

Thus the implementation of PPBS into the federal health field has provided an additional incentive for the use of cost-benefit and cost-effectiveness analyses.

Objectives of the Health Service System

All the techniques and studies discussed so far are analytic methods to assist a decision-maker in selecting the alternative which best meets his objectives. Hence, the following question plays a central role in these techniques: what are the appropriate objectives in the health service system?

The importance of this question was highlighted by the Surgeon General of the United States Public Health Service, Dr. William H. Stewart, at the Fifty-Sixth Ross Conference on Pediatric Research, where he stated:

> However, having declared our firm intent to use our resources more effectively, we still have an unanswered question. It is a very important question -- using them effectively for what? Until we have answered that question there is no way in the world to assess the effectiveness of child health services or anything else (1967, p. 9).

Dr. Kerr White of Johns Hopkins University agrees completely. At the same conference, he expressed the view that "the central problem in evaluating the effectiveness of personal health services, both for adults and for children is the definition of the objectives" (1967a, p. 24).

What is the objective of the health service system?

1. Dr. Stewart says it is "health improvement" (1967, p. 10).
2. Dr. Robert Kohn: "the objective of the entire health services complex is the health of the people" (1966b, p. 13).

3. A year later, Kohn gave a similar definition: "the purpose of health services is to preserve and improve the health of the people or to minimize consequences of ill-health" (1967, p. 4).
4. Rashi Fein: "the end product is the health of the population" (1967b, p. 90).
5. Dr. W.L. Kissick: "The ultimate goal in the United States is the realization of the highest level of health attainable for every person" (1969, p. 39).

The consensus is clear that the objective of the health service system is to improve the health of the people, or more precisely, to allocate that portion of society's scarce resources which society is willing to devote to health services, in a manner which will maximize the health of the people. But this raises the issue: what is health? A widely-used definition is the one in the Charter of the World Health Organization:

> Health is a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity (cited in Kohn, 1966b, p. 2).

A similar definition is provided by a Work Party of the Technical Development Board under the chairmanship of Dr. Samuel M. Wishik:

> [Positive health is] a full sense of physical vigour and mental well-being and maintaining a constructive and wholesome relation with others in a safe and pleasant environment that promises longevity and happiness (Kandle, 1961, p. 288).

So now we come to the difficult part. We have agreement that the objective is improved health, and reasonable agreement on what health is, but before we can go further, we must be able to measure health. The various approaches to this problem are reviewed in the next section.

Health Index Approach

The importance of developing a health index or measure of health is highlighted regularly in the literature. For example, the report of the World Health Organization study group on the Measurement of Levels of Health states:

> No more fundamental problem confronts the health administrator than the measurement of the level of health of his community; and nothing could be more valuable than to have at his command one or more measuring rods to help him in his task and also in assessing his specific problems relating to the health of the people, in designing his plans to deal with these, in guiding his administration and in evaluating his schemes (World Health Organization, 1957, p. 5).

A number of other writers have made similar statements:

> In promoting and assuring "the highest level of health attainable", we must have some index of health against which to measure our success (Kissick, 1967, p. 210).

> Until we discover a universal unit for quantifying the value of health, ways to measure benefits will continue to hamper comparisons among alternate health programs (Smith, 1968, p. 900).

Traditionally, the health of populations has been measured by mortality data and its many variations. For

example, in 1953, the United Nations convened a Committee of Experts to discuss the subject of "International Definition and Measurement of Standards and Levels of Living". In its report in 1954, this Committee listed twelve components which should be measured to reflect the level of living. The first component "Health, Including Demographic Conditions" was then investigated by a Study Group of the World Health Organization. They reported in 1957 with the following conclusions (World Health Organization, 1957):

a) Measuring the level of health in a community is extremely important.

b) There is no general comprehensive health indicator which can be recommended, but the following three mortality-based measures are available:

   i) Proportional mortality of 50 years and above. This is the number of deaths of age 50 and above as a percentage of the total deaths. This measure indicates the relative contribution of chronic diseases to total mortality.

   ii) Life expectancy at various ages; for example, at birth, at one year, et cetera. This is useful for displaying the impact of health problems that are highly age-specific; such as perinatal, infectious, and childbearing mortality.

   iii) Crude death rate. This is usually reserved for primitive countries where good demographic informa-

tion is not obtainable.

c) A measure for positive health is badly needed but, "in the light of available statistical information, only deviations from health are susceptible to measurement" (p. 15).

The problems with mortality-based indexes like those suggested above by the World Health Organization are discussed by Sullivan:

> Recently, however, crude and age-adjusted death rates for the U.S. population have shown little change after a long period of decline over the years 1900-1954...Stability of the death rate would not imply no change in health status. It would merely emphasize a difficulty inherent in the use of mortality statistics as measures of health status. They tell little about the living, while the health of the living has become a very important aspect of health status (1966, p. 1).

This problem has led recent researchers to investigate additional more sensitive measures of health. For example, Dr. W.H. Stewart (1967) lists the three basic measures of health improvement as:

1. Reduced mortality,
2. Reduced morbidity -- including illnesses and disabilities, and
3. Improved development and release of the human potential.

Dr. Kerr White says, "The measurements that count are such factors as Death, Disease, Disability, Discomfort and Dissatisfaction" (1967b, p. 851). These five factors have become known as the 5 D's for measuring the end-results of health care.

Sanazaro and Williamson (1968) published a

classification scheme for end results of patient care based on reports by internists. This scheme consists of the following twelve categories:

1. longevity
2. physical abnormalities
3. phychological abnormalities
4. physical symptoms
5. psychological symptoms
6. function
7. attitudes toward physician and care received
8. attitudes toward understanding of condition responsible for episode of care
9. compliance
10. risks and unnecessary procedures
11. hospitalization
12. cost

This is similar to White's classification, only a little more detailed.

The end-result oriented schemes outlined above produce a multi-dimensional measure of health: health is measured simultaneously on a number of incommensurable scales. Other researchers have attempted to develop a single overall scale for health.

A basis for such a composite health index was first outlined in 1964 in a paper by B.S. Sanders. He suggested the use of a "functional adequacy" concept: "functional adequacy of an individual to fulfill the role which a healthy member of his age and sex is expected to fulfill in his society" (Sanders, 1964, p. 1067). Sanders suggested a modified life table which would start with 100,000 conceptions and would determine the "productive man-years" or "effective life-years" resulting from this cohort of

conceptions. Then the community with the higher number of productive man-years per 100,000 conceptions would be considered to have more adequate health care. The problem with Sanders' method, of course, is how to measure "functional adequacy".

Chiang's proposed index (Chiang, 1965) simplifies the measurement problems immensely, but unfortunately, it does so at the expense of the usefulness of the index. In Chiang's proposal, measurement consists only of recognizing two different states: healthy and unhealthy. Dead is included in unhealthy. Then, the index of health for any specific year is the average fraction of the year people are healthy; or phrased another way, it is the number of healthy man-days per year divided by the potential total man-days per year. Chiang shows how it is then a simple matter to rearrange the data to calculate the index for any age group, an overall crude index, or an overall age-adjusted index. Despite the mathematical sophistication with which Chiang develops his proposal, it has a very serious conceptual shortcoming: a day of unhealthiness from any cause affects the index identically. Thus, to take two extremes, a day of a common cold would be considered equal to a day of premature death. Chiang could have overcome this problem by introducing Sanders' concept of functional adequacy whereby each unhealthy day would be

weighted according to its seriousness on the yet-to-be-developed functional adequacy scale, and the weighted per cent unhealthiness in a year would become the index.

In 1966, Sullivan produced a survey paper on health indexes which has become widely cited. He reviewed the three ways that morbidity can be measured: (1) clinical evidence, (2) subjective evidence (an individual's opinion of his health status), and (3) behavioral evidence (days of restricted activity, insitutional confinement, et cetera; and concluded that behavioral evidence is the most appropriate for an index of health. He then proposed the following four mutually exclusive states as a system for measuring disability based on behavioral evidence: (i) confined - confined to a resident institution, (ii) limited mobility - serious continuing limitation of mobility, (iii) limited activity - serious continuing activity limitation, and (iv) restricted activity - restricted activity for that day (p. 12).

The morbidity index, according to Sullivan, would be the total number of disability-days for the population under question. He suggests that mortality data might also be converted into disability-days and included so that the result would become a combined mortality-morbidity index of health. Again his suggestion suffers from the same problem as Chiang's. That is, all types of disability, from a

minor illness to premature death, are considered equal in the index. And again, the solution appears to be to introduce Sanders' concept of functional adequacy, and to thereby weight the disabilities according to their seriousness.

Essentially this is the approach proposed by Packer in a recent paper (Packer, 1968). He suggests adding two more disability levels to Sullivan's four; "an initial state (controlled disease - minor disability) and a terminal state (premature death)" (p. 240) and then weighting each of these six disability levels with the patient's individual weighting factors. Then, the system's effectiveness would be given by

$$I^P = \sum_{i=1}^{m} c_i t_i \text{ , where}$$

m = the number of disability states

c_i = the weighting factor for disability state i, and

t_i = the duration of stay in state i (p. 239)

As Packer points out, the nub of the problem is obtaining the c_i's.

> Certainly the values imputed to each c_i may not only vary among individuals at any point in time, but also vary for a single individual among different points in time (p. 240).

Although Packer developed this reasonably sophisticated outcome-oriented measure of effectiveness for health services, he unfortunately did not follow-through in his applications. The research group, of which he was a member, developed a computer simulation model of a Comprehensive Maternal and Infant Health Care project as their pilot demonstration. In this application, they used the following rather traditional four-point measure of effectiveness:

i) Clinic attendance ratio,

ii) Personnel utilization ratio,

iii) Infant abnormality ratio, and

iv) Infant illness ratio (Kennedy, 1969, p. 6).

More recently, Modi, from the same research organization, proposed a measure of effectiveness similar to Packer's in a paper on the cost-effectiveness of various artificial kidney systems (Modi, 1969). His proposal differs from Packer's in two respects:

i) The disability states are clinically oriented (hypertension, hepatitis, fever, etc.) rather than behaviorally oriented (limited activity, mobility, etc.).

ii) The seriousness weights are supplied by the examining physician rather than by the patient and only three weights are available: barely detectable, mild, and disabling.

Thus, a health professional is required to implement this scale. It should also be noted that Modi's model, like Packer's, has not yet been tested in practice.

A simple health index for morbidity only was reported recently from the University of California (Kisch, et. al., 1969). It consists of a short questionnaire which can be administered to an individual in two minutes to determine his health status. The result is a number which is interpreted as follows:
0-20 represents good health (0 is perfect health),
21-60 represents medium health, and over 60 represents poor health. The technique has validated well when the same individuals have been categorized into good, medium and poor health by an examining physician.

A combined morbidity-mortality index which is currently being used to assist health administrators in making program decisions was developed by the Indian Health Service of the U.S. Department of Health, Education and Welfare and reported at the April 1970 Operations Research Society of America meeting in Washington, D.C. (Miller, 1970a). It consists of three equations, one each for preventive, control and curative health programs. The equa-

tion for preventive programs is given below as an example:

$$P = dl + \left(\frac{a}{365} + \frac{b}{1095} + \frac{c}{3650}\right) \frac{10^5}{N}$$

where,

P = program performance index (to be minimized),
d = death rate per 100,000 per year for the specific population at risk,
l = average years of life lost due to premature death,
a = number of hospital days per year,
b = number of outpatient visits per year,
c = prevalence of the disease in the population at risk, and
N = total population.

This equation is essentially an undiscounted weighted disability-days concept, similar to that proposed by Packer, with the following implicit weights:

Disability Day	Weight
A day of premature death	1.00
A day of hospitalization	1.00
A day involving an outpatient visit	0.33
A day of disease	0.10
A healthy day	0.00

According to Miller (1970b), these weights were selected as an attempt to approximate the fraction of the day which is lost by a patient due to the disease. The time may be lost either directly from the effects of disease itself, or from time spent in obtaining preventive treatment.

A health index research project is currently underway at New York University under the direction of Dr. J.W. Bush and funded by the U.S. Center for Health Services Research and Development. The project will use subjective

value measuring techniques similar to those used in this research to determine the utilities for the following eleven-point health scale:

1. Well being
2. Dissatisfaction
3. Discomfort
4. Disability-minor
5. Disability-major
6. Disabled
7. Confined-isolated
8. Confined-bedridden
9. Confined-special
10. Coma
11. Dead

The utilities can then be used as disability-day weights to create a combined morbidity-mortality index of health.

Summary of Existing Approaches

The fundamental problem addressed by this research is one of evaluating and comparing health programs to determine their relative merit, so that the limited resources available may be optimally allocated to the feasible alternatives.

Two basic approaches have been applied to this problem. Cost-benefit analysis is a thorough and well-documented technique for measuring the economic consequences of a program. However, at its present stage of development, it is not well suited for incorporating the health benefits into the formal analysis (since they must be converted to monetary units). Researchers are working on this problem,

and if the measurement difficulties can be overcome, the consumption benefit approach may prove to be a viable solution. Cost-effectiveness analysis, on the other hand, avoids this problem by not attempting to convert the health improvement to monetary terms. However, this results in health benefits measured in program-specific units, thus excluding any inter-program comparisons.

Linear programming and PPBS complement rather than compete with the two basic approaches outlined above. Linear programming is a sophisticated modelling and optimization technique which is useful if the number of alternatives is large and a linear model of the problem can be developed. PPBS is an administrative technique which encourages the formal evaluation of programs by either cost-benefit or cost-effectiveness analysis.

The optimal allocation of resources implies a solution which maximizes the objectives of the system. The objective of the health service system is to maintain and improve the health of the people. This is measured by means of a health scale or health index. Traditional mortality-based indexes are no longer sufficiently sensitive. A new combined morbidity-mortality index is required but has not yet been developed.

CHAPTER II

THE PROPOSED MODEL

Introduction to the Model

The basic problem being addressed by this research is the selection, within specified constraints, of the optimal sub-set of health service programs from a set of feasible programs. The existing approaches to this problem were reviewed in the last chapter and found inadequate. A new approach is required and one is proposed in this chapter. It employs a generalized cost-effectiveness model which combines the better features of a number of the existing approaches.

Operations research methodology

The proposed approach was developed by attacking the basic problem with the standard Operations Research methodology as laid down primarily by Russell L. Ackoff.[1] This methodology consists of the following steps:

---

[1] See for example Ackoff, Gupta and Minas, 1962 or Ackoff and Sasieni, 1968.

Step 1: Formulate the problem.

(a) Define the system under study.

(b) Define the decision-makers.

(c) Define the relevant objectives of the decision-makers.

(d) Define the alternatives.

(e) Develop methods to measure the degrees to which the different alternatives attain the relevant objectives.

Step 2: Construct a model $U = f(X,Y)$ and specify the constraints. Here U is utility, X are controllable variables and Y are uncontrollable variables.

Step 3: Solve the model. This really means to specify the values of the controllable variables (X) which will maximize the utility (U).

Step 4: Test the model.

Step 5: Implement the solution.

The research reported here consists of the application of Steps 1 to 4 to the basic problem. Step 5 is omitted since the purpose of this work is not to develop a solution to a specific health program selection problem but to propose a general model which would be applicable to all such problems. Hopefully, the model will be acceptable to the decision makers and implemented by them, thus completing the final step.

Step 1: Formulate the problem.

(a) Define the system under study.

(b) Define the decision-makers.

(c) Define the relevant objectives of the decision-makers.

(d) Define the alternatives.

(e) Develop methods to measure the degrees to which the different alternatives attain the relevant objectives.

Step 2: Construct a model $U = f(X,Y)$ and specify the constraints. Here U is utility, X are controllable variables and Y are uncontrollable variables.

Step 3: Solve the model. This really means to specify the values of the controllable variables (X) which will maximize the utility (U).

Step 4: Test the model.

Step 5: Implement the solution.

The research reported here consists of the application of Steps 1 to 4 to the basic problem. Step 5 is omitted since the purpose of this work is not to develop a solution to a specific health program selection problem but to propose a general model which would be applicable to all such problems. Hopefully, the model will be acceptable to the decision makers and implemented by them, thus completing the final step.

Step 1 (problem formulation) was applied as follows:

(a) The system under study is the health service system. This includes all activities directed primarily at the maintenance and improvement of the health of the people. It embraces not only such obvious components as doctors, nurses, hospitals and ambulances but also activities such as environmental control programs, industrial accident prevention programs and traffic safety programs. Although none of the latter are included in the examples in this research, their structure is similar to that of the more conventional health programs and the proposed model is applicable to them as well.[1]

(b) The decision-makers are those people in the health service system who determine which programs shall be implemented, which shall not, and what level of support shall be provided to implemented programs.

(c) It is assumed that the objective of the decision-makers is to manage the health service system in such a way as

---

[1] For a discussion of programs to control the hazards of technology, with particular emphasis on industrial accident prevention, see Sinclair (1969). This article points out the similarity of these programs to conventional public health programs. In a subsequent private communication, Dr. Sinclair agreed that the model proposed in this research could be usefully applied to his hazard control programs (Sinclair, 1970).

to maximize the attainment of the system's objectives. The latter has previously been defined as: the allocation of that portion of society's scarce resources which society is willing to devote to health in a manner which will maximize the health of the people.[1]

However, the model does allow the decision-maker to use other objectives if he so desires. For example, he may wish to allocate the specific limited resources under his direct control in order to maximize the health improvement produced.

(d) The alternatives are the various health programs and the different levels of support which can be provided to each. The total set of alternatives available to the decision-maker consists of all possible combinations of programs and levels of support which are feasible within the constraints of the system.

(e) In order to measure the degree to which different programs achieve the system's objectives, it is necessary to measure the resources consumed by a program and the health improvement created by it. The former is no problem, but the latter requires the development of a new scale for measuring health. Such a scale is proposed and tested in this research.

---

[1] See p. 24 above.

Steps 2 and 3, model construction and solution, are handled in two ways. First, a cost-effectiveness ranking algorithm is developed which should handle the vast majority of problems, at least in the near-term future. Then, to handle the more elaborate problems beyond the power of this technique, an optimization model is developed based on a 0-1 integer linear programming algorithm.

Step 4, model testing, is achieved by implementing the models on real data obtained from the following four health programs: mass screening for tuberculosis, mass screening for the prevention of hemolytic disease of the newborn, a kidney dialysis and transplantation program, and a coronary emergency rescue service.

The basic model

The objective of the health service system has been previously stated as the improvement or the maximization of the health of the people.[1] Hence, the model must allocate the limited resources to the alternative programs in a manner which will maximize the health improvement obtained. This demands the ability to measure both the resources required by the program and the health improvement created by it.

---

[1]See p. 23 above for a more detailed treatment of the objectives of the system.

The determination of the resources consumed by a program is a straight-forward measurement task (or estimation task for a proposed program). In addition to consuming resources most health programs also create resources. These must also be measured, so the net resource requirement of the program to society may be determined. The theory and methods of cost-benefit analysis[1] are used for this calculation.

The determination of the health improvement created by a program is considerably more difficult. In many cases, objective data is not available.[2] Even if suitable data can be obtained, there is a further problem of converting it into a universal unit of health improvement. The latter problem is solved by the development of a health scale or health index which measures the utility assigned to various health states by society. Thus, the model will allocate society's limited resources in a manner which will maximize the health utility achieved for society.

It should be noted that the resulting model is essentially a cost-effectiveness model, except that, in the

---

[1]That is, the "productive resources" version of the cost-benefit approach. See p. 8 above.

[2]For example, see Sackett (1970).

past, such models have measured the output or effectiveness in program-specific units (patients cured, cases prevented, life-years added), which prevented inter-program comparisons. In this research, the traditional cost-effectiveness approach has been considerably generalized by integrating it with the new health scale. The result is a generalized cost-effectiveness model which can be applied to a wide variety of health programs (perhaps all) no matter how different.

In summary, the proposed approach is a generalized cost-effectiveness model with the following characteristics:

1. Cost. -- The total resources both used and created by a program are converted to dollars, discounted to their equivalent present values, and summed to give the total cost of the program to society.
2. Effectiveness. -- The effectiveness of a program is the health improvement (health benefit) created by the program as measured by the increase in units of health for the population. Future benefits, like costs, are also discounted to their equivalent present value.
3. Constraints. -- In the normal approach there would generally be only a single resource constraint -- the total amount of resources, as expressed in dollars, which society is willing to allocate to health problems. There could, however, be other constraints representing

mutually-exclusive relationships among programs.

Variations from the single total resource constraint are possible in the following circumstances:

(a) Where the resource constraint must be expressed as a function of time: for example, if different amounts are available in different years.

(b) Where the various types of resources (physician time, hospital beds, money, etc.) are not interchangeable and it is necessary to express a constraint on each one.

(c) Where the decision maker wishes to add a constraint to the cost for some segment of society: for example, the total cost to the provincial government.

4. Criterion. -- The criterion is to maximize the health improvement produced, as measured by the health utility scale, without violating the constraints.

5. Algorithms. -- Two solution algorithms are provided, one for the case with a single total resource constraint and the other for more complicated variations. The first is a cost-effectiveness ranking technique; the other, a 0-1 integer linear programming algorithm.

6. Intangible Benefits. -- The intangible benefits of a health program will be handled outside the formal mathematical model. For example, benefits such as patient satisfaction, staff satisfaction, public image and political benefits will be listed for inclusion by the decision maker in his final deliberations.

Introduction to the health scale

It is proposed in this research to develop a universal health utility scale and a measuring technique which will be applicable to a wide variety of possible health conditions.

Health is not an easy item to measure. The World Health Organization has defined health as "a state of complete physical, mental and social well-being and not merely the absense of disease and infirmity."[1] By this definition, health is a three dimensional quantity consisting of physical, emotional and social components. Each dimension has a large range of possible states, varying from perfect health to complete non-functioning. The health of an individual can be considered as a point in three-dimensional space, with the axes being, respectively, physical health, emotional health and social health. Most points in this three dimensional space are feasible -- people may be acutely ill on one of the three scales and yet quite healthy on the other two.

Health can be measured a number of ways depending upon the purpose. A physician treating a patient measures health on a clinical scale which includes observations of

---

[1]Cited in Kohn, 1967, p. 2.

signs and symptoms, laboratory test results, and tissue pathology. Most health surveys measure health on a behavioral scale embracing such indicators as absenteeism, bed-disability, institutional confinement, and premature death. Health is sometimes measured on an opinion scale where the individual verbalizes his health status. In this research health will be measured on a utility or value scale.

A health utility scale is one which measures the subjective utility (value, worth)[1] of any possible state of health. The scale may measure the utility for a particular individual or for society as a whole. This research develops and tests a technique for obtaining individual utility scales and aggregating these into a society scale.

The scale value (health index) for a particular health state is the utility of that state as perceived by society. A health state is a particular combination of physical, emotional and social health. This is an important concept. Two patients with the identical physical ailments may have vastly different emotional and social health, and thus, by the definitions used here, they would be in different health states with (probably) different utilities.

---

[1]Adams defines utility as follows: "The utility of an alternative may be roughly characterized as a measure of the strength of an individual's preference for it" (1960, p. 159).

signs and symptoms, laboratory test results, and tissue pathology. Most health surveys measure health on a behavioral scale embracing such indicators as absenteeism, bed-disability, institutional confinement, and premature death. Health is sometimes measured on an opinion scale where the individual verbalizes his health status. In this research health will be measured on a utility or value scale.

A health utility scale is one which measures the subjective utility (value, worth)[1] of any possible state of health. The scale may measure the utility for a particular individual or for society as a whole. This research develops and tests a technique for obtaining individual utility scales and aggregating these into a society scale.

The scale value (health index) for a particular health state is the utility of that state as perceived by society. A health state is a particular combination of physical, emotional and social health. This is an important concept. Two patients with the identical physical ailments may have vastly different emotional and social health, and thus, by the definitions used here, they would be in different health states with (probably) different utilities.

---

[1]Adams defines utility as follows: "The utility of an alternative may be roughly characterized as a measure of the strength of an individual's preference for it" (1960, p. 159).

A utility scale was selected as the appropriate measure of health for this research, since this will result in the allocation of resources in a manner which will maximize the utility achieved by society. This is merely a formal way of saying that this approach will spend society's money on those things that society considers important.

The utility of a health state is measured with techniques that produce a linear interval scale. Such a scale can have the values for any two points arbitrarily assigned. The point corresponding to the healthy state is assigned a value of one, and the point corresponding to death, a value of zero. The health utility scale is thus a linear interval scale which includes all possible health states and has a value of one for healthy and zero for death.

Discount rate

The proposed model provides for the discounting of future costs and future health benefits at their respective discount rates. In reality, though, the model is completely general. If discounting is considered inappropriate for some or all of the costs or health benefits it is easily omitted by setting the particular discount rates equal to zero. However, it is argued below that the proper discount rate for both costs and health benefits is somewhat greater than zero.

A utility scale was selected as the appropriate measure of health for this research, since this will result in the allocation of resources in a manner which will maximize the utility achieved by society. This is merely a formal way of saying that this approach will spend society's money on those things that society considers important.

The utility of a health state is measured with techniques that produce a linear interval scale. Such a scale can have the values for any two points arbitrarily assigned. The point corresponding to the healthy state is assigned a value of one, and the point corresponding to death, a value of zero. The health utility scale is thus a linear interval scale which includes all possible health states and has a value of one for healthy and zero for death.

Discount rate

The proposed model provides for the discounting of future costs and future health benefits at their respective discount rates. In reality, though, the model is completely general. If discounting is considered inappropriate for some or all of the costs or health benefits it is easily omitted by setting the particular discount rates equal to zero. However, it is argued below that the proper discount rate for both costs and health benefits is somewhat greater than zero.

On the cost side, there is little question about this. It is generally agreed that future costs should be discounted at an appropriate interest rate to reflect the risks and uncertainties of the future. The classical unresolved question is: what is this appropriate discount rate? A great variety of rates have been used in the past. Table 1 contains a sample of such rates which have been used in health program studies.

Theoretical support can be found in the literature for practically any figure at all between the pure time preference (riskless) rate, as low as 4% but currently closer to 8%, and the corporate return on capital, currently in the neighbourhood of 20%.[1] However, the more recent writers are definitely favoring the higher end of this spectrum (Baumol, 1968; Schwartz, 1970). The heart of their argument is summarized by Baumol as follows:

---

[1]For a selection of some of these arguments, see Feldstein, 1964; Prest and Turvey, 1965; Harberger, 1965; Feldstein, 1965; Baumol, 1968; Arrow, 1969; and Schwartz, 1970.

On the cost side, there is little question about this. It is generally agreed that future costs should be discounted at an appropriate interest rate to reflect the risks and uncertainties of the future. The classical unresolved question is: what is this appropriate discount rate? A great variety of rates have been used in the past. Table 1 contains a sample of such rates which have been used in health program studies.

Theoretical support can be found in the literature for practically any figure at all between the pure time preference (riskless) rate, as low as 4% but currently closer to 8%, and the corporate return on capital, currently in the neighbourhood of 20%.[1] However, the more recent writers are definitely favoring the higher end of this spectrum (Baumol, 1968; Schwartz, 1970). The heart of their argument is summarized by Baumol as follows:

---

[1]For a selection of some of these arguments, see Feldstein, 1964; Prest and Turvey, 1965; Harberger, 1965; Feldstein, 1965; Baumol, 1968; Arrow, 1969; and Schwartz, 1970.

TABLE 1

DISCOUNT RATES USED IN PAST HEALTH PROGRAM STUDIES

Year	Discount Rate	Researcher	Type of Study	Reference
1958	2 - 5%	Fein	Mental Illness	Rice (1967b) p. 1955
1961	8%	Thedie & Abraham	Road Accidents	p. 591
1961	4%, 10%	Weisbrod	General	p. 57
1962	5%	Mushkin	General	p. 147
1965	4%	Klarman	Syphilis	(1965b) p. 373
1965	4%, 6%	Klarman	Heart	(1965c) p. 701
1965	4% - 8%	Prest & Turvey	General	p. 700
1967	4%, 5%	Gottschalk	Kidney	p. 149
1967	4%, 10%	Neenan	Tuberculosis	p. 39
1967	4%	Piot & Sundaresan	Tuberculosis	p. 33
1968	4 - 6%	Klarman et al	Kidney	p. 51
1969	4%	Rice	General	p. 97

> Thus, nothing said so far argues for or against low rates of discount. It states merely that society will not benefit if it increases long-term investment in a wasteful and inefficient manner, by forcing the transfer of resources from employments with a high marginal yield to uses with a low marginal yield. For that is exactly what can be expected to result from the usual sort of figure of, say, 5 per cent for discount rates on public projects when the corporate rate of return is perhaps three times that high (1968, p. 797).

However, as Baumol further points out, it is fruitless for one government agency to unilaterally raise its rate to a more appropriate figure.

> But if the discount rate is raised it should surely be done by all government agencies simultaneously. For otherwise the change will only produce wastes in the interagency allocation of resources beyond those that already characterize the apportionment of inputs between the government and private enterprise (p. 798).

Thus, we are forced to the conclusion that, despite our feelings about the proper rate of interest, we must use the same figure as that used by other government agencies in order to avoid this interagency wastage. Consequently the applications in this research use an interest rate of 8 per cent which is the current rate for Ontario Government projects (Harper, 1969).

The appropriate discount rate for health benefits is more difficult to determine than that for costs. But first, let us explore the philosophical implications of a discount rate at all. Using a non-zero rate for health benefits says, in effect, that the elimination of a day of dis-

ability today is worth more than a promissory note to eliminate a day of disability five years from now. This is reasonable since the future is risky and uncertain. For example, when the time comes to collect the promissory note, the note-holder may have died from some other problem. Even if the note is transferable new preventive medicine may have eliminated the disease or new and better cures may have been discovered so that the note is no longer as useful as it used to be. Baumol contributes the following additional argument:

> Suppose we feel we can afford to give up some fixed amount for the benefit of others. We must then ask ourselves whether there are so few diseased, illiterate, underprivileged today, so few persons who excite our sympathy that we must look to the prospectively wealthy future for a source of worthy recipients of our bounty (1968, p. 800).

Thus, it becomes clear that the proper discount rate for health benefits is greater than zero. But how much greater than zero?

One possible way to determine this would be to conduct an experiment to investigate the subjective time-preference for health exhibited by individuals. Since this is a problem in measuring subjective values, similar techniques to those used in this research should be applicable. For example, it might be possible to ask a number of questions like the following: suppose you could be given health

coupons which would immediately cure a specified list of ailments, would you prefer one coupon redeemable at any time from now on, or two coupons which become due in 2 years, 5 years, 10 years, 20 years? The discount rate could be calculated from the indifference point. Considerable further research in this area is obviously required.

In the absence of any real data on the proper discount rate for health benefits, the best advice would appear to be to use the same rate for this item as for the costs. The only justification for this, other than for consistency, is that this has been the past practice. In cost-benefit studies, where all health benefits including the consumption benefit are converted to dollars, it has been the habit to use the same discount rate throughout. Thus, in the applications described later, an 8 per cent annual discount rate is used for the health benefits as well as the costs.

Mathematical Models of Health

The linear algebra notation used in this research is identical to Hadley (1961), except in the use of a superscript t for transpose where Hadley uses a prime. Specifically then, the notation conventions used are as follows:

Scalar - a

Row vector - $\underline{a} = (a_1, a_2, \ldots a_n)$

Column vector - $\underline{a} = [a_1, a_2, \ldots a_n] = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix}$

Matrix - $A = \| a_{ij} \| = \begin{bmatrix} a_{11} & a_{12} \ldots a_{1n} \\ a_{21} & a_{22} \ldots a_{2n} \\ \vdots & \vdots \quad \vdots \\ a_{m1} & a_{m2} \ldots a_{mn} \end{bmatrix}$

Transpose of $A = A^t$

Individual model

The health of an individual as he progresses through life is a non-time-homogeneous, non-Markovian, multi-dimensional stochastic process with continuous states in continuous time. State "death" is an absorption barrier while state "health" is an elastic barrier.

The process is non-time-homegeneous since the state transition probabilities are a function of time. For

example, as time (age) progresses the probability of going from state "healthy" to state "confined to a sanitorium" in a specified interval of time increases.

The process is non-Markovian in two ways. First, the transition probabilities are a function of, among other things, the length of time which has already been spent in a particular state. For example, if a patient has minimal active tuberculosis his probability of going from the state "confined to a sanitorium" to the state "healthy" is essentially zero for the first few months and then approaches one. This particular behavior is clearly non-Markovian, but can sometimes be approximated by a Markovian process with subdivided state (Thomas, 1968). Second, the transition probabilities are also a function of which states have been visited in the past and for how long. For example, the probability of going from the "healthy" state to the "confined to a sanitorium" state is higher if the latter state has been visited sometime in the past.

The process is multidimensional since health is a multidimensional variable. Generally, health is classified in three dimensions: physical health, emotional health and social health. It is possible to be healthy on one of these scales while very sick on another.

Considering health as three-dimensional, death can be defined as the (0, 0, 0) state -- dead on all three dimensions of health, and this is obviously an absorption barrier. Similarly, healthy is the (1, 1, 1) state --

healthy on all three dimensions, and this is an elastic barrier: it can either absorb or reflect.

Figure 1 displays a sketch of this model with a hypothetical realization shown.

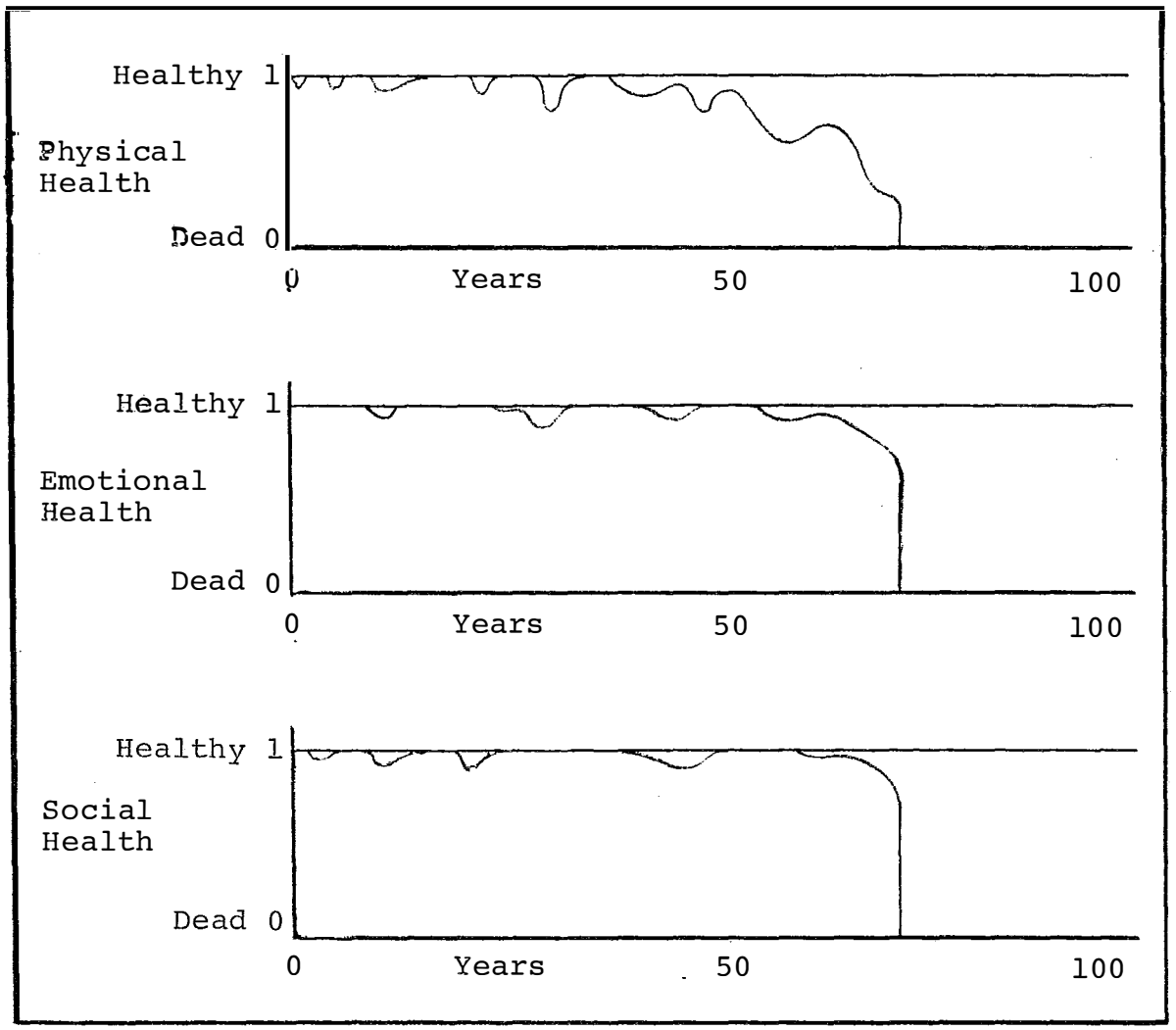

Fig. 1.--Stochastic Model for the Health of an Individual with a Hypothetical Realization Shown.

Population model

Fortunately, the evaluation of health programs is concerned with their impact on populations of people rather than specific individuals. This simplifies the model considerably.

For example, consider the non-time-homogeneity caused by the aging of the individual. Since a population doesn't age in the sense that an individual does -- because of the generally constant flow of members into and out of the population -- this factor drops out and the process becomes approximately time-homogeneous. It is not completely so, because the transition probabilities still change slowly with time -- as new medical knowledge is applied, as the age-sex population ratios change, and as social and living habits evolve (smoking, pollution, drugs). However, for any relatively short period of time, which is all that program assessment is concerned with, the system may be considered to be time-homogeneous. An additional safeguard in this assumption is provided by the discounting factor which makes the solution less sensitive to errors the further they are in the future.

In the population model, the marked non-Markovian behavior also disappears. For example, consider individuals in the state "confined to a sanitorium". In any given unit of time these individuals can go to the healthy state, the dead state, or they can stay in the confined to a sanitorium

state. Thus, there are three transition probabilities required to determine where these people will be at the end of this unit of time. These probabilities are independent of the previous behavior of the system and hence we have the memoryless Markovian property. It is important to note that while these probabilities can be used to determine how many people will move from one state to another, they are of no value in determining which ones will move. This is the difference between the population model and the individual model.

The multidimensional characteristic of the model is eliminated by introducing the use of the single-dimensional health utility scale. This scale measures the utility of each health state as perceived by society. It can be considered as a mapping process whereby every point in the three-dimensional health space can be mapped to a point on the single-dimensional health utility scale. Death, point (0, 0, 0) in the three-dimensional space will map to 0 on the new scale; healthy, previously (1, 1, 1) will map to 1 on the new scale, and all other points will fall at their corresponding utility value. There will be no attempt in this research to develop the actual mapping function. Rather, the particular points in the three-dimensional health space that are of interest will be defined, and their utility will be measured experimentally.

Finally, to simplify the calculations, a discrete

approximation will be used to the true continuous model. Continuous time will be approximated by discrete time in units of one day. This unit is sufficiently small that it should introduce negligible error. Continuous health will be approximated by discrete states. For example, the healthy state will include mild discomforts which do not significantly affect a day's behavior (mild headaches, colds, etc.). Theoretically, this assumption also introduces only limited error since the discrete states can be made as small as necessary to provide as accurate an approximation as desired.

These modifications result in an approximation model for the health of populations which is a conventional time-homogeneous finite Markov chain. Figure 2 illustrates this model.

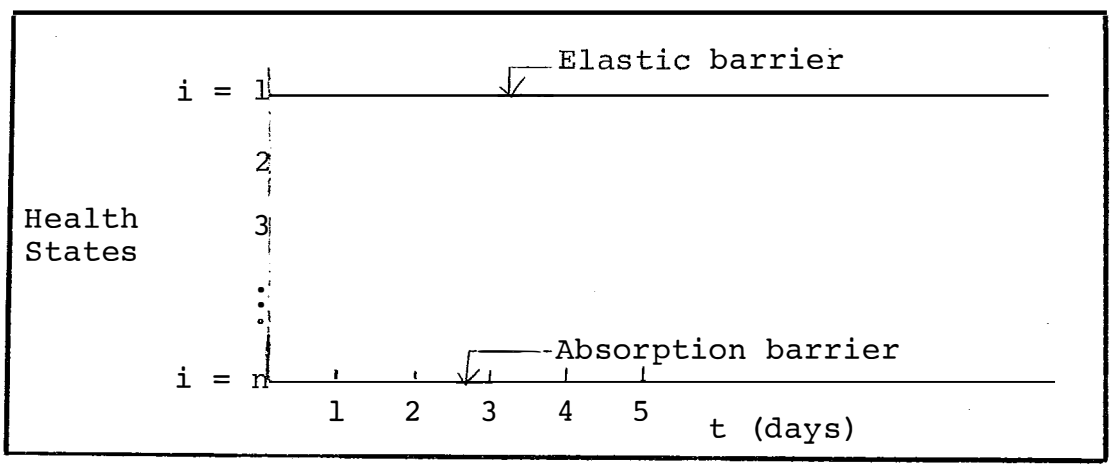

Fig. 2.--Stochastic Model for the Health of a Population.

Mathematical Models for the Calculation of Health Benefits

Given the stochastic model for the health of populations introduced above and illustrated in Figure 2, how does one calculate the health benefit from a particular health program? Several methods are available and will be described below. First, let us define the following:

$i = 1,2,\ldots,n$ are the n discrete health states,
where $i = 1$ is the healthy state (elastic state)
and $i = n$ is the dead state (absorption state).

$\underline{h} = [h_1, h_2,\ldots,h_n]$ is a column vector of the health utilities for these particular states,
where $h_1 = 1$
and $h_n = 0$.

p_{jk} = the probability of going from state j to state k in one time period.

$P = \| p_{jk} \|$ is the 1-step transition matrix.

$\underline{p}(t) = (p_1(t), p_2(t),\ldots,p_n(t))$ is a row vector
where $p_i(t)$ = the probability of being in state i at time t.

$\underline{n}(t) = (n_1(t), n_2(t),\ldots,n_n(t))$ is a row vector
where $n_i(t)$ = the number of people in state i at time t.

$\underline{1} = [1, 1,\ldots,1]$ an n-dimensional unit column vector.

$N(t) = \underline{n}(t)\ \underline{1}$ is the total number of people in the system at time t.

Primed symbols represent values with the health program. Unprimed symbols represent values without the program (the benchmark).

Fundamental formulae

The amount of health utility with the program at time t is $H'(t) = N(t)\ \underline{p}'(t)\underline{h}$ (1)

The amount of health utility without the program at time t is

$$H(t) = N(t)\underline{p}(t)\underline{h} \quad (2)$$

The increase in health utility (health improvement) created by the program at time t is

$$\Delta H(t) = H'(t) - H(t)$$

$$= N(t)\underline{p}'(t)\underline{h} - N(t)\underline{p}(t)\underline{h}$$

$$= N(t)[\underline{p}'(t) - \underline{p}(t)]\underline{h} \quad (3)$$

$$= [\underline{n}'(t) - \underline{n}(t)]\underline{h} \quad (4)$$

The total health improvement created by the program and discounted at an interest rate of r per unit time is

$$\Delta H = \sum_{t=0}^{\infty} \Delta H(t)/(1+r)^t \quad (5)$$

$$= \sum_{t=0}^{\infty} [\underline{n}'(t) - \underline{n}(t)]\ \underline{h}/(1+r)^t \quad (6)$$

Equivalence to the weighted disability-days concept

The weighted disability-days concept, as suggested by Packer (1968), was reviewed briefly in Chapter I.[1] In this method weights are assigned to each disability state.

[1] See pp. 31-32 above.

Let $\underline{w} = [w_1, w_2, \ldots w_n]$ = a column vector of disability weights for health states 1, 2,...n;

with $w_1 = 0$ (the healthy state)

and $w_n = 1$ (the dead state).

Then the amount of unhealthiness at time t without the program is

$$U(t) = \underline{n}(t)\,\underline{w}$$

and with the program is

$$U'(t) = \underline{n}'(t)\underline{w}$$

The health improvement created by the program is the reduction in the amount of unhealthiness, that is:

$$\begin{aligned}\Delta H(t) &= U(t) - U'(t)\\ &= \underline{n}(t)\underline{w} - \underline{n}'(t)\underline{w}\\ &= [\underline{n}(t) - \underline{n}'(t)]\underline{w}\end{aligned}$$

Now, if we define the disability weights to be the complements of the health utilities for the same states,

then $\underline{w} = \underline{1} - \underline{h}$

and $$\begin{aligned}\Delta H(t) &= [\underline{n}(t) - \underline{n}'(t)][\underline{1} - \underline{h}]\\ &= [\underline{n}(t) - \underline{n}'(t)]\underline{1} - [\underline{n}(t) - \underline{n}'(t)]\underline{h}\\ &= \underline{n}(t)\underline{1} - \underline{n}'(t)\underline{1} - [\underline{n}(t) - \underline{n}'(t)]\underline{h}\\ &= N(t) - N(t) - [\underline{n}(t) - \underline{n}'(t)]\underline{h}\\ &= [\underline{n}'(t) - \underline{n}(t)]\underline{h}\end{aligned}$$

which is identical to equation (4).

Hence, the health utility system proposed in this research and the weighted disability-days system proposed pre-

viously by Packer are identical, if the disability weight for a state is defined as the complement of its health utility.

Calculation based on annual man-days in each state

The fundamental equation for calculating the health benefit of a program, equation (6), has two awkward features, both resulting from the fact that the unit of time is one day. First, the discount rate r is on a daily basis and will compound on a daily basis.[1] This is neither usual in practice nor consistent with the treatment of the costs where the discount rate is applied on an annual basis. Second, if the effect of the program is to be calculated for a reasonable number of years into the future, a great deal of repetitive calculation is involved in determining $\underline{n}'(t)$ and $\underline{n}(t)$ for the large number of days involved.

Fortunately, both of these complications can be removed by determining the increase in health for each year and then discounting on an annual basis.

---

[1] For the applications in this study the annual discount rate is .08, hence r = .08/365.

Let i = the annual discount rate, and

y = the year of the program

$$\text{Then } \Delta H = \sum_{t=0}^{\infty} [\underline{n}'(t) - \underline{n}(t)]\underline{h}/(1+r)^t$$

$$= \sum_{y=1}^{\infty} \sum_{t=1+365(y-1)}^{365y} [\underline{n}'(t) - \underline{n}(t)]\underline{h}/(1+r)^t ,$$

since $\Delta H(0) = 0$

This can be approximated[1] by

$$\sum_{y=1}^{\infty} \frac{1}{(1+i)^y} \sum_{t=1+365(y-1)}^{365y} [\underline{n}'(t) - \underline{n}(t)]\underline{h} \qquad (7)$$

$$= \sum_{y=1}^{\infty} \frac{1}{(1+i)^y} \left[\sum_{t=1+365(y-1)}^{365y} \underline{n}'(t) - \sum_{t=1+365(y-1)}^{365y} \underline{n}(t) \right] \underline{h} \qquad (8)$$

---

[1]Note, the approximation here represents only a change in the frequency of compounding the discounting -- from daily compounding at a daily rate of r, to annual compounding at an annual rate of i = 365r. This approximation has a negligible effect on the accuracy of the results. First, the difference between the two methods is small. When i = .08, as it does in this research, the difference in the ΔH obtained by the two methods is two to three per cent depending upon the number of years involved in the summation. Second, and more important, it can be argued that the annual discounting is not an "approximation" at all, but is really the correct approach since this puts the discounting of the benefits and the costs on the same basis. In this project, this is clearly the case, since the discount rate selected for use with the benefits is 8 per cent per year (see p. 52 above).

Now $\sum_{t=1+365(y-1)}^{365y} \underline{n}'(t)$ is merely a row vector of the man-days in each health state in year y with the program, and $\sum_{t=1+365(y-1)}^{365} \underline{n}(t)$ is the man-days in each state in the same year without the program.

Then, letting $\underline{m}'(y) = \sum_{t=1365(y-1)}^{365y} \underline{n}'(t)$ and $\underline{m}(y) = \sum_{t=1+365(y-1)}^{365} \underline{n}(t)$, (8) becomes

$$\Delta H = \sum_{y=1}^{\infty} \frac{\underline{m}'(y) - \underline{m}(y)}{(1+i)^y} \underline{h} \qquad (9)$$

Calculation based on program effect on specific individuals

The method described in the previous section (equation 9) requires the determination of the total annual man-days in each health state both with and without the program. It is possible to obtain the same result with a simpler calculation if the impact of the program is available as specific state-duration changes for individuals or groups of individuals. For example: this program in its first year, will eliminate two deaths, assumed to occur half-way through the year, replacing them with a mild disability state, and will reduce hospitalization by one week for 100 people replacing this with normal healthy living.

For a specific year of the program, let d_{jk} be the number of man-days changed from state j to state k by the program. Hence $d_{kj} = -d_{jk}$, but, since we wish to deal with all the changes once only, we will use the positive values of d_{jk} only by letting $c_{jk} = \max. [0, d_{jk}]$. Also, let $C = \| c_{jk} \|$,

$\underline{m}$ = the row vector of man-days in each state without the program, and

$\underline{m}'$ = the row vector of man-days in each state with the program.

Now, from (9) the health benefit in a particular year is

$$\Delta H = [\underline{m}' - \underline{m}]\underline{h} \tag{10}$$

But, consider vector $\underline{m}'$. The i^{th} element of this vector is just the i^{th} element of the $\underline{m}$ vector plus any changes to state i less any changes from state i.

That is, $m'_i = m_i + \sum_{j=1}^{n} c_{ji} - \sum_{k=1}^{n} c_{ik}$

In vector notation, this is equivalent to

$$\underline{m}' = \underline{m} + \underline{1}^t C - (C\underline{1})^t \tag{11}$$

From (10), $\Delta H = [\underline{m}' - \underline{m}]\underline{h}$

$$= [\underline{m} + \underline{1}^t C - (C\underline{1})^t - \underline{m}]\underline{h}$$

$$= \underline{1}^t C\underline{h} - (C\underline{1})^t\underline{h}$$

$$= \underline{1}^t C\underline{h} - \underline{h}^t C\underline{1} \qquad (12)$$

$$= \sum_{j=1}^{n} \sum_{k=1}^{n} c_{jk}\, h_k - \sum_{j=1}^{n} \sum_{k=1}^{n} c_{jk}\, h_j$$

$$= \sum_{j=1}^{n} \sum_{k=1}^{n} c_{jk}\, (h_k - h_j) \qquad (13)$$

Equations (12) and (13) represent the health benefit for one year only. From these, the following expressions for the health benefit of a whole program are obtained:

$$\Delta H = \sum_{y=1}^{\infty} \frac{\underline{1}^t C(y)\underline{h} - \underline{h}^t C(y)\underline{1}}{(1+i)^y} \qquad (14)$$

$$= \sum_{y=1}^{\infty} \frac{1}{(1+i)^y} \sum_{j=1}^{n} \sum_{k=1}^{n} c_{jk}(y)\, (h_k - h_j) \qquad (15)$$

where $d_{jk}(y)$ is the number of man-days changed from state j to state k by the program in year y,

$c_{jk}(y) = \max.\ [0,\ d_{jk}(y)]$ and $C(y) = \left\| c_{jk}(y) \right\|$

Essentially all equation (15) says is that if a program causes a man-day which would have been spent in a state with a health value of value of 0.5 to instead be spent in a state with a health value of 0.8, the health benefit is 0.3. Equation (15) will frequently be convenient for manual calculations of the health benefits from real programs. On the other hand, for computer calculations, especially in languages

with powerful matrix algebra capabilities, equation (14) is more suitable.

Calculation based on transition matrices

If the 1-step transition matrices with and without the program (P'and P) are known, two approaches to the calculation are possible. First, the transition matrices can be used to calculate $\underline{n}'(t)$ and $\underline{n}(t)$ and then equation (6) used to determine the health benefit. Second, the transition matrices can be used directly in equation (16) developed below.

Consider a health program applied to a cohort of N people at time t = 0. Note that $\underline{n}'(0) = \underline{n}(0)$. From (6), the program health benefit is

$$\Delta H = \sum_{t=0}^{\infty} [\underline{n}'(t) - \underline{n}(t)]\underline{h}/(1+r)^t$$

$$= \sum_{t=0}^{\infty} [\underline{n}'(0)\ P'^{(t)} - \underline{n}(0)\ P^{(t)}]\underline{h}/(1+r)^t$$

$$= \sum_{t=0}^{\infty} \underline{n}(0)\ [P'^{(t)} - P^{(t)}]\underline{h}/(1+r)^t \qquad (16)$$

The major drawback with this method is the virtual impossibility at the present time of obtaining the required transition matrices when the unit of time is one day. The few probabilities that are available are on an annual basis (eg., age-specific annual mortality probabilities with and without a program are sometimes available) and therefore unsuitable for this model which uses a discrete time unit of one day.

Mathematical Models for Optimization

Once the health benefit from each program has been calculated the problem becomes one of determining which programs should be implemented and what level of funding should be provided to each -- in other words, the selection, within specified constraints, of that sub-set of health programs which will maximize the health benefit.

The following data is required for each health program under consideration:

1. The health benefit (ΔH) for the program. For consistency with the cost-effectiveness literature, this will be called the program effectiveness, symbolically represented by E.
2. The cost (C) of the program. This is the total cost of the program to society on a present value basis.
3. Depending upon the constraints to be imposed on the solution, greater detail may be required in the cost data. For example, the portion of this cost which will be the responsibility of the provincial government will be required if a constraint is to be imposed on this item.
4. Other resource requirements of the program may be neces-

sary if constraints are imposed on the total amounts of these resources available. For example, physician time, hospital beds, etc.

Most health programs can be funded at a number of different levels and most will conform to the well-known law of diminishing returns. That is; doubling the funding does not produce double the benefits. Hence, the question is not only: is this a good program, but also: what is the optimum level of funding for it? A useful method for handling this situation is to treat each level of each program as though it were a completely different program; gather all the basic data accordingly; and then, in the selection algorithm, define the different levels of the same program as mutually exclusive programs.

Cost-effectiveness ranking algorithm

If there is only one resource constraint on the solution and this applies to total costs, a cost-effectiveness ranking algorithm may be used to determine the health program priorities. This technique can be readily illustrated through the use of a cost-effectiveness graph.

Consider a single program with total cost and total effectiveness of c and e respectively. The point (c,e) may theoretically fall in any quadrant since negative values are possible (see figure 3 below). However, quadrants 3 and 4 can be quickly dismissed by agreeing to the conven-

tion that any program falling in one of these two will be re-defined as its complement. Then the new point (c,e) becomes the negative of the old point (c,e) locating the new point in the diagonally opposite quadrant.[1]

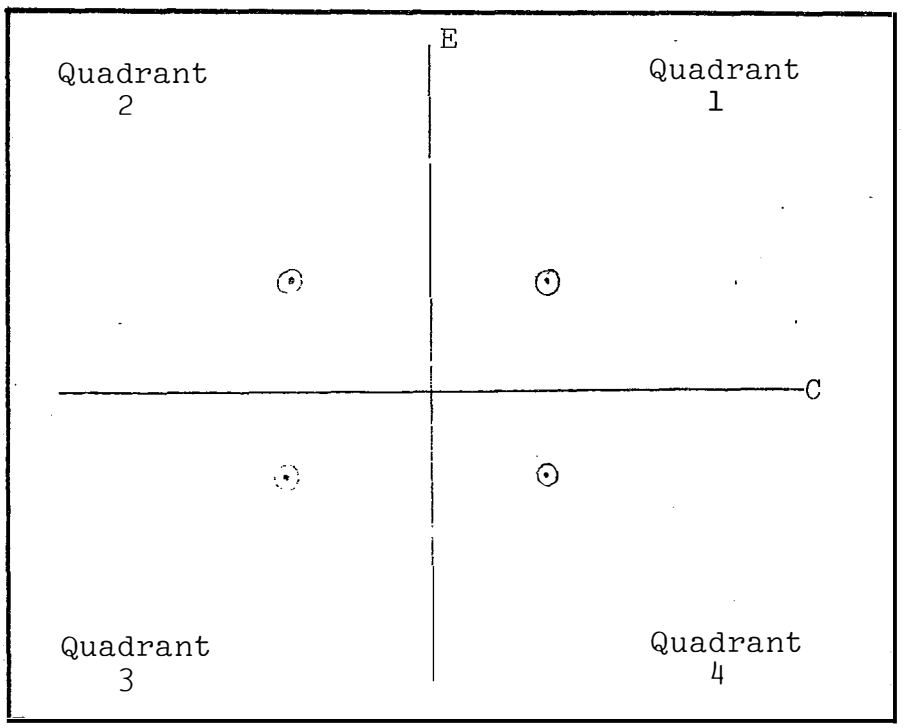

Fig. 3.--Basic Single Program Possibilities on a C-E Graph

---

[1] Of course, it would be unusual for a program to fall in quadrant 3 or 4 but this method of handling the situation is included for just such a contingency. It could occur if a project was defined as the removal of some existing health program, or perhaps it could occur if a program had some health reducing side-effects which were not entirely recognized prior to the analysis.

With independent programs

First, let us investigate the case with independent programs -- that is, no mutually exclusive nor interacting programs.

Now consider a number of these independent programs plotted on the same C-E graph. An example is shown in figure 4 with the programs numbered in their cost-effectiveness priority ranking.

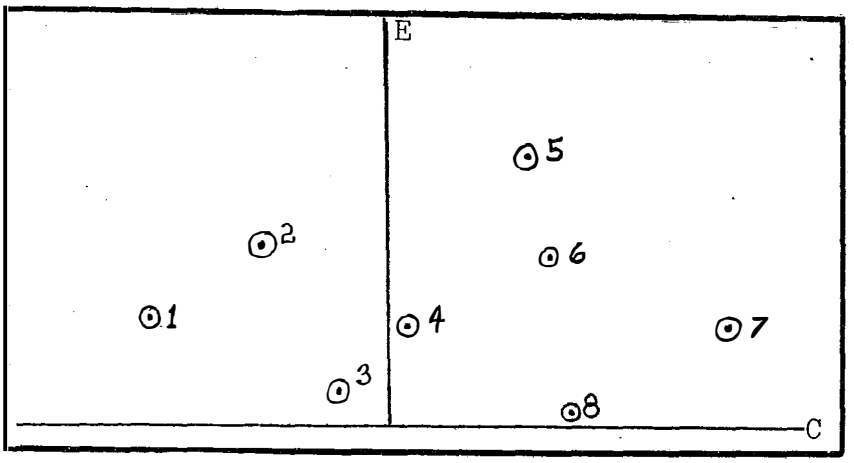

Fig. 4.--Plot with Independent Programs Only.

Let c_i and e_i be the cost and the effectiveness respectively of the ith program. Then the procedure for ranking independent projects is the following:

Criterion 1: If any c_i are non-positive these programs have top priority and are ranked in ascending order of c_i.

Criterion 2: The remaining projects are ranked in descending order of e_i/c_i, their effectiveness-cost ratio.

Criterion 1 can be explained as follows: Projects which save money and do not reduce health should have a higher priority than projects which cost money, since implementation of the former will free money for use in the latter. Among those projects which save money, the best is the one that saves the most, regardless of their respective health benefits. This seemingly heartless view is justified when one appreciates the implications of doing otherwise. For example, in figure 4, consider the situation where project 2 is implemented rather than project 1 (because it has greater health benefits). This decision would cost society $c_2 - c_1$ dollars to obtain a health improvement of $e_2 - e_1$, and this might not be particularly good value in terms of the health improvement gained per dollar spent. In fact, it's clearly poorer value than getting some health benefit free as occurs if project 1 is selected first.

Further support for this criterion is obtained by noting that it is identical to the cost-benefit approach. In the cost-benefit approach, the best project is the one with the maximum present value of economic benefits less costs, or equivalently, the minimum present value of costs less economic benefits. In this research, "costs less economic benefits" has been redefined as the net cost of a program to society; and hence, the cost-benefit criterion is equivalent to selecting the project with the minimum net cost to society. Thus, for those projects with negative total

costs, this model and the traditional cost-benefit model yield identical results.

Criterion 2 should be self-evident. All it says is that, since the total amount of funds is limited, the first programs to be implemented should be those with the highest yield of health benefits per dollar.

The result of this method is a list of programs ranked in their cost-effectiveness priority sequence. The list may be used by a decision-maker in two basic ways:

1. If his objective is to produce a specified health improvement at minimum cost, he should select programs in sequence from the list until the desired health improvement has been achieved. This will be the minimum-cost set for the resulting health improvement.
2. If his objective is to produce the maximum health improvement for a given cost, he should select programs in sequence from the list until the cumulative cost has reached the cost constraint. This will be the set that maximizes the health improvement for the cumulative cost of the programs.

In either case, the set of programs so selected may not represent the final decision. The intangible benefits from each program must be considered by the decision-maker and the set of selected programs adjusted accordingly.

With mutually exclusive programs

Now consider multiple programs, some mutually exclusive, plotted on the same C-E graph. An example is shown in figure 5, with mutually exclusive programs connected by straight lines. This convention is used since frequently the mutually exclusive programs are merely different levels of the same program. In this case, the line connecting the points has a natural interpretation as the C-E curve for the basic program itself. However, it is important to note that the method which follows in no way depends on this interpretation. Any set of points (programs) whatsoever may be specified as mutually exclusive.

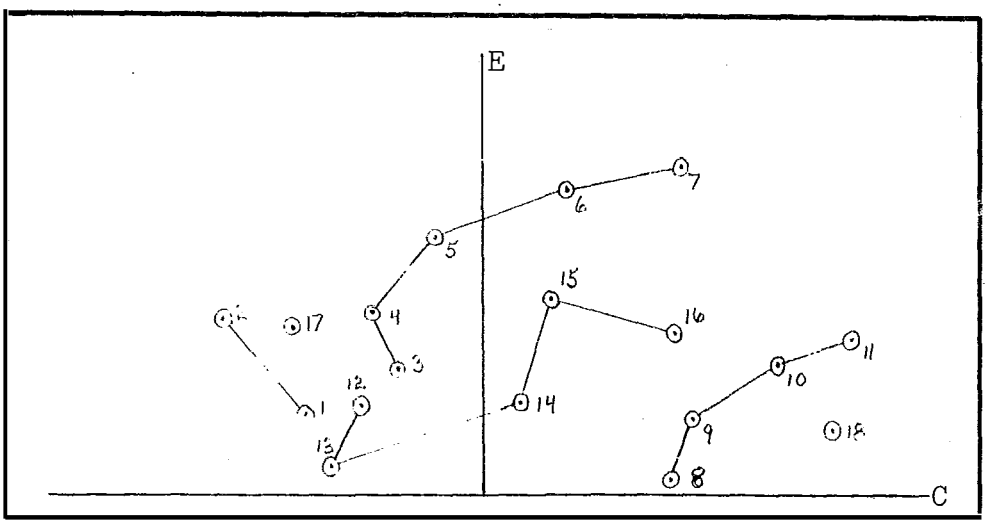

Fig. 5.--Multiple Programs on a C-E Graph

Figure 4 shows several different types of programs. Points 1 and 2 are two levels of an outstanding program which not only saves money for society but provides health benefits as well. Points 3 to 7 are different levels of a program which saves money in the beginning, but when pressed to higher levels, costs money and produces a diminishing marginal return. This pattern might resemble mass screening for tuberculosis where the initial levels represent a program in the high prevalence areas and the higher levels include rural screening as well. Points 8 to 11 are levels of a program which displays a threshold cost before which little health benefit is received at all, and then the typical diminishing marginal return pattern. Points 12 to 16 are a random collection of points to indicate that no special pattern is required by the method. Points 17 and 18 are included to show that single independent programs can, of course, be mixed with mutually exclusive programs in this analysis.

The method used in this section requires an understanding of the concept of marginal or incremental analysis. Consider the situation where program 5 is in solution and we are now debating whether or not to replace it with program 6. The cost and the effectiveness of program 6 are c_6 and e_6 respectively on a total basis, and $c_6 - c_5$ and $e_6 - e_5$ respectively on a marginal basis. The latter figures are the relevant ones. That is, if we replace program 5 with

program 6, we will be spending $c_6 - c_5$ dollars to gain $e_6 - e_5$ units of health. This must then be compared against all other possibilities for adding programs to the solution; so that, at this step, the best possible program addition is made. Thus, in any set of mutually exclusive programs, the best program for replacement of the existing program is the one with the maximum incremental effectiveness-cost ratio.

We are now in a position to specify the algorithm for producing a cost-effectiveness priority ranking for programs some of which are mutually exclusive.

1. For each set of mutually exclusive programs determine the best initial increment and add it to the list of increments.
   (a) If a set has any $c_i < 0$, the best initial increment is the point with the minimum c_i. In case of a tie, select the point with the maximum e_i.
   (b) If a set has no $c_i < 0$, the best initial increment is the point with the maximum $\Delta E/\Delta C$. (For the initial list $\Delta E/\Delta C = e_i/c_i$) In case of a tie select the point with the minimum ΔC -- this will cause the tied programs to be adjacent on the final priority listing in ascending sequence of program cost. (This will occur regardless of how many points are involved in the tie.)
2. Select the best program from the list of candidate increments using the same criteria as step 1 above, and enter it into the solution.

3. Replace this program in the list of candidate increments by the next best program from the same mutually exclusive set. If program r is currently in solution, the replacement for it is the program i which maximizes $\Delta E/\Delta C$, $\Delta E>0$, where $\Delta E = e_i - e_r$ and $\Delta C = c_i - c_r$. In case of a tie, select the increment with the minimum ΔC.
4. Repeat steps 2 and 3 until programs for consideration are exhausted.
5. The sequence with which programs enter the solution gives their cost-effectiveness priority ranking.

Further details on the above algorithm may be obtained in Appendix III which contains a listing of the computer program CERANK and its output. Once again, this method results in a list of projects in their cost-effectiveness priority order and all the comments made in the previous section about the use of this list by a decision-maker still apply.

With individual programs

The previous two algorithms assume that all possible programs are evaluated simultaneously, say once a year, and any program which comes up in the interim must wait until the next year for consideration. However, it may be desired to perform an interim evaluation on a program to determine the level of support it should receive. This can be done two ways:

1. By rerunning the last evaluation of all programs with the new program included, to see where it ranks, or
2. By determining a threshold $\Delta E/\Delta C$ ratio which each program increment must achieve to be implemented. One possibility for this ratio would be to use the minimum ratio which was implemented at the last complete evaluation. This approach would ensure that only programs which were equal to or better than existing programs would be implemented at an interim evaluation.

Mathematical programming algorithm

The cost-effectiveness ranking algorithm has two limitations:

1. It will not necessarily select the sub-set of programs that will produce the maximum health improvement for a given cost constraint. In fact, this optimal condition is only guaranteed if the cumulative cost from selecting projects in sequence from the list exactly equals the cost constraint. Otherwise, unused funds will be left since the next-best program will be too large to be accepted. In this case, a large number of improved solutions may be available: for example, spend the remaining money on some combination of lower-ranked programs which can be afforded; or drop one or two small programs which have been accepted if this would provide the extra funds required to afford the large next-best program.

2. It cannot handle a problem with multiple resource constraints. This could occur if the resource constraint was to be considered a function of time: if different amounts were available in different years. It could also occur if different resources (physician time, drugs, capital, provincial government contributions) were not to be considered interchangeable, but were to be individually limited to some total amount available.

Both of these limitations can be overcome by the use of a 0-1 integer linear programming algorithm. It requires the same basic approach as that proposed by a number of authors for optimal capital budgeting in a firm (Hadley, 1964, p. 269; Weingartner, 1967, p. 33; Mao, 1969, p. 240).

The basic model is formulated as follows:

$$\text{Max } Z = \sum_{i=1}^{n} e_i x_i \qquad (17)$$

$$\sum_{i=1}^{n} c_i x_i \leq C \qquad (18)$$

$$0 \leq x_i \leq 1,\ x_i \text{ an integer, } i = 1,2,\ldots,n \qquad (19)$$

$$\sum_{i \in I_j} x_i \leq 1,\ j = 1,2\ldots,p \qquad (20)$$

where $x_i = 1$ implies the i^{th} program is in the solution (accepted),

$x_i = 0$ implies the i^{th} program is not in the solution (rejected),

I_j is the j^{th} sub-set of mutually exclusive programs,

C is the total amount of dollars available,

e_i is the effectiveness (in units of health) of the i^{th} program, and

c_i is the net cost to society (in dollars) of the i^{th} program.

Multiple resource constraints may be added to this model quite simply. Suppose, for example, that it is desired to individually constrain the amount of physician time, the amount of nurse time, and the number of hospital bed-days to no more than the total amounts available; P, F, and B respectively. Let p_i, f_i and b_i be the amounts of each of these resources used by the i^{th} program. Then the following three additional constraints should be included:

$$\sum_{i=1}^{n} p_i x_i \leq P \qquad (21)$$

$$\sum_{i=1}^{n} f_i x_i \leq F \qquad (22)$$

$$\sum_{i=1}^{n} b_i x_i \leq B \qquad (23)$$

Note that this formulation allows the analyst to investigate the marginal value of additional units of each type of resource. That is, it can answer the question: how much additional

health would be created by adding an additional unit of physician time, of nursing time, or of hospital beds? The answer is not directly available from the solution, the way it is with linear programming, since the 0-1 algorithm used is an implicit enumeration (branch and bound) type. Rather, the marginal values must be obtained by a parametric analysis in which the problem is re-solved at increasingly larger values of the parameter (P, F or B) and the increase in the objective function can then be related to the increase in the particular resource. A convenient restart procedure is available to improve the efficiency of these parametric reruns. Providing a constraint has been relaxed, rather than tightened, for a rerun, the previous solution can be used as an efficient starting point. This will exclude all worse solutions from consideration and vastly reduce the number of points that must be investigated.

Resources may be broken down as finely as required for use in these multiple resource constraints. For example, physician-time may be too broad a category and, if so, could be replaced by a separate constraint for each type of physician specialty.

In a similar fashion, a constraint may be added to limit the costs incurred by one of the levels of government, if so desired. The government may wish to limit its gross expenditures only (the money it spends to support the pro-

grams); or it may limit its net costs (the difference between the government expenditures for the health programs and the government receipts from them[1]).

A further complexity is introduced if one or all of these constraints are to be expressed on an annual basis. For example if

C_k = the amount of total cost which society can afford in year k,

P_k = the amount of physician time available in year k,

c_{ik} = the total cost of program i in year k,

p_{ik} = the physician time required by program i in year k,

K = the number of years into the future which must be considered, then constraints (18) and (21) can be rewritten as follows:

$$\sum_{i=1}^{n} c_{ik} x_i \leq C_k, \quad k = 1, 2, \ldots, K \qquad (24)$$

$$\sum_{i=1}^{n} p_{ik} x_i \leq P_k, \quad k = 1, 2, \ldots, K \qquad (25)$$

Similarly, any constraint can be established on an annual basis. This feature could be particularly appealing to

---

[1]A government obtains receipts or cost reductions from health programs two ways; first, from increased taxes received from the additional earnings of the people whose health was improved by the program and second, from a reduced utilization of government-subsidized health facilities (hospitals etc.) also due to the improved health created by the program.

government departments that wished to limit their commitment for future program costs to specified annual amounts.

Comparison of the two algorithms

Two algorithms have been introduced for determining the optimal sub-set of health programs from a larger set of feasible programs: a cost-effectiveness ranking algorithm developed specifically for this research, and a standard 0-1 integer linear programming algorithm. Both are applied to a sample of health programs in Chapter V, and a detailed comparison of the two is performed. In summary, the conclusions are that the cost-effectiveness ranking algorithm is superior for those problems to which it is applicable -- an application with any number of programs, any number of mutual-exclusivity constraints, and one cost constraint. It has the following advantages: (1) simplicity, (2) computational efficiency, (3) the ability to handle larger sets of programs, (4) only "peak"[1] solutions are produced and these are normally to be preferred, and (5) better information is provided along with the solution (specifically the incremental effectiveness-cost ratios which are useful for the rational incorporation of the intangible

[1] See p. 204 below for an elaboration on what is meant by "peak" solutions.

benefits and also for interim single program evaluations). On the other hand, the cost-effectiveness ranking algorithm is not applicable to problems with multiple resource constraints, and such problems must be handled with the 0-1 integer linear programming algorithm.

CHAPTER III

HEALTH SCALE MEASUREMENTS

The proposed model described in the previous chapter requires a linear interval (or ratio) health scale and a measuring technique which can be used to determine the scale value (health index) for any possible health state (or, at least, for a wide variety of health states). The proposed scale and measuring technique are described in this chapter and tested by measuring the health value for five different health states. The following definitions and notation will be used:

1. Health state.--A health state is a specific combination of physical health, emotional health, and social health.

   s_i denotes health state i.

   s_1 is state healthy - that is, the state of being simultaneously healthy on all three dimensions of health (physical, emotional and social).

   s_n is state dead.

2. Health state value.--The health state value (health state utility value, health index) is the utility of that state as perceived by society.

   h_i denotes the health value for health state i.

$h_1 = 1$, by definition.

$h_n = 0$, by definition.

A health value is a characteristic of a particular health state. It has the dimension of quantity only; no time dimension.

3. Units of health.--The amount of health or amount of health utility for a particular population for a specified period of time is measured in units of health. The population may be one or more people; the duration one or more days. The unit of health is a health-value-day. That is, it is the sum of the health values for each man-day involved. Or, phrased another way, it is the weighted health-days where each day (man-day) is weighted by the value of the health state of that individual for that day.

Development of the Measurement Techniques

Survey of potential methods[1]

A number of techniques have been developed by various researchers for the measurement of utilities. Many measure only ordinal utilities, and these were discarded as inappropriate for the required purpose. Others measure utilities on an interval or ratio scale, and these were reviewed to determine their suitability for this project. Specifically

[1]The six utility measurement techniques listed in this section are critically reviewed in Appendix I, Exhibit 11.

the following techniques were investigated:

1. The von Neumann-Morgenstern standard gamble (von Neumann and Morgenstern, 1953).
2. The simplified von Neumann-Morgenstern standard gamble by Ackoff and Sasieni (1968, p. 49).
3. The decision theoretic method by Flagle (1966, p. 400).
4. The direct measurement method suggested by Stevens (1959, p. 52) and applied by Miller (1966) and Stimson (1969).
5. The Churchman-Ackoff method (Churchman and Ackoff, 1954).
6. The method of indifference curves (Stevens, 1959, p. 56).

Number 5 was determined to be unsuitable. Numbers 2 and 3 were found to be variations of number 1. Number 1, the standard gamble was selected as one of the methods to be used, with the alternatives phrased as realistically as possible as suggested by Flagle's decision-theoretic approach. The direct measurement method was the other technique selected for use, and this approach evolved, in application, into a time trade-off technique which has some aspects in common with the method of indifference curves.

Pilot applications

In this project the techniques for measuring health state values progressed through three pilot applications, during which they were under constant evolution, and one final application, to implement and test the final refined methods. Table 2 summarizes the highlights of this evolution.

TABLE 2

EVOLUTION OF HEALTH VALUE MEASUREMENT TECHNIQUE

Version	Date	Subjects	Method	Comments
1	Sept. 1969	24 part-time graduate students	Group Questionnaire	5 general states, 2 durations each
2	Apr. 1970	26 full and part-time graduate students	Group Questionnaire	5 specific states, 2 durations for some
3	May 1970	8 faculty members	Individual Interviews	5 specific states, various durations
4	June-July 1970	11 general practitioners	Individual Interviews	5 specific states, 1 duration each, replication, use of cards

Effect of time on health state utilities

In measuring the utilities for health states, other factors must be held constant, and only the health states varied. One of the other factors is time -- the duration of time spent in a particular health state. That is accomplished quite simply in the von Neumann-Morgenstern standard gamble and the direct measurement technique by holding the time constant for all alternatives, and in the time trade-off method by carefully controlling the time and accounting for it in the calculations.[1]

However, one must still select the specified time to be held constant. In versions 1, 2 and part of 3 (Table 2) two times were used for each state to determine whether or not the health state utility is sensitive to time. It appears that it is.

First the data was analyzed to determine if there was a statistically significant difference between the short-term health value and the long-term health value for the same state determined in the same pilot study. A paired t-test with a two-tailed 5 per cent level of significance was used.[2]

---

[1] These measurement methods are described in detail further on in this chapter. See pp. 94-105 below.

[2] See Appendix I, Exhibit 1 for the detailed results.

There was no state where the difference was statistically significant but there were a number of cases where this result appeared to be due to the small sample. That is, it was suspected that a larger sample would indeed show the difference to be statistically significant.

A pattern began to emerge. It appeared that frequently the health value of a confinement state would decline with time while that of a chronic disability would increase. This was framed as a hypothesis and tested statistically. All confinement states that had been tested at two different times were aggregated and similarly all chronic states. A paired t-test was felt to require too strong an assumption -- it assumes that differences are identically and normally distributed and since these differences come from different health states, measured on different subjects, with different versions of the measuring instruments this was considered unlikely to hold. So the hypothesis was tested using the non-parametric sign test[1] which assumes only that the health value has a continuous distribution. The result was that the decline in the health value of the confinement states with time was statistically significant at a one-tailed 5 per cent level of significance and so was the increase in value of the chronic states.[2]

---

[1]For an explanation of this test, see Siegel, 1956, p. 68.

[2]See Appendix I, Exhibit 2 for the calculations.

A possible explanation for this phenomenon is that as the duration in a specific health condition increases, an individual's emotional and social health changes. For example, an individual may find the first few days of bed-confinement quite enjoyable but by the 365th day, his emotional and social health has deteriorated to a low level. He has actually shifted into a new health state with a lower value. Similarly, a chronic disability may be most upsetting for the first while and may become quite routine once a person has successfully adjusted. Here the shift is to a higher-valued health state.

This finding means that a health condition for one period of time must be treated as a different health state with (possibly) a different value than the same condition for some other period of time. Thus, in measuring the health value for a specific condition the expected duration of the condition must be carefully defined. This led to a modification, introduced in version 4, to specify the duration of a health state as that duration that pertains to the specific health program under evaluation.

Effect of prognosis and financial considerations

Prognosis

The health value for a particular state represents the average utility of being in that state as perceived by society. It does not represent the utility of future states which may follow this one. In other words, the prognosis for a particular health state does not enter directly into the determination of the health state value. This is achieved in practice by holding the outcome constant for each alternative in the measurement procedure.[1]

A good example of this occurs in the application to follow, where a kidney transplant has a higher utility than confinement to a sanitorium under treatment for tuberculosis. This implies that a day (week, month) of life with a kidney transplant is to be preferred to a day (week, month) of life confined to a sanitorium. This does not imply that chronic kidney disease is to be preferred to tuberculosis. On the contrary, a person with chronic kidney disease has a lower amount of expected health in total (higher health utility values in the immediate future followed by a poorer prognosis) than a person with tuberculosis (lower health

---

[1] The measurement procedure is described in detail on pp. 94-105 below.

utility values in the immediate future followed by a better prognosis).

Although the prognosis does not enter into the determination of the health state utilities it does, as the example above is intended to show, most certainly enter into the calculation of the expected total amount (units) of health and, hence, into the evaluation of health programs.

Financial considerations

The model proposed in this research takes a society-wide view. It attempts to allocate society's scarce resources in a manner which will maximize the health utility achieved as perceived by society. It assumes that society will arrange the necessary transfer payments to effect the optimal allocation so determined. This means that the health utilities should be measured free of any financial considerations. For example, if a person really prefers a heart transplant but feels he can't afford one, his utility should display this preference. The cost factor will be incorporated into the program evaluation by the model.

Financial considerations are excluded in practice by asking the respondent to imagine that he is fully insured -- complete medical insurance, salary continuation insurance, and life insurance -- so that regardless of the outcome, there are no financial implications to him or his family.

Development of the von Neumann-Morgenstern standard gamble technique for measuring health

Originally (versions 1, 2 and part of 3 in Table 2) the standard gamble was applied to this problem as follows:

1. Holding time constant (t) the subject was asked to preference rank the health states. Let i = 1,2,...,n represent the particular preference sequence for this respondent. Furthermore assume that the respondent preferred health the most and death the least.[1]
2. The respondent was asked to choose between the following alternatives:[2]

   Alternative 1: s_{n-1} for t, followed by death.

   Alternative 2: A hypothetical drug with instantaneous effect which would result in

   (a) s_1 for t, followed by death, with probability p, or

   (b) immediate death with probability (1-p).

   The value of p was varied to locate the respondent's indifference point and, from this, the value for state n-1 was calculated, assuming the respondent was indifferent when the expected amount of health utility from each alternative was equal. See Figure 6 below for a graphical display of this standard gamble.

---

[1]This was always the case except in an early preliminary version where coma was one of the states and a few respondents preferred death to it. Even if this occurs, the required modifications to the calculations are quite straightforward.

[2]For more details on the interview technique see pp. 103-105 below.

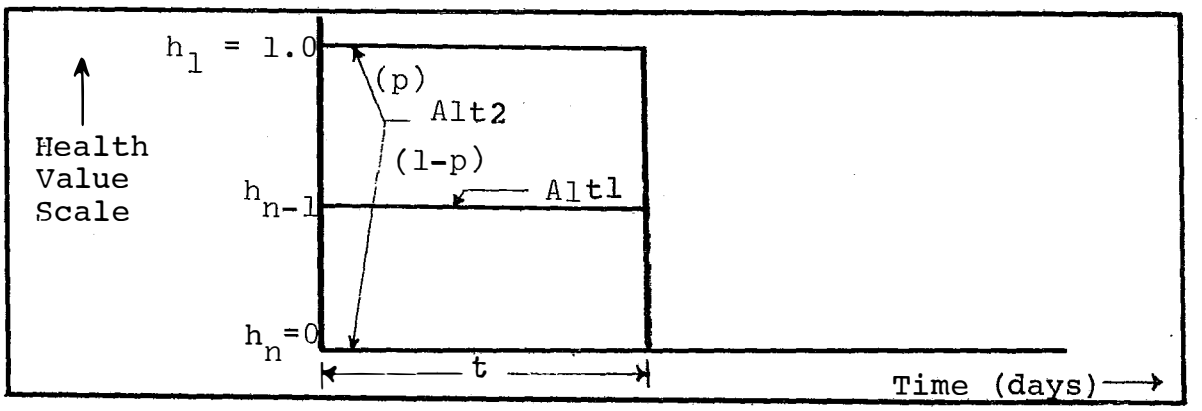

Fig. 6.--Standard Gamble for State n-1.

Utility of alternative 1 = utility of alternative 2.

$$h_{n-1}\ t = h_1 t\ p + h_n\ t(1-p)$$

$$h_{n-1} = p \qquad (1)$$

3. The other states, s_2 to s_{n-2} were measured as follows:

   Alternative 1: s_i for t, followed by healthy.

   Alternative 2: A hypothetical drug with instantaneous effect which would result in

   (a) immediate cure with probability p, or

   (b) s_{i+1} for t, followed by healthy, with probability (1-p).

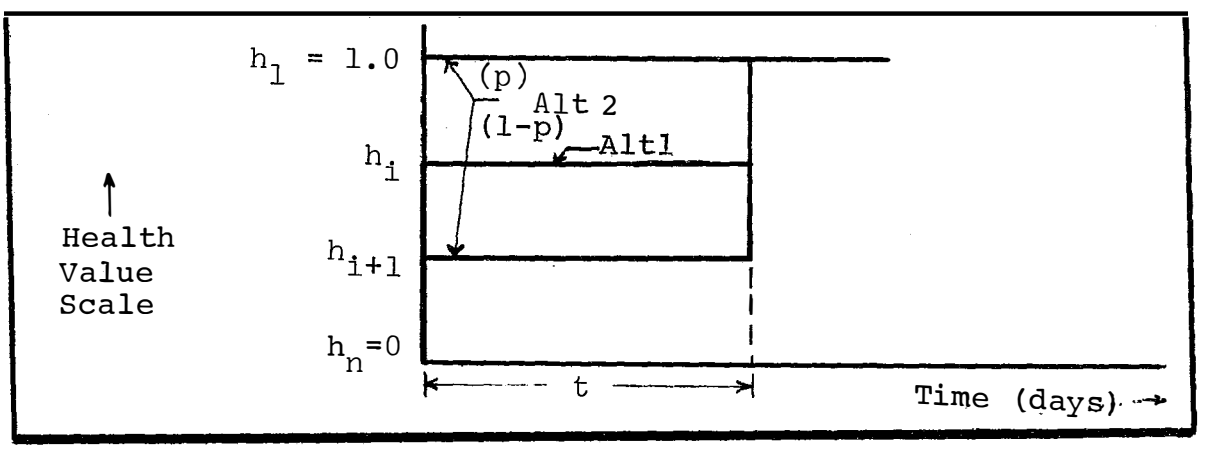

Fig. 7.--Standard Gamble for State i.

Once again the indifference probability p was used to calculate h_i as follows (see figure 7):

Utility of alternative 1 = utility of alternative 2

$$h_i \; t = h_1 \; t \; p + h_{i+1} t(1-p)$$

$$h_i = p + h_{i+1} \; (1-p) \qquad (2)$$

It can be readily seen that formula (2) is the general expression and contains formula (1) as a special case.

It will be noted that the format of this step is a slight variation on the classic von Neumann-Morgenstern standard gamble. In the latter, the gamble alternative (alternative 2) always relates back to the original benchmark states at the ends of the scale: in this case healthy and dead. The slight rearrangement outlined above is preferred for two reasons: it avoids continual reference to the state dead but, more importantly, it keeps the indifference probabilities nearer to 0.5 where they can be more accurately interpreted by the respondent.[1]

The standard gamble technique as outlined above and originally implemented in this research presented two problems. The first was a problem frequently mentioned in the literature as the reason why this technique is not applicable to health measurements. It stems from step 2, where

---

[1] See p. 236 below for the background discussion on this point.

the subject was faced with a probability of immediate death, and this prospect is so dreadful to many that they reacted strongly against it, resulting in high indifference probabilities (p) and consequently high health values (near 1.0) for all states other than dead.

Of course, these could be the proper values, except for the following factors:

(a) With the other measurement technique, where the subject was dealing with his future death rather than his immediate death, the resulting health state values were considerably lower.

(b) Similar lower values were obtained with the standard gamble technique when it was modified to also deal with deferred death only.

(c) The values are to be used in decision-making concerning future health programs and as a result the trade-offs to be evaluated will all be in the future.

Consequently, step 2 was modified as follows to deal only with deferred death:

Alternative 1: s_1 for t, s_{n-1} for t, followed by death.

Alternative 2: A hypothetical drug with a delayed reaction (delay time of t) to be taken now, which would result in one of the following two outcomes:

(a) s_1 for 2t, followed by death, with probability p, or

(b) s_1 for t, followed by death, with probability (1-p). Again p was varied to locate the point of indifference from which the value of the state was calculated. See figure 8 and the calculation below.

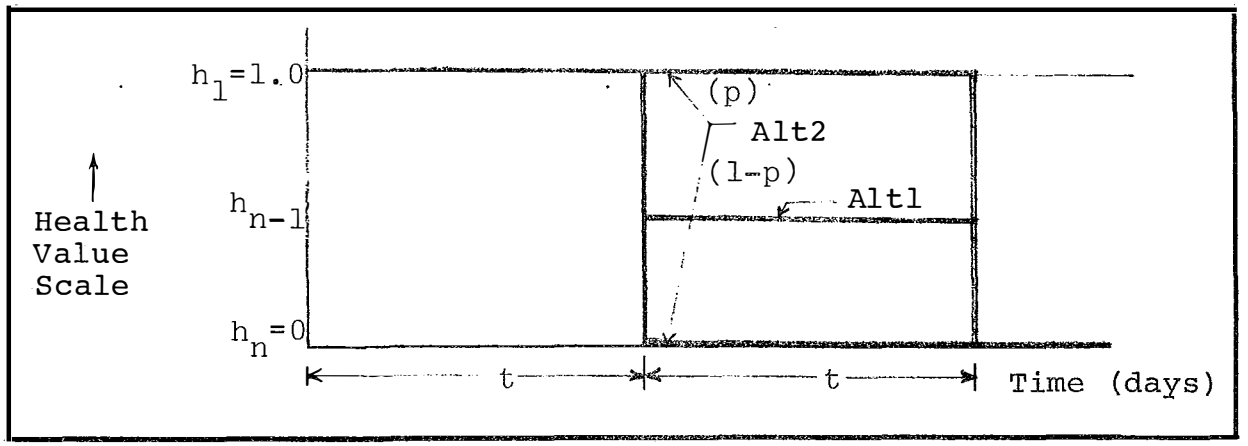

Fig. 8.--Modified Standard Gamble for State n-1.

Utility of alternative 1 = utility of alternative 2

$$h_1\ t + h_{n-1}\ t = h_1 t + h_1\ t\ p + h_n\ t\ (1-p)$$

$$h_{n-1} = p \qquad (3)$$

The second problem with the standard gamble technique was the difficulty in explaining the alternatives to the subject, especially one who was unfamiliar with probabilities. This problem was further compounded by the above modification to defer death which resulted in posing quite a complicated question to the subject. This problem was mitigated by developing a set of cards, such that each card would display one alternative. In the interview, the subject is merely shown two cards and asked to indicate the one he prefers.

These cards not only reduced the explanation problem but also shortened the interview time by approximately 50 per cent (from about 1 hour to 1/2 hour).

Development of the direct measurement and time trade-off techniques for measuring health

The second basic technique used to measure the health state values began as a direct measurement method, implemented as follows:

1. Holding time (t) constant the subject was asked to preference rank the health states. Let $i = 1, 2, \ldots, n$ represent the particular preference sequence for this respondent.
2. For all but the first two states, the subject was asked to state how many times worse he considered this state than the state immediately above it in his preference ranking. Let x_i represent this value for state i; then the health values could be calculated from the recursive relationship

$$x_i = \frac{1 - h_i}{1 - h_{i-1}} \qquad (4)$$

and the knowledge that $h_1 = 1$ and $h_n = 0$.

In fact, by rearranging (4) to

$$h_{i-1} = 1 - \frac{1 - h_i}{x_i} \qquad (5)$$

it can be seen the solution was very simple indeed by

merely starting with h_n.

In versions 1 and 2, it was suggested to the subjects that they use a time trade-off to help them establish their times worse figures. For example, if a person considers s_i two times worse than s_{i-1}, he should be indifferent between s_i for a duration of t, and s_{i-1} for a duration of 2t.

By version 3, the times trade-off was incorporated as the only method and all reference to times worse was dropped. There were several reasons for this:

(a) The time trade-off technique was being used almost universally by the subjects anyway to develop their times worse figures.

(b) The time trade-off concept was consistent with the eventual application of this data to health programs where time trade-offs would be required between various health states.

The time trade-off technique was applied as follows:

1. Holding time (t) constant the subject was asked to preference rank the health states. Let i = 1, 2,...,n represent this ranking. Assume state healthy was the most preferred and state dead the least preferred.[1]

---

[1]Once again, the modifications to the method are quite straightforward in the unlikely event that this is not so.

2. To determine the value for state n-1, the subject was given the following two alternatives:

   Alternative 1: s_{n-1} for t, followed by death.

   Alternative 2: s_1 for $x < t$, followed by death.

   Then x was varied to determine the indifference point, and the required health state value (h_{n-1}) was calculated as shown below.

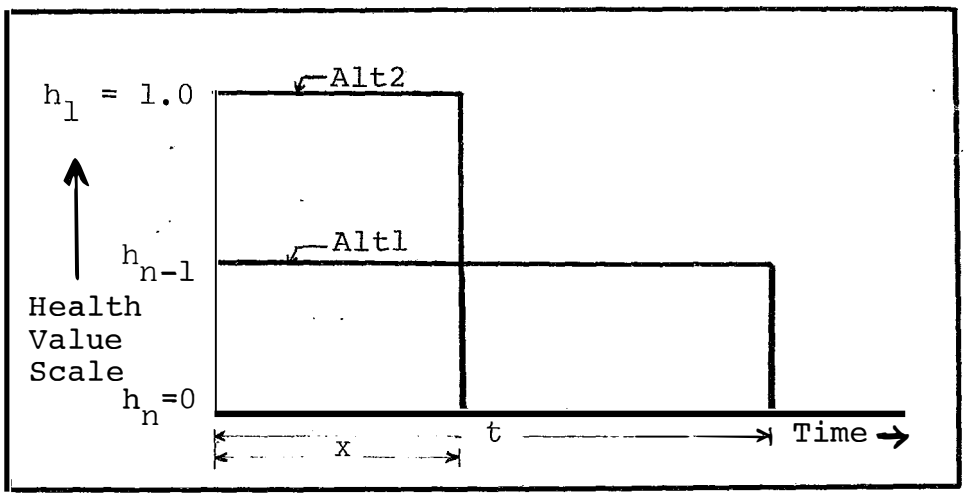

Fig. 9.--Time Trade-off for State n-1.

Utility of alternative 1 = utility of alternative 2

$$h_{n-1}\, t = h_1 x + h_n (t-x)$$

$$h_{n-1} = x/t \qquad (6)$$

3. To determine the value for any other state i, the subject was given the following two alternatives:

   Alternative 1: s_i for $x > t$, followed by healthy.

   Alternative 2: s_{i+1} for t, followed by healthy.

   Again x was varied to determine the indifference point.

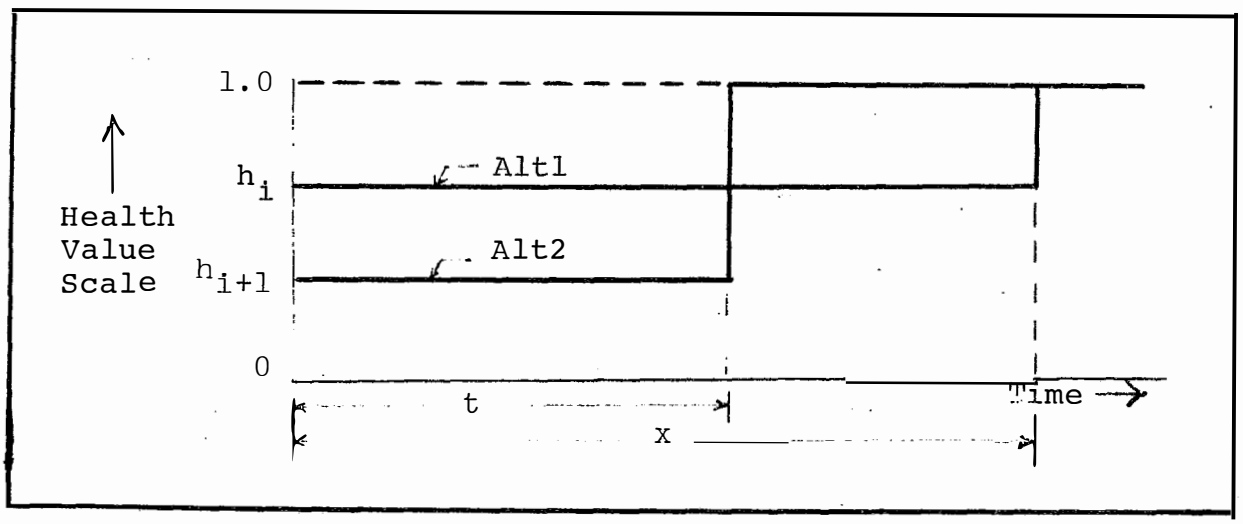

Fig. 10.--Time Trade-off for State i.

Utility of alternative 1 = utility of alternative 2

$$h_i\, x = h_{i+1}\, t + h_1\, (x-t)$$

$$h_i = 1-\frac{t}{x}\,(1-h_{i+1}) \qquad (7)$$

If we define t_n as t-x as displayed in figure 9 and t_i as the time in state i, i = 2,3,...,n-1, formulae (6) and (7) can be combined into the following single formula:

$$h_i = 1 - \frac{t_{i+1}}{t_i}\,(1 - h_{i+1}) \qquad (8)$$

Summary of the procedure for measuring health

Two techniques for the measurement of health state values have been developed in this research: a von Neumann-Morgenstern standard gamble method and a time trade-off technique. The detailed procedure for using these instruments is outlined below.

1. Define the health states to be valued and prepare a written description of each. The clinical description is of background interest only; the prognosis should be omitted. What is important are such factors as the degree of confinement, mobility, pain, depression, dietary restrictions, inconvenience, and social interactions. In other words, the factors which define the type of life-style implied by this health state. If the descriptions are listed in any manner, produce several randomized versions of the list for use in the experiment to eliminate any bias introduced by the order of the states as presented to the subject.
2. Determine the average time duration of interest for each health state.
3. States with similar times should be grouped into a common-time set. Use the same value of t for all states in such a set.
4. Determine all possible decisions which could be required of the subjects and prepare cards or some type of device to assist and speed up the explanation of each situation.

5. Determine the population of interest and use an appropriate statistical sampling scheme to select the subjects and to determine the size of the sample.
6. Ask the subject to make the following assumptions in answering the questions:
   (a) Answer for himself and not according to some stereotype that he feels is "right".
   (b) Assume there are no financial considerations involved. That is, he has complete medical insurance, salary-continuation insurance and life insurance.
   (c) Assume the outcomes will occur as stated in the alternatives. That is, the subject should ignore his own conception of the likely prognosis for each state.
   (d) Assume his affairs are in order.
7. For each individual randomize the order of presentation of the common-time sets.
8. For each common-time set ask the individual to preference rank the health states. This will completely determine all the forced-choice questions which must be asked.
9. For each individual randomize the sequence of the questions.[1]

---

[1]In this project, the questions were randomized within common-time sets, since it was felt that this would be easier for the subjects. However, there is theoretically no reason against, and some advantages for, randomizing the complete set of all questions.

10. Pose each question and locate and record the indifference point.
11. Calculate the health state value from each question using the appropriate formula developed in the previous section -- either (2) or (8) depending on the measurement technique.
12. Estimate the population value for each health state using conventional statistical inference.
    (a) The sample mean is the best point estimate of the true population mean.
    (b) Determine the confidence interval of the sample mean and, if this is larger than the permissable total error,[1] additional samples must be taken.

---

[1] One method of determining the allowable total error for a health state value is to perform sensitivity analysis on the model to discover the maximum error that can be tolerated without affecting the solution.

Application of the Measurement Techniques

The two measurement techniques developed in the previous section were applied in a carefully-controlled manner to a pilot sample of individuals. The purpose of this application was the following:

(a) To demonstrate the application of the health value measurement techniques.

(b) To test the techniques in actual practice in order to make recommendations for other researchers who may wish to apply them.

(c) To obtain some tentative values for the specific health states required for the applications which follow.

Sample

A limited convenience sample consisting of eleven General Practitioners in the Hamilton area was selected for the pilot testing of the measurement techniques. This sample was chosen to test and display the method only. It was not intended that the values obtained be used for other than illustrative purposes. (Indeed, a broad representative sample required to develop an accurate set of health values for a large population would not have been possible within the temporal and monetary constraints on the project.) However, it was intended that the method used on this limited sample could serve as a model for future applications to lar-

ger and more representative samples.

The sample used physicians rather than the general public for the following reasons:

(a) Physicians have a better understanding of the nature of the various health states than the average lay person. For example, how many lay people really know what it's like to be on renal dialysis? So it was reasoned that the physicians' responses would be based on superior knowledge compared to lay responses.

(b) A physician's value system with respect to health is often imparted to his patients anyway. It is quite common for patients to lean heavily on the advice of their doctor when making important health decisions and in this way the lay value system becomes, to some extent, a reflection of the physician value system.

(c) Part of the Operations Research method[1] is to define the decision-makers for the system under study and their relevant objectives. Then the best solution is the one which maximizes the attainment of these objectives. In the health service system, the decision-makers are primarily physicians. Thus, the physician health value system can be used as an approximation to that of the health system decision-makers'.

---

[1] See p. 37 above for a more complete discussion on the Operations Research method.

This is not meant to imply that the general public's health value system should not be measured. Indeed, one of the specific recommendations of this project is that it should be. Rather, it is an explanation of why, for this project, a sample of physicians was used.

The sample consisted of general practitioners only, rather than specialists, for very specific reasons. It was felt that the former were more in touch with the general public, had more influence over the public's value system, and had a more balanced view[1] of all diseases and disability states. The sample was selected by mailing a letter[2] to twenty physicians in general practice in the Hamilton area who were associated with the McMaster Faculty of Medicine. Of these, eleven agreed to participate. Thus, the sample is clearly non-random and non-representative and the specific results obtained cannot be generalized to any population at all. However, such was never the intent. What can be generalized, though, are the conclusions about the health value measurement techniques per se and the recommendations for others who wish to apply the instruments.

---

[1]The unbalanced view of the specialist which is implied here refers to the fact that a specialist may have a biased view of the importance of the specific diseases and disability states treated by his specialty.

[2]See Appendix I, Exhibit 3, for a copy of this letter.

Experimental method

Health States and Descriptions

Values were required for five specific health states; home confinement, sanitorium confinement, home dialysis, hospital dialysis and kidney transplant. Descriptions of these states were prepared in conjunction with physicians specializing in these particular diseases[1] and were listed on two sheets for the convenience of the subjects. Two randomized versions of each sheet were produced to eliminate positional bias and the sheets were randomly assigned to the subjects.[2]

The relevant time duration for the two tuberculosis states was considerably shorter than that for the kidney states, so the descriptions were grouped into two common-time sets with selected times (t) of 4 months and 5 years respectively.

---

[1] Dr. W.D. Wigle, Tuberculosis Prevention Branch, Department of Health, Government of Ontario, for the tuberculosis states; Dr. E.K.M. Smith, Associate Professor, Department of Medicine, McMaster University, for the kidney disease states; and Dr. D.L. Sackett, Chairman, Department of Clinical Epidemiology and Biostatistics, McMaster University, for all states.

[2] See Appendix I, Exhibit 4, for samples of the description sheets.

Questions and Replications

Each of the five health states was measured in two ways for each individual -- with the time trade-off and the standard gamble techniques. This alone, without replication, required the subject to deal with 10 different situations (questions), reaching an indifference point in each. Complete replication, although statistically desirable, was ruled out because it would have doubled this number and the interview time was already approaching its upper limit. A second reason complete replication was avoided was the difficulty foreseen in properly disguising so many repeated questions. Hence, it was decided to replicate only one state in each common time set for each measurement method. That is, 4 of the 10 values for each individual were replicated.

The problem in replication is to modify the situation enough to disguise it but not enough to change it in any basic way. This was accomplished in the following manner. In the time trade-off replication the time duration was changed (from 4 to 6 months and from 5 to 7 years) and the states were reversed as to which one was fixed and which was incremented in locating the indifference point. In the standard gamble replication, the time duration was changed and the card describing the gamble alternative was drawn up in reverse order. In both cases, the randomization of

the question sequence was organized to separate the replicates, one near each end of the sequence.

To aid in describing the hypothetical decision situation to the respondent, a set of cards was created in advance; one card representing each alternative. Some cards contained variable data which was modified during the course of the interview. In all, 34 cards were required to allow the creation of any of the 60 possible questions.

Data Collection

The data was collected by a two-man interview team (the author and a research assistant) who visited each general practitioner in the sample. After a brief explanation of the overall project, the actual measurement was conducted by following steps 6 to 10 as previously described on pages 104 and 105. The time required to conduct the measurement portion of the interview ranged from 16 to 45 minutes with a median value of 25 minutes. All the subjects were interested and cooperative and, contrary to the experi-

ence of other researchers,[1] none rebelled against the concept of quantifying the value of health states or against the techniques used.

Discarded data

The data was gathered by asking 11 subjects 14 questions each, or a total of 154 questions. Of these 2 had to be discarded as invalid. One was a replicated question recognized by the respondent. The other was a time trade-off question on state n-1 with one of the early subjects in which he placed a constraint on his answer by assuming his affairs were not in order. This constrained him from reaching his true indifference point on this question, and, hence, his true utility. This problem was avoided with subsequent subjects by asking them to assume their affairs were in order.

---

[1]See for example: Flagle, 1966, p. 400; Stimson, 1969, p. B-24; and Sanders, 1970b.

Reliability of the measurement techniques

A measurement technique is reliable if it is consistent -- if the same phenomenon can be measured a second time and the same result obtained. Used in this sense reliability is synonymous with reproducibility, precision, and freedom from random error.[1] It is determined by computing a correlation coefficient between two sets of measurements presumably measuring the same thing. This may be done in three different ways.[2]

(a) Test-retest method -- repeat the identical test on the same subjects six months to a year later.

(b) Equivalent measures -- measure each item with two different but equivalent instruments.

---

[1] Relevant definitions are as follows:

1. Reliability is "consistency of measurement...a synonyn for repeatability" (Guion, 1965, p. 29).
2. Reliability is "the extent to which a set of measurements is free from random-error variance" (Guion, 1965, p. 30).
3. Precision is "the closeness together of successive independent measurements of a single magnitude generated by repeated applications of the process under specified conditions" (Natrella, 1963, p. 23-1).

[2] For a more detailed description of these methods see Guion, 1965, Chapter 2.

(c) Internal consistency -- replicate some or all of the questions by modifying them sufficiently to disguise them, but leaving their basic content unchanged. If this method is used, the question sequence randomization should be organized to separate the replicates as far apart as possible to minimize the risk that some subjects will recognize the similarity of the two questions.

The last two methods were used in this project to test the reliability of the measurement technique. Specifically, the following three reliabilities were determined: (1) the internal consistency of the von Neumann-Morgenstern standard gamble; (2) the internal consistency of the time trade-off; and (3) the equivalence of the two techniques.

1. Internal Consistency of the Standard Gamble

In determining the reliability of the standard gamble technique, all calculations were performed as though this technique had been the only one used. Specifically, in computing h_i for an individual, only the value of h_{i+1} determined from the standard gamble was used; the value determined from the time trade-off was ignored.

The reliability of the standard gamble technique was determined by replicating two questions for each subject for a total of 22 replications. The first concern in analyzing the resulting data was to determine whether or not the

modifications made to the questions for replication had been successful. First, these modifications should have disguised the questions sufficiently that the respondents would not recognize them as repeated questions. This appeared to be successful. Of the 22 replications there was only 1 case where the subject commented that this was a repeated question and gave the same value as he had used previously (this reading was discarded); there were 2 where the subject thought he had previously answered a question like this but when he was told that this was different, he proceeded to answer it and give a different figure, and in the remaining 19 cases, the subject appeared completely unaware of the replication.

Secondly, these modifications should not change the questions to the extent that they would measure something different. That is, there should not be a significant difference in the values obtained with the original questions and those obtained with the modified questions. This was tested with a paired t-test. The mean difference between paired values (the figure obtained from the original question minus that obtained from the modified question for the same state and the same individual) was 0.010 and this was not statistically significant at a level of significance of 5 per cent. Thus, it can be concluded that the modifications made to the standard gamble question were successful in providing the desired hidden replicates.

The reliability of the standard gamble technique was determined using the method outlined by Guion (1965, p. 30). The computed correlation coefficient (coefficient of reliability) for the 21 pairs of data was 0.965, with a 95 per cent confidence interval of 0.920 to 0.985.[1] This high reliability means that in this application the standard gamble was relatively free from random error. In fact, the coefficient of reliability, 0.965, can be interpreted directly as an estimate of the proportion of the total variance accounted for by systematic sources[2] (health states, individuals, and state-individual interactions). The remainder, 0.035, would be the proportion contributed by random-error.

2. Internal Consistency of the Time Trade-Off Technique

The reliability of the time trade-off technique was determined in exactly the same manner. The calculation of the health state values was performed as though this technique had been used alone. The validity of the modified questions was investigated, with similar results to the standard gamble. No respondents recognized a repeated question with certainty, on only one question did a respon-

---

[1] See Appendix I, Exhibit 5, for the calculations.

[2] See Guion, 1965, p. 31.

dent hesitate because he thought he had answered it before, and on the other 21 questions, the subjects appeared completely unaware of the replication.

The mean difference between paired values was -0.026 and again this was not significant at the 5 per cent level.

The coefficient of reliability for the time trade-off technique was 0.858 with a 95 per cent confidence interval of 0.676 to 0.941.[1] Although 0.858 represents good reliability, it is interesting to note that this is significantly lower (at a 5 per cent level of significance)[2] than 0.965, the coefficient of reliability obtained for the standard gamble. This would suggest that the standard gamble is a more reliable method than the time trade-off technique. Numerically, this is undoubtedly so. But whether or not the higher reliability leads to higher validity depends upon the underlying causes of the high correlation coefficient.

From examining the original data and the interview technique, the following reasons can be suggested for this high correlation:

---

[1] See Appendix I, Exhibit 6, for the calculations.

[2] See Appendix I, Exhibit 7, for the calculations.

(a) The replicated questions in the standard gamble method did not appear to be quite as well disguised as those in the time trade-off technique. This, of course, could contribute to a high reliability for the standard gamble.

(b) Although both measurement techniques are theoretically continuous, in actual practice they tend to be discrete and this favours the standard gamble for reliability. For example, in the standard gamble, a respondent could theoretically select any indifference probability at all between 0 and 1. However, most respondents were uncomfortable with decimal probabilities and fractions were used instead. This resulted in the frequent appearance of such probabilities as 1/2, 1/3, 1/4, 1/5, 1/10 and 1/100. This limited set made it quite possible that a respondent with good consistency would obtain the identical value on a replicated question. (This happended 9 times out of 21.) Similarly the time trade-off technique tended to use discrete points -- in this case, years. However, the replicated questions were such that if a consistent subject responded in discrete years only, it was often arithmetically impossible for him to obtain an identical result. For example, suppose he were indifferent between 5 years of A and 6 years of B the first time.

The replicated question would show him 7 years of B and ask at how many years of A would he now be indifferent. Answering in discrete years only, it would be impossible to be completely consistent (make the two ratios equal).

3. Equivalence of the Two Techniques

The final test of reliability was to examine the values obtained for the same states from each of the two techniques. In this case, all the data was used in the calculations. For example, in the determination of h_i, the best estimate of h_{i+1} was assumed to be the mean value of h_{i+1} as determined by each technique. Similarly, for replicated questions, the mean value of the replications was used as the best point estimate of the true figure for that individual, that state and that measurement method.

Again a paired difference test was used to determine whether or not the two techniques were yielding significantly different results. The mean difference between paired values (the time trade-off figure less the standard gamble figure for the same state and the same individual) was 0.037 and this was not statistically significant at a 5 per cent level of significance.[1] This suggests that the

[1] See Appendix I, Exhibit 8 for the calculations.

two techniques are indeed measuring the same characteristic and can be considered equivalent.

This conclusion is further supported by the high coefficient of reliability obtained between the two methods. The coefficient of correlation between the values obtained from each technique was 0.850 with a 95 per cent confidence interval of 0.756 to 0.911.[1]

In summary, then, the reliability studies proved quite encouraging. The modified questions for replication purposes worked well; each measurement technique was highly reliable on a stand-alone basis; and when combined, the two methods proved to be equivalent and quite reliable.

Health state values

One objective of taking a sample of individuals and measuring their health state values in this research, was to estimate, for each health state, the true population mean health value. Both a point estimate and an interval estimate were desired.

In determining these population estimates, the individuals were treated as a random sample from the population of interest.[2] However, the repeated measurements on

---

[1] See Appendix I, Exhibit 8 for the calculations.

[2] In this experiment the sample was far from random and the appropriate qualifications and limitations were discussed on pp. 106-108 above.

the same health state for any one individual could not be considered as additional data points in the random sample. Rather they had to be viewed as random samples from within a homogeneous group -- the individual. A further complication in the analysis was created by the unequal number of repeated measurements for different individuals.[1] Dixon and Massey discuss the technique required to make point and interval estimates of the population mean in this situation (1957, p. 129). Basically, it consists of treating the group means (individual means) as independent random observations from the population, but weighting them for the different group sizes.

The results of this calculation on the data from the experiment are summarized in Table 3 below and graphically displayed in Figure 11.

---

[1]The unbalanced replicates can be readily seen in the data matrix of Appendix I, Exhibit 9.

TABLE 3

HEALTH STATE VALUES[1]

Health State	Point Estimate (of Population Mean Value	Standard Error	df	95 Per Cent Confidence Interval
A. Healthy	1.00	.00	--	--
D. Kidney Transplant	.83	.04	10	.74- .92
E. Home Dialysis	.66	.08	10	.47- .85
B. Home Confinement	.56	.07	10	.40- .72
F. Hospital Dialysis	.53	.10	10	.31- .75
C. Sanitorium Confinement	.34	.10	10	.11- .57
G. Dead	0.00	.00	--	--

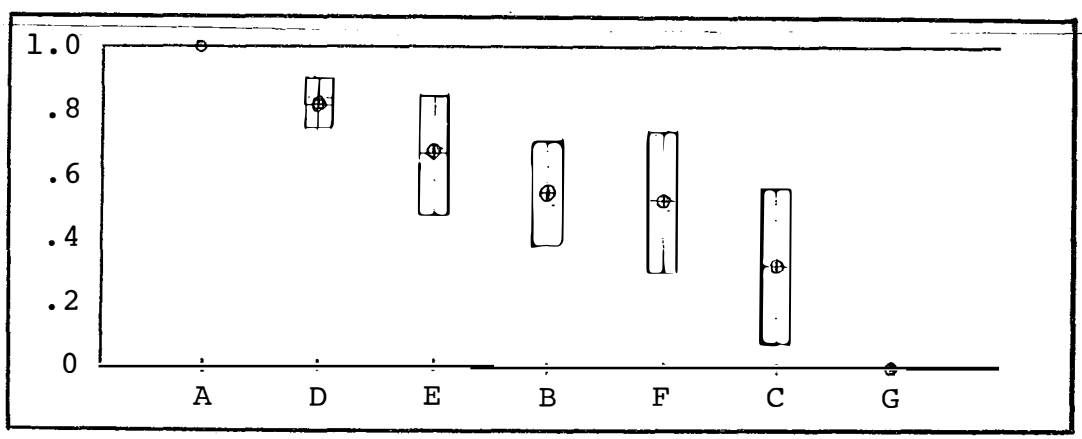

Fig. 11 - Health State Values and 95% Confidence Intervals

[1]The data on which these results are based is displayed in Appendix I, Exhibit 9; the method and details of the calculations in Appendix I, Exhibit 10.

The interpretation of these results is as follows: The best point estimate of the true population mean health value for kidney transplant is 0.83. Furthermore, there is a 95 per cent probability that this true value lies between 0.74 and 0.92. Thus, a day of living with a kidney transplant has a utility of 0.83, as compared to a day of healthy living with a utility of 1.0. The interpretation for the other states is the same.

The confidence intervals on this data are fairly large. However, these can be reduced by taking a larger sample of individuals. In fact, the confidence interval is approximately inversely proportional to the square root of the sample size.[1] For example, if the sample size is increased four times the confidence intervals will be cut in half. This, then, is just a normal sampling situation -- the size of the sample required depends upon the error or confidence interval one is willing to tolerate in the estimates.

This implies that the accuracy of the results can be improved to a high level by increasing the sample size. This is only true if the measurement technique is valid -- that is, if it measures the characteristic which it intended

---

[1] This is exactly true, as long as the samples have common variance and the sample size is greater than 30. For example, let S^2 be the common variance, then for all N greater than 30, the 95 per cent confidence interval is $1.96S^2/\sqrt{N}$.

to measure.

In this case, that was the utility of the health states as perceived by society. To test whether or not the results measure this characteristic, an independent "true" measure of the same trait is required. One possible method of doing this would be to assume that people make their health care decisions based on this underlying utility -- this is really quite a plausible assumption since the utilities were measured by presenting individuals with hypothetical health care decisions and determining the implicit utilities they exhibited in making these decisions. Thus, the measured utility should be identical to the health care decision utility. With this assumption, then, actual decisions made by individuals or groups of individuals could be studied to determine if these could be explained (predicted) by the measured utilities.

The scope of this project could not include a thorough investigation of this question of validity. Consequently, it is recommended that further research be conducted in this area.

Conclusions

In this research project, two measurement techniques (a von Neumann-Morgenstern standard gamble method and a time trade-off method) were applied to a pilot sample of eleven general practitioners in the Hamilton area. While this sample was too small and too restricted for drawing general inferences concerning the health values obtained, it was suitable for forming some preliminary conclusions about the usefulness of the measurement techniques themselves.

The first conclusion is that the measurement techniques were quite satisfactory, in fact, better than had been expected. The format of the approach (individual interviews, description cards, disguised replicate questions) proved effective. Each technique was highly reliable on a stand-alone basis; and when combined, the two methods proved to be equivalent and quite reliable. The final health state values contained considerable variance but this was almost exclusively the result of the small sample size with little contribution from random measurement error (as reflected by the high coefficients of reliability); and hence, could be readily rectified by enlarging the sample.

Neither of the two measurement techniques was obviously superior to the other. The standard gamble approach had the better reliability, although this appeared to be at least partly due to the discrete nature of the responses.

On the other hand, the time trade-off method had better-disguised replicated questions, as measured by respondent discovery, and this was not only an advantage in itself, but also may partially account for the lower reliability determined for this method. A major advantage of the time trade-off approach was the ease of explaining it to the subjects. The standard gamble question, with its probabilities, was often difficult for the subject to grasp -- frequently the question had to be repeated before a respondent could understand it. There is no doubt that the standard gamble technique would be very difficult indeed to apply to subjects with less education than physicians: for example, the man-on-the-street. In summary, then the time trade-off method would appear to be slightly better than the von Neumann-Morgenstern standard gamble for measuring health state utility values.

A further advantage of the time trade-off technique is its potential for use in a mailed questionnaire. This would be a significant advantage if a large sample was desired. In a mailed questionnaire, it would be difficult to properly disguise replicated questions and it would probably be best to omit these. This should pose little problem since most of the variation in each health state is caused by individual differences rather than random error. Furthermore, if it were desired to measure reliability on a mailed questionnaire, it could readily be handled by a test-retest

approach.

In using the individual interview technique again, it would be worthwhile to attempt replication of each question. If this can be achieved, it produces a balanced design which has significant computational and statistical advantages.

It is recommended that further research be conducted in two specific aspects of health utility measurement: validity and general health states. Validity was discussed briefly on pages 123 and 124 and is obviously a critical high priority research item. General health states are disease-independent disability categories. The concept would be to specify a complete spectrum of such states, such that any possible health condition would be approximately equivalent to one of these general states. Then the health value for each state would be measured, producing a universal set of values which could be used to evaluate any type of health program regardless of the disease, the type of program, or the type of patient.

CHAPTER IV

HEALTH PROGRAM ANALYSES

Data Required to Analyze a Health Program with this Model

Program definition

In this model, the term health program is used in its broadest possible context. Any activity in the health service system will be defined as a program. It is immaterial whether or not this activity is sponsored by some organization or institution and labelled as one of their programs. All that matters is that the program (activity) can be precisely defined.

The definition of a health program requires the specification of the activity -- its scope, intensity and duration. The scope of a program refers to its population coverage. That is, at what group of people is this program directed and how many of them will avail themselves of it? The intensity of a program pertains to the level of resources committed to it; what level of support is planned for the program -- minimal, maximal or something in-between? And finally, the duration of a program refers to the time during which these changes are expected to be in effect.

Frequently a proposed change to the health service system can be directed at different groups of the total population, can be supported at various possible levels, and can be planned for various time durations. When this is so, it is generally desired to evaluate the proposed change at all possible combinations of its scope, intensity and duration. For the purposes of this model, each potential combination is defined as a separate program. Many of these programs will be mutually exclusive -- for example, programs for the same population at different levels of intensity and duration.

To evaluate a proposed program, we must predict what would happen both with and without the change. The latter requires the definition of a no-program or benchmark situation. Generally this will be the continuation of the status-quo. Sometimes it will be the continuation of the existing situation with some future improvements built in, where these are already planned or authorized.

The above discussion has been phrased in terms of the evaluation of proposed programs. But what about the evaluation of existing programs? In this case, there are really two questions, and they might have quite different answers: (a) how well has the existing program performed in the past, and (b) should the existing program be continued into the

future.[1] However, both questions can be handled by the same model -- the one proposed in this research. In the first question, the program is treated as the change and the benchmark is the situation that would have existed had the program not been in effect. In the other question, there is a choice of two methods, either of which will yield the same results. The proposed program may be defined as the continuation of the existing program, in which case the benchmark is the situation which would exist if the program were cancelled. Or, the proposed program may be defined as the cancellation of the existing program with the benchmark its continuation. These two formulations of the problem are completely equivalent.[2]

The specific information required to analyze a health program with the model developed in this research can be summarized as follows:

1. Define the general nature of the proposed change.
2. Define all possible programs inherent in the proposed change -- all feasible combinations of all levels of scope, intensity and duration.

---

[1]These two questions are exactly analagous to the concepts of control and planning in the management literature: see for example Anthony, 1965, pp. 1-23. The exploration of this analogy could likely lead to valuable research into the management of the health service system.

[2]See p. 69 above for the explanation of this point.

3. Partition this total set of programs into subsets of mutually exclusive programs.
4. Define the no-program or benchmark situation.

Data requirement

The following data is required for each program defined in the previous section. In each case, the data is measured as the difference between the program situation and the benchmark situation.

1. The net cost of the program to society each year. For each year the net cost is:
   a) the direct cost of the program (administration costs; facility costs - hospital space, office space, special equipment; manpower costs - physician time, nurse time; and materials cost - drugs, laboratory materials), plus
   b) the indirect cost of the program (productivity lost because people participate in the program - for example, time off-work to attend a mass chest x-ray program), less
   c) the direct savings of the program (the direct health care costs which would have been spent on the cases prevented or cured by the program), less
   d) the indirect savings of the program (the lost earnings due to illness and premature death prevented by the program).

This net cost of the program to society is precisely the same figure (with the opposite sign) as the net benefits of the program when calculated by a cost-benefit analysis. In fact, it is recommended that the assumptions and procedures that are used in cost-benefit analysis[1] should be applied to the determination of this net cost.

A finer breakdown of this net cost to society may be required in some cases. For example, it may be desired to identify those items in the net cost which are the responsibility of a particular level of government or a particular agency. This would be necessary if a constraint were to be imposed on these funds available.

2. The health benefit from the program each year, measured in units of health. This may be calculated using any of the alternative formulae developed in Chapter IV (pp. 57-66). Regardless of which formulation is used, the following information is required:
   a) a list of the different health states involved in the program plus any additional ones required for the benchmark situation;
   b) the health value for each of these states;

[1] Specifically the productive resources version of cost-benefit, outlined on p. 8 above.

c) the health effect of the program each year relative to these health states. This may be specified in one of the following ways: (1) the annual man-days in each state with and without the program, (2) the health state changes for specific groups of people caused by the program, or (3) the health state transition probabilities with and without the program.

This health effect of the program is required for each year that the program has any effect and this may be for many years indeed. For example, consider a program, even of short duration, that saves a life. For as many years as this person lives the program is providing health benefits since in the benchmark situation the person would be dead.

The difficulty in estimating these health effects increases with their distance into the future, but fortunately, due to the discounting, so does the insensitivity of the solution to errors.

Tuberculosis Screening Program

Program definition

Description[1]

The Ontario Department of Health through its Tuberculosis Prevention Service operates a number of programs directed at all phases of tuberculosis control. These include the financing of provincial sanitoria, the operation of district chest clinics, the maintenance of a provincial case registry, special studies on certain types of tuberculosis, a mass chest x-ray and tuberculosis testing survey, a hospital admission chest x-ray program, a jail chest x-ray program, and tuberculin testing and chest x-ray programs for special groups of individuals such as food handlers and barbers.

From this list the mass survey was chosen to be one of the example applications. It was selected because of the relatively extensive and accurate data available -- the Province has been operating this program and maintaining detailed statistics for many years. It is not intended that this work constitutes an evaluation of this particular program (a more detailed study would be required for this purpose), but rather it is hoped that it will display the way in which the model developed in this research can be applied to a real on-going health program.

---

[1]The material in this section is primarily extracted from the 1968 Annual Report of the Tuberculosis Prevention Service (Ontario Department of Health, 1969a).

The program is a mass chest x-ray and tuberculin testing survey which operates as follows:

a) All school children in public school or high school receive a Mantoux Test and positive reactors are x-rayed. In addition, the local Health Department conducts a follow-up of the contacts of such positive reactors in an effort to determine the source case.
b) All adults who attend the clinic receive a Mantoux Test and a chest x-ray.
c) A separate unit visits local industry and provides chest x-rays only.

The analysis of this program is oriented to the future. The question is what are the expected costs and benefits of continuing this program and how do they compare with other alternatives which may be available?

Specific Programs

For the purpose of the model, each specific combination of scope, intensity and duration constitutes a separate program.[1] In this analysis the total Provincial mass chest x-ray and tuberculin testing program was divided into smaller programs as follows:

---

[1] See p. 141 above for a more detailed explanation of this point.

a) 73 geographic areas in the Province were defined - 19 cities and 54 counties,[1]

b) 3 intensities were investigated -- once per 2 years, once per 4 years and once per 8 years, and

c) 3 time durations were examined -- a 1 year program, a 5 year program and a 15 year program.

Each geographical area was investigated at each intensity and each time duration, resulting in a total of 657 different programs; which were then partitioned into 54 mutually exclusive sets. Each country was the basis of such a set. In the case of a rural county, the mutually exclusive set consisted of 9 programs -- the county at each of the 3 levels of intensity and 3 durations. If the county contained one or more of the 19 cities the set consisted of an additional 9 programs for each such city.

The no-program or benchmark case, to which all programs were compared, was the situation that would exist if the Provincial mass surveys were eliminated.

---

[1] See Ontario Department of Health, 1969c, pp. 40-42, 48 for the list of these areas.

Calculation of health benefits

Assumptions

1. The health states involved in assessing a tuberculosis mass screening program can be reasonably approximated by the following four: (1) healthy, (2) home confinement, (3) sanitorium confinement, and (4) dead. As an example of the amount of approximation introduced by this assumption, a patient is considered healthy as soon as he is discharged from the sanitorium even though he may be feeling less than perfect for a period of time.
2. The best estimates of the mean population health values for the people of Ontario for these four states are 1.00, 0.56, 0.34 and 0.00 respectively, as determined from the limited sample taken in this research. Whereas these estimates may be the best available, they're certainly not very good. They are used here only for illustrative purposes.
3. The epidemiological model of tuberculosis published by Ferebee (1967) is assumed to hold. This is considered to be the most appropriate model for Ontario by the specialists in the Tuberculosis Prevention Service.
4. The findings of Iversen (1967a and 1967b) in his study of the mortality rates for tuberculosis patients in Denmark is assumed to apply to Ontario. This may be quite a questionable assumption but until a similar study is conducted locally, Iversen's data is all that is available.

5. The population of the Province of Ontario is assumed to be growing at a constant rate of 1.56 per cent per year.[1] It is further assumed that this growth will be uniform throughout the province.

6. It is estimated that a mass survey will screen approximately 40 per cent of the population in a city and 60 per cent in a rural area.[2] For a mixed area, a weighted average is used.

7. If a mass survey is planned for a geographical region on a once per n year basis, it is assumed, for ease of calculation, that 1/n th of the population of that region will be targeted for screening each year. This is not an unrealistic assumption -- for example, the current program for the city of Toronto is being operated exactly this way.

8. It is assumed that the current rate of decrease for the incidence of tuberculosis in Ontario of 6.9 per cent per year[3] will continue.

9. The number of active cases found in a mass survey will be proportional to the prevalence of tuberculosis in the population of the district being screened.

---

[1] This is the growth rate used for short-term population projections by the Ontario Department of Treasury and Economics (1968).

[2] Estimate provided by Dr. W. D. Wigle, Tuberculosis Prevention Service, Ontario Department of Health.

[3] See Appendix II, Exhibit 1 for the calculation of this rate of decrease.

10. It is assumed that pulmonary tuberculosis will continue to account for the same fraction of active tuberculosis as it now does, 80.2 per cent.[1]

11. During 1967-68, the new active pulmonary tuberculosis cases discovered by mass surveys were 4.6 per cent for advanced, 32.2 per cent moderately advanced and 63.2 per cent minimal.[2] These porportions are assumed to continue to hold.

12. During 1967-68, the new active pulmonary tuberculosis cases discovered from symptoms were 29.5 per cent for advanced, 38.6 per cent moderately advanced, and 31.9 per cent minimal.[2] These proportions are assumed to continue to hold.

13. It is assumed that, on the average, active cases are discovered by the mass screening program a year earlier than they would have otherwise been discovered.[3]

14. In recent years, an increasing percentage of the active pulmonary tuberculosis cases have not been admitted to

---

[1]This is a 5 year average figure (1964-1968) from Ontario Department of Health (1969c, p. 12) and previous years of the same publication.

[2]See Appendix II, Exhibit 2 for the supporting data and calculations.

[3]Although no data was available to substantiate this assumption, it was considered a reasonable estimate by Dr. W.D. Wigle (1970).

a sanitorium. During 1968 (the latest data available), this figure was 14.7 per cent. For those with far advanced tuberculosis, 3.4 per cent were not admitted; for moderately advanced the figure was 11.9 per cent and for minimal 24.3 per cent. It is assumed that these proportions will continue to hold.

15. To determine the mean duration of stay for patients admitted to a sanitorium, a five-year average was calculated for the period 1964 to 1968.[1] The resulting durations were 268.7 days for patients with advanced tuberculosis, 179.3 days for moderately advanced and 130.2 days for minimal. These durations were assumed to continue to hold. This assumption is a simplification for calculation purposes. In actual fact, sanitorium durations of stay have been decreasing in the past and may continue to do so in the future. If one wished to incorporate a rate of decrease it could be handled by the method outlined for projecting the prevalence rate.[2]

16. Patients treated for tuberculosis at home are confined for a considerably shorter period of time than those in a sanitorium. It is estimated that this period of

---

[1]Source: Ontario Department of Health, 1969b, Table 12.

[2]See Appendix II, Exhibit 1 for this method.

home confinement averages 93 days for patients with advanced disease, 73 days for moderately advanced and 44 days for minimal.[1]

17. It is assumed that there will be no major breakthrough in therapeutic techniques for the treatment of tuberculosis.

Calculation Algorithm

A tuberculosis screening program creates health benefits in two ways:

a) Active cases are discovered earlier than they would have been otherwise. This results in fewer infections from these active cases and ultimately, less disease in the population.

b) Active cases are discovered at an earlier stage of the disease than they would have been otherwise. That is, more of the cases are in the minimal category and fewer have progressed to the advanced state. This results in shorter treatment periods and less reduction in life expectation for the patients.

The calculation algorithm for determining the annual health benefits of a mass survey is developed below:

Let S be the first year of the program to be evaluated,

P(X) be the population of the target group in some base year, X,

---

[1]Estimated by Dr. W.D. Wigle (1970).

$R(Y)$ be the rate of active tuberculosis per 100,000 people in the target population in some base year, Y,[1]

α be the fraction of the target population screened by the mass survey (from assumption 6), and

ω be the intensity of the program -- fraction of the population targeted for screening each year (from assumption 7).

Then, from assumption 5, the population of the target group in year N is

$$P(N) = (1.0156)^{N-X} P(X) \qquad (1)$$

The number of people screened in year N is

$$B(N) = \alpha\omega P(N) \qquad (2)$$

From assumption 8, the rate of active tuberculosis (prevalence) per 100,000 people in year N is

$$R(N) = (.931)^{N-Y} R(Y) \qquad (3)$$

From assumption 10, the rate of active pulmonary tuberculosis per 100,000 people in year N is

$$A(N) = 0.802\ R(N) \qquad (4)$$

The number of cases found by screening is also a function of the survey factor -- the ratio of the rate of active cases

---

[1] In the application a five-year average rate was used to provide a more stable projection base.

found in the screened group to the rate in the target population. This was found to be 0.69.[1] The estimated number of active cases of pulmonary tuberculosis which will be found in year N by the mass survey is then

$$F(N) = 0.69\ A(N)\ B(N)\ 10^{-5} \qquad (5)$$

From assumption 11, the number of cases that will be advanced, moderate and minimal is 0.046 F(N), 0.322 F(N) and 0.632 F(N) respectively. If the program did not exist, these F(N) cases would be discovered a year later[2] (in year N+1), at which time a higher proportion of them would be in the more advanced states (see assumption 12). During the time that the F(N) active cases went undiscovered in the population, they would be infecting additional people, thereby causing additional active cases. The number of additional active cases caused in this way can be computed by the following formulae (formulae 6 and 7):[3]

---

[1] This is an average of the survey factors for 1964-1968. For the prevalence rate in the screened group, see Ontario Department of Health, 1969a, p. 35.

[2] See assumption 13, p. 139 above.

[3] These formulae are derived from the epidemiological model of tuberculosis published by Ferebee (1967). See Appendix II, Exhibit 3 for their detailed development.

Let $V_N(J)$ be the number of new active cases caused in year J from the infection chain begun in year N by the F(N) active cases, and

$W_N(J)$ be the size of the pool of infected people in year J caused by the infection chain begun in year N by the F(N) active cases.

Then,

$$V_N(J) = .25V_N(J-1)+.0016W_N(J-1),\ J = N+1,\ N+2,... \quad (6)$$

where

$$V_N(N) = F(N)$$

$$W_N(N) = 0$$

and $$W_N(J) = .9788\ [W_N(J-1)+3V_N(J-1)-V_N(J)] \quad (7)$$

Let X(J) be the total number of new active cases created in year J from this infection-chain effect. That is, from the cumulative effect of all previous years of the program -- from all F(N) with N<J. Then

$$X(J) = \sum_{N=S}^{J-1} V_N(J) \quad (8)$$

Let T'(N) represent the change in the number of new active cases of advanced pulmonary tuberculosis caused by the existence of the mass survey -- that is, this is the number of advanced cases discovered in year N with the program, less the number which would have been discovered in year N without the program. Similarly T''(N) represents the change in moderately advanced cases and T'''(N) the change in minimal cases. Then, from assumptions 11, 12 and 13

$$T'(N) = .046\ F(N) - .295[F(N-1) + X(N)] \quad (9)$$

$$T''(N) = .322\ F(N) - .386[F(N-1) + X(N)] \quad (10)$$

$$T'''(N) = .632\ F(N) - .319[F(N-1) + X(N)] \quad (11)$$

Assuming that all treatments begin at the midpoint of the year; that fractions B', B'' and B''' of the advanced, moderate and minimal cases respectively are not admitted to a sanitorium (see assumption 14 for these values); and that the treatment times for such patients are 93, 73 and 44 days for advanced, moderate and minimal cases (assumption 16), the change in man-days of home confinement in year N caused by the program is[1]

$$M(N,2) = 93B'T'(N) + 73B''T''(N) + 44B'''T'''(N) \quad (12)$$

Using the treatment durations from assumption 15, the change in man-days of sanitorium confinement is[2]

$$M(N,3) = (1-B')\ [86.2T'(N-1) + 182.5T'(N)] + 179.3(1-B'')\ T''(N) + 130.2(1-B''')\ T'''(N) \quad (13)$$

---

[1]The second subscript on variable M has no numerical significance. It is merely used as a convenient designator for a unique variable in the same way as primes are often used.

[2]The portion of this equation for advanced patients may not be entirely obvious. It develops from the fact that these patients spend an average of 268.7 days in a sanitorium and, assuming that all treatment begins at the midpoint of the year, only 182.5 days of this falls in the same year. The remaining 86.2 days fall in the next year. Thus, the amount of sanitorium confinement in year N is affected by not only the advanced cases discovered in year N, but also the advanced cases discovered in year N-1.

Patients with active tuberculosis have a higher mortality rate than the general population. That is, the age- and sex-specific case fatality rate for active tuberculosis is higher than the equivalent general mortality rate. Furthermore, this case fatality rate increases with the severity of the presenting disease. Thus a program, like the mass survey, that reduces the amount and severity of tuberculosis reduces the amount of premature death in the population. The change in man-days of premature death resulting from the change in the number and severity of cases in year N (with all man-days in future years present-valued to year N) can be calculated by the following formula:[1]

$$M(N,4) = 365\,[1.67T'(N)+1.22T''(N)+0.82T'''(N)] \qquad (14)$$

In this analysis, all relevant health states are approximated by the following four: (1) healthy, (2) home confinement, (3) sanitorium confinement, and (4) dead. Since in a specific year and a specific target population there is a fixed number of man-days available to be allocated to the four health states, the changes in allocation caused by the program must sum to zero. That is, the program cannot add or subtract man-days to the system. Hence, the change in healthy man-days in year N caused by the program is

$$M(N,1) = -M(N,2) - M(N,3) - M(N,4) \qquad (15)$$

---

[1] See Appendix II, Exhibit 4 for the data, assumptions and calculations involved in developing this formula.

The health benefit of the program may now be calculated using equation (9) p. 62, with

$$\underline{m}'(y)-\underline{m}(y) = (M(y,1), M(y,2), M(y,3), M(y,4)) \qquad (16)$$

Equation (9), p. 62 shows the summation to infinity. In actual fact, because of the effect of the discounting, the summation can be truncated after a finite number of years with negligible error.[1]

Calculation of costs

The total cost of a health program to society is the sum of the direct cost of the program plus the indirect cost of the program less the direct savings from the program less the indirect savings from the program.

The cost of a mass survey averages $1.25 per person screened.[2] From (2), then, the direct cost of the program in year N is

$$C(N,1) = 1.25\ B(N) \qquad (17)$$

---

[1] In the actual application this was truncated after 75 years. See Appendix II, Exhibit 6 for the results of sensitivity runs on the number of years which led to the selection of this figure of 75.

[2] Provided by Dr. W.D. Wigle (1970).

The indirect cost of the program is the lost earnings of those people who take time off work to be screened. Since most participants come at a time when no lost earnings will be incurred[1] this cost is assumed to be zero.

The direct savings from the program are threefold: reduction in sanitorium costs, reduction in drug costs and reduction in the costs of follow-up clinic visits. Since a sanitorium day costs $23.56,[2] the change in sanitorium costs caused by the program is

$$C(N,2) = 23.56\ M(N,3) \qquad (18)$$

The average duration of total treatment for a tuberculosis patient is 2.25 years for advanced cases, 2 years for moderately advanced cases and 1.75 years for minimal.[3] During this entire time, a patient is on the two drugs

---

[1] Provided by Dr. W.D. Wigle (1970).

[2] Provided by Dr. C.H. Rorabeck, Chief Tuberculosis Prevention Service, Ontario Department of Health. This figure includes annual operating expenses (excluding drug costs).

[3] Estimated by Dr. W.D. Wigle (1970).

isoniazide (INH) and para-amino salicyclic acid (PAS) which cost \$2.18 and \$20.59 per patient-year of administration respectively (\$22.77 per patient-year in total).

Let S(N) be the change in patient-years under treatment in year N caused by the program.

Then, letting T(N) = T'(N) + T''(N) + T'''(N) and assuming that all cases are discovered at the mid-point of the year,

$$S(N) = .5T(N)+T(N-1)+.75T'(N-2)+.50T''(N-2)+.25T'''(N-2) \quad (19)$$

Equation (19) can be explained as follows. Consider advanced cases. Those diagnosed in year N-2 will begin treatment in the middle of that year and will complete treatment 2.25 years later or three-quarters of the way through year N. Those diagnosed in year N-1 will be under treatment for all of year N. Those diagnosed in year N (at the mid-point) will be under treatment for half of year N. Thus, the change in patient-years of treatment for advanced patients in year N is $0.5T'(N)+T'(N-1)+0.75T'(N-2)$

Similarly the change for moderately advanced patients is $0.5T''(N)+T''(N-1)+0.5T''(N-2)$ and for minimal patients $0.5T'''(N)+T'''(N-1)+0.25T'''(N-2)$. Equation (19) is merely the sum of these three expressions. Since INH and PAS are administered throughout the entire treatment period, the change in the cost of these two drugs in year N, caused by the program, is 22.77S(N). Patients who are admitted to a sanitorium are on the additional drug, streptomycin, during

their sanitorium stay. The cost of this drug is $45.76 per patient-year of administration and thus, the change in the cost of this drug in year N, caused by the program is 45.76M(N,3)/365. The total change in drug costs in year N, caused by the program, is

$$C(N,3) = 22.77S(N) + 45.76M(N,3)/365 \quad (20)$$

While a patient is under treatment for tuberculosis but not in a sanitorium, he makes periodic visits to his local chest clinic. In any one year, the number of patient-days on a clinic visiting regimen, c, is the total number of patient-days of treatment, t, less the total number of patient-days in the sanitorium, s. That is,

$$c = t - s \quad (21)$$

The change in c, caused by the program, is

$$\begin{aligned} c' - c &= (t' - s') - (t - s) \\ &= (t' - t) - (s' - s) \\ &= 365S(N) - M(N,3) \quad (22) \end{aligned}$$

Since the average cost of these clinic visits is $17.35 per patient-year,[1] the change in this cost in year N, caused by the program, is

$$\begin{aligned} C(N,4) &= \frac{17.35}{365}\,[365S(N) - M(N,3)] \\ &= 17.35[S(N) - M(N,3)/365] \quad (23) \end{aligned}$$

---

[1]Provided by Dr. W.D. Wigle, 1970.

Patients admitted to a sanitorium lose earnings during the period of their stay. Patients not admitted to a sanitorium lose earnings during the home confinement portion of their treatment. In both cases, it is assumed that when these patients return to work, they will be earning at the same level as they would have had they not contracted tuberculosis. Patients who die lose earnings for the remainder of their normal working life. The lost earnings is one of the costs to society of tuberculosis -- the indirect cost. A mass survey reduces this cost. Letting δ be the average annual earnings for tuberculosis patients,[1] the change in the indirect cost to society in year N, caused by the program, is

$$C(N,5) = \frac{\delta}{365} [M(N,2) + M(N,3) + M'(N,4)] \qquad (24)$$

where $M'(N,4)$ is $M(N,4)$ recalculated to include only the years the patient would have been working. That is, $M'(N,4)$ is the change in the working-days-lost due to premature death as a result of the operation of the program in year N (with all lost-working-days in future years present-valued to year N), and may be calculated as follows:[2]

---

[1] In this study, δ was \$3617. See Appendix II, Exhibit 5 for the calculation.

[2] See Appendix II, Exhibit 4 for the development of this formula.

$$M'(N,4) = 365\ [1.56\ T'(N) + 1.15\ T''(N) + 0.77\ T'''(N)] \quad (25)$$

The total cost to society of the program in year N is

$$C(N) = C(N,1) + C(N,2) + C(N,3) + C(N,4) + C(N,5) \quad (26)$$

The total cost to society of the program summed over all the years on a present value basis at an annual interest rate i is

$$C = \sum_{N=1}^{\infty} \frac{C(N)}{(1+i)^N} \quad (27)$$

where N=0 represents the point in time at which the evaluation is being made (in this project that was January 1, 1970). The summation is shown to infinity, but like the health benefits, it can also be truncated after a finite number of years with limited error.[1]

Results

The calculation algorithm developed above was programmed for computation on a G.E.430 computer through a remote time-sharing terminal.[2] A partial listing of the output from this program is shown below in Table 4.[3]

---

[1] See Appendix II, Exhibit 6.

[2] The program, TBCALC, is listed in Appendix II, Exhibit 10.

[3] The complete output is shown in Appendix II, Exhibit 11.

TABLE 4

PARTIAL LISTING OF THE TUBERCULOSIS CALCULATION OUTPUT

TUBERCULOSIS SCREENING PROGRAM
G W TORRANCE
AUGUST, 1970

PROGRAM NUMBER	REGION	DURATION	FREQUENCY	E PRESENT VALUE OF HEALTH BENEFITS (UNITS OF HEALTH)	C PRESENT VALUE OF COSTS (DOLLARS)	1000E/C EFFECTIVENESS-COST RATIO (X1000)
23- 1	1	1	2	10722	252848	42.4
23- 2	1	1	4	5361	126424	42.4
23- 3	1	1	8	2680	63212	42.4
23- 4	1	5	2	41820	1230893	34.0
23- 5	1	5	4	20910	615446	34.0
23- 6	1	5	8	10455	307723	34.0
23- 7	1	15	2	74388	3193662	23.3
23- 8	1	15	4	37194	1596831	23.3
23- 9	1	15	8	18597	798415	23.3
23-10	2	1	2	6965	33107	210.4
23-11	2	1	4	3482	16553	210.4
23-12	2	1	8	1741	8276	210.4
23-13	2	5	2	27169	217554	124.9
23-14	2	5	4	13584	108777	124.9
23-15	2	5	8	6792	54388	124.9
23-16	2	15	2	48327	749863	64.4
23-17	2	15	4	24163	374931	64.4
23-18	2	15	8	12081	187465	64.4
28- 1	3	1	2	1251	47574	26.3
28- 2	3	1	4	625	23787	26.3
28- 3	3	1	8	312	11893	26.3
28- 4	3	5	2	4882	223836	21.8
28- 5	3	5	4	2441	111918	21.8
28- 6	3	5	8	1220	55959	21.8
28- 7	3	15	2	8684	555243	15.6
28- 8	3	15	4	4342	277621	15.6
28- 9	3	15	8	2171	138810	15.6

Table 4 shows the results for the first 3 of the 73 regions. Region 1 is Metropolitan Toronto (which includes region 2); region 2 is the city of Toronto, and region 3 is the city of Hamilton. Each program is designated by a two part number: the first part specifies the mutually exclusive group to which the program belongs, while the second represents the program number within this group. The duration is the number of years that the program will be run, in this case, 1, 5 or 15 years. The frequency is the number of years to complete one cycle of screening in a region - in this case 2, 4 or 8 years. Thus 23-5 for example, is a mass screening program covering all of Metropolitan Toronto on a four-year cycle and calculated for a five-year duration. This program would have a total cost to society of $615,446 and would produce 20,910 units of health benefits for an effectiveness-cost ratio of 34.0 units of health per $1,000.

One interesting aspect of the results in Table 4 is the similar pattern exhibited by each region. In every case, the effectiveness-cost ratio is constant for three programs, decreases to a lower level for the next three and decreases again for the final three. To appreciate this situation consider region 1: program 23-3 is a one-year program covering one-eighth of the population of Metropolitan Toronto; program 23-2 is a one-year program covering

one-quarter of the population of Metropolitan Toronto, or twice as many people as program 23-3. Hence, it is not surprising that 23-2 costs twice as much and produces twice the health benfits. This of course results in the same effectiveness-cost ratio.

In actual fact, these constant effectiveness-cost ratios for programs of the same duration but different frequencies are an approximation resulting from the simplifying assumption made in the calculations. It is likely that the true ratios diminish slightly with increasing frequency according to the law of diminishing marginal returns. That is, doubling the frequency will double the costs but not double the benefits. No data was available on this point so the constant ratios will be assumed to be valid.

The decrease in the effectiveness-cost ratio with increasing duration is readily explained. Since the prevalence of tuberculosis is assumed to be falling, it becomes increasingly expensive in future years to locate an active case through screening. These results support the widely-held opinion that mass screening for tuberculosis is becoming less productive as the prevalence of the disease decreases.

This declining effectiveness of the program with time highlights the importance of the incremental analysis

technique for program decision making. For example, when considering whether to switch from a 5-year program like 23-5 to a comparable 15-year program, 23-8, the important ratio is not that of the 15-year program, which is 23.3, but that of the increment, which is

1000 (37,194-20,910)/(1,596,831-615,446) = 16.6

Because of the large number of potential increments to be examined, it is difficult to make any statements about which set of programs would be best based strictly on the output of the calculations, as displayed in Table 4. Fortunately, this is not necessary. The task is handled by the optimal selection algorithm which accepts the results for all 657 different tuberculosis screening programs as input and determines the optimal sub-set of programs which will maximize the health improvement for any given cost.

All of these calculations have been based on the premise that no therapeutic breakthrough will be discovered for the treatment of tuberculosis. If such a breakthrough were discovered it would, presumably, reduce the time and cost for treatment and improve the prognosis. This would have the effect of reducing the effectiveness-cost ratios for the mass screening programs. The logic to this can be seen if one considers the limiting case, where the breakthrough is so great that tuberculosis can be cured instantly at virtually no cost. In such a case, a screening program for early detection has practically no value -- the pre-

ferred approach would be to wait until each case becomes symptomatic and then cure it.

On the other hand, these calculations have also presumed no breakthrough in tuberculosis screening methods. If improvements are developed here (lower costs, improved ability to get the high risk groups out for screening), these changes would increase the effectiveness-cost ratios of the screening programs. Hence, depending upon which are considered more likely, screening breakthroughs or treatment breakthroughs, the effectiveness-cost ratios for mass screening programs may be expected either to increase or to decrease. If neither is considered very likely (the assumption of this analysis), the ratios will steadily decline.

Screening Program for the Prevention of Hemolytic Disease of the Newborn

Program definition

When a baby has an Rh negative mother and an Rh positive father, its blood is frequently Rh positive. During late pregancy and delivery, some of the baby's blood can enter the mother's bloodstream. When this happens, the Rh negative mother develops antibodies (becomes immunized) against the Rh positive red cells of her infant. The probability of an Rh negative mother becoming immunized from any single Rh positive pregnancy is about 10 per cent.

If the mother does become immunized, the antibodies can make their way into the bloodstream of a later Rh positive baby and, when they do, they destroy the infant's red blood cells producing the severe anaemia called hemolytic disease of the newborn.

If a mother has not yet developed Rh antibodies, the disease can be prevented by giving her an injection of anti-Rh gamma globulin each time she delivers or miscarries an Rh positive baby. This injection protects the mother from the foreign Rh positive red cells and prevents her from producing her own permanent antibodies.

If this treatment is provided on a comprehensive basis to all Rh negative mothers with Rh positive babies, it would appear possible, in the long run, to completely prevent hemolytic disease of the newborn. This is not quite correct. There is a small proportion of the cases in which the treatment is not effective either because the baby's blood enters the mother's bloodstream during the pregnancy rather than only at delivery, or because the amount of blood entering the mother's circulation at delivery is a much larger quantity than normal. Furthermore, it is unlikely that such a program could be truly 100 per cent comprehensive: it is anticipated that there would be some Rh negative mothers with Rh positive babies who, for a variety of reasons, would not receive the Rh immune gamma globulin (for example, an abortion prior to the first antenatal visit). In the analysis to follow, it is assumed that the program

would be 90 per cent effective in the prevention of hemolytic disease of the newborn.[1]

Specifically, the program would consist of the following steps:

1. Each pregnant female in the target population would be tested prior to delivery or miscarriage for total blood group. Those that were Rh negative would be tested for Rh antibodies.
2. If the mother were Rh negative, the baby would be tested for total blood group and Coombs test.
3. If the baby were Rh positive, the mother would be injected with 1 cc of anti-Rh gamma globulin.

Steps 1 and 2 are required therapeutic procedures regardless of the preventive program. Step 3 is the only additional procedure required because of the program.

This would be a long-term program. It would produce no health benefits (prevent no hemolytic disease of the newborn) in its first year of operation - since the benefits can only accrue to subsequent babies. In later years of operation, the benefits would increase until an equilibrium level was attained, where it is assumed that 90 per cent of the disease would be prevented.

This program is analyzed assuming such an equilibrium has been achieved. That is, the initial transient build-up period is ignored. This approximation will slightly

[1]Estimated by Dr. A. Zipursky, Chairman, Department of Pediatrics, McMaster University.

overstate the benefits of the program.

Unlike the tuberculosis example, only one program is analyzed here - a comprehensive continuing screening program which has achieved equilibrium for a specified target population. It would be possible to investigate other alternatives - such as temporary programs (for a limited time period) and non-comprehensive programs covering only a fraction of a specified target population (the high risk fraction if this can be identified) -- but these were omitted for the sake of brevity. The investigation of these alternative programs might be a worthwhile area for further research.

In this analysis the no-program or benchmark situation is measured by determining the outcomes and costs that would occur without the preventive program but with a high quality of treatment care as exemplified by the recent experience of the Henderson General Hospital, Hamilton, Ontario.

Calculations

The calculation of the health benefits and costs for this program are based on the following assumptions:

1. The program is assumed to be 90 per cent effective in preventing hemolytic disease of the newborn.[1]

---

[1] See p. 159 above.

2. Only two health states are involved -- healthy and dead. That is, with the high quality of care assumed for the benchmark situation, there are only two possible outcomes for a baby with hemolytic disease - cure or death. Cured babies are assumed to be absolutely normal.[1]
3. The required health values are one for healthy and zero for dead.
4. All frequencies (of hemolytic disease and of the various outcomes) and treatment costs are taken from a study of the Henderson General Hospital, Hamilton, Ontario, for the period 1966 to 1969 inclusive.

The calculations are performed for a single year of the program applied to an arbitrary cohort of 100,000 people in the Province of Ontario. The basic frequencies with and without the program are summarized in Table 5 below.

---

[1]Dr. A. Zipursky, Chairman, Department of Pediatrics, McMaster University.

TABLE 5

BASIC FREQUENCIES FOR THE ERADICATION PROGRAM

	Without Program	With Program
Population Cohort	100,000	100,000
Live Births[a]	1,787.0	1,787.0
Stillbirths[b]	20.5	20.5
Total Births	1,807.5	1,807.5
Pregnancies (.990 x total births)[c]	1,789.4	1,789.4
Babies with Hemolytic Disease[d]	15.906	1.591
Outcomes:[e]		
- Stillborn (10.9%)	1.734	.173
- Neonatal Death (5.0%)	.795	.080
- Well, Mild Case (42.9%)	6.824	.683
- Well, Exchange Transfusion (41.2%)	6.553	.655

[a]The live birth rate in Ontario was 17.87 per 1000 population for the period 1966-1968 (Dominion Bureau of Statistics, 1968b, Table B1).

[b]11.47 stillbirths/1000 live births (Dominion Bureau of Statistics, 1968b, Table B16).

[c]Calculated from Dominion Bureau of Statistics, 1968b, Table B5, by deducting the number of sets of twins plus twice the number of sets of triplets, or from the number of total births to obtain the number of pregnancies. The ratio of pregnancies to total births (including stillbirths) was .990.

[d]The without-program frequency is taken from a study of the Henderson General Hospital where 0.88 per cent of total births had hemolytic disease of the newborn. See Appendix II, Exhibit 7, for the actual data. The with-program frequency is 10 per cent of the without-program frequency.

[e]The outcome frequencies come from the same study -- see Appendix II, Exhibit 7.

The health benefit from the program is the elimination of the 2.276 deaths from hemolytic disease.[1] With a current life expectancy of 71.36 years,[2] this represents a life-year gain of 162.42 years on a total basis or 28.33 years when present valued at 8 per cent per year.

The health benefit is the life-years gained converted to days and multiplied by the increase in health value (see equation 15, p. 66 for the formal statement of this relationship). This yields the following health benefit for one year of the program applied to a population of 100,000 people:

$$E = 28.33 \times 365 \times (1.0 - 0.0)$$
$$= 10{,}349$$

The annual direct costs of the program per 100,000 population are summarized in Table 6 below.

---

[1] This is the difference between the number of stillborn and neonatal deaths without and with the program. See Table 4 above; 2.276 = (1.734 + .795) - (.173 + .080).

[2] Dominion Bureau of Statistics, 1964, pp. 12-15.

TABLE 6

ANNUAL DIRECT COSTS PER 100,000 POPULATION

Pregnancies (from Table 5, p. 162)	1,789.4
Rh^- mothers (16%[a] of pregnancies)	286.304
Rh^- mothers with Rh^+ babies (62%[b] of Rh^- mothers)	177.508
Cost of gamma globulin injection for these Rh^- mothers with Rh^+ babies @ $37.90[c] per injection	$6,727.57

[a]The frequency of the Rh^- allele in the white population is 0.16 (16 per cent). See, for example, Stern, 1960, p. 343.

[b]The frequency of the cde gene complex in the general population is 0.38 (Race and Sanger, 1968, p. 178). This gene complex from the father would produce an Rh^- baby. All other complexes from the father (frequency of 0.62) would produce an Rh^+ baby.

[c] As this gamma globulin is supplied free of charge by the Canadian Red Cross, the figure quoted is the market price of "Rhogam" (Ortho Pharmaceuticals).

The direct savings from the eradication program arise from the fact that hemolytic disease of the newborn is expensive to treat. The additional costs created by a case are summarized in Table 7 below.

TABLE 7

ADDITIONAL COSTS FOR A CASE OF HEMOLYTIC DISEASE OF THE NEWBORN[1]

	Severe Case	Mild Case
Additional Days Stay	$ 196.27	$ 66.69
Additional Tests	115.75	50.88
Additional Procedures	251.33	107.58
Total	$ 563.35/Case	$ 225.15/Case

The total savings from this source is the reduction in cases times the additional treatment costs. This amounts to

$563.35 (6.553-.655) + $225.15 (6.824-.683) = $4,705.29

per year per 100,000 of population. In addition, there is a small savings from the reduction in Rh antibody tests required when the preventive program is in effect. This arises from the fact that an Rh negative pregnant woman with Rh antibodies will receive more antibody tests than one without. This is estimated to amount to two additional tests on the average.[2] With the program, there are 14.315 fewer women in this category.[3] Thus, there are 2 x 14.315 = 28.630 fewer

---

[1] See Appendix II, Exhibit 8 for the detailed data and calculations.

[2] Estimated by Dr. A. Zipursky, Chairman, Department of Pediatrics, McMaster University.

[3] 14.315 = 15.906 - 1.591 (see Table 5, p. 162 above).

Rh antibody tests required and at a cost of $10 per test[1] this amounts to a savings of $286.30 per year per 100,000 of population. Hence, the total direct savings from the program is 4705.29 + 286.30 = $4,991.59 per year per 100,000 of population.

The indirect savings of the eradication program are the discounted life-time earnings of the lives saved. These are calculated in Table 8 below.

TABLE 8

INDIRECT SAVINGS OF THE ERADICATION PROGRAM

(1) Lives saved	2.276
(2) Average years in work force[a]	51
(3) Working years saved [(1) x (2)]	116.076
(4) Average income[b]	$ 4,191.85
(5) Earnings saved [(3) x (4)]	$ 486,573.18
(6) Present value (at 8%) of working years saved	9.495
(7) Present value of earnings saved [(6) x (4)]	$ 39,801.62

[a]By definition, work force participation commences at age 14 (Dominion Bureau of Statistics, 1969) and is assumed to terminate at age 65.

[b]Assuming 50 per cent of the lives saved are male and 50 per cent female, this is an average of the average male income, $5,505.78 and the average female income, $2,877.92 (Department of National Revenue, Taxation, 1969, Table 11).

[1]See Ontario Medical Association, 1969.

The total cost to society of this program for a cohort of 100,000 people for a period of one year is the direct costs less the direct savings less the indirect savings, or

C = $6,727.57 - 4,991.59 - 39,801.62 = -$38,065.64

Thus the total net cost of this program to society is negative. That is, it saves money for society, or phrased another way, it creates more resources than it consumes. In such a case, the effectiveness-cost ratio does not apply.

For ease of calculation, these results have been based on a population of 100,000. If we now assume that the eradication program will be applied to the entire Province of Ontario with a population of 7,405,530,[1] the corresponding results are

E = 10,349 (7,405,530/100,000) = 766,398.3 units of health

C = -38,065.64 (7,405,530/100,000) = -$2,818,962.39

These results are for a single year of the program only. If the program is to be operated for N years and if the population of the Province is growing at a rate of 1.56 per cent per year,[2] the values become

---

[1] Estimated 1970 population. See Ontario Department of Treasury and Economics, 1968.

[2] See assumption number 5, p. 138 above.

$$E = \sum_{n=1}^{N} \frac{766,398.3(1.0156)^n}{(1.08)^n} = \sum_{n=1}^{N} 766,398.3(.94037)^n$$

$$C = \sum_{n=1}^{N} -2,818,962.39(.94037)^n$$

The results are tabulated below for various values of N.

TABLE 9

RESULTS FOR VARIOUS PROGRAM DURATIONS

Program Number	N	E	C
--	1	766,398	-2,818,962
55-1	10	5,549,926	-20,413,798
55-2	50	11,526,189	-42,395,376
55-3	100	12,060,794	-44,362,521
55-4	∞	12,859,036	-47,299,320

This means, for example, that a 10-year program for the prevention of hemolytic disease in the Province of Ontario would produce a net economic return of $20,413,798 as well as producing an increase of 5,549,926 units of health, both on a present value basis. Similarly, a continuing program would produce a net return of $47,299,320 and a health benefit of 12,859,036 units, on a present value basis.

The various durations calculated above can be viewed as different mutually exclusive programs. That is,

one can implement a 10-year program or a 50-year program, but not both. The 1-year program is considered infeasible since equilibrium could not be achieved in so short a period of time. The other durations are considered feasible and are included in the list of programs for consideration by the selection algorithm.

As in the tuberculosis case, this program has been analyzed assuming there will be no major changes which will affect it. And again, the same conclusions hold: if there are improvements in the treatment of the disease, the relative value of the preventive program decreases; whereas, if the improvements occur in the screening and preventive program itself, its relative value increases.

Kidney Dialysis and Transplant Program

Program definition

Chronic kidney disease can cause irreversible kidney failure. When this occurs the patient can be kept alive only by a program of regular renal dialysis or by a kidney transplant.

This analysis deals with three potential programs:

1. Kidney transplant program. The patient is kept on dialysis until a transplant is available and surviving patients whose transplant fails return to dialysis. Some patients receive two or more transplants.
2. Hospital dialysis program. The patient is dialysed regularly at a kidney center, frequently located in a hospital.
3. Home dialysis program. The patient dialyses himself regularly with equipment at home.

The no-program or benchmark situation is considered to be the death of the patient. This is the prognosis if no treatment is administered.

Calculations

The pattern of this analysis follows that laid down by the Report of the Committee on Chronic Kidney Disease (Gottschalk, 1967) and, where possible, the same data and assumptions are used. For comparative purposes, frequent reference will be made to this report.

The major changes in data and assumptions from those of the Gottschalk report are as follows:

1. The costs have been up-dated to reflect recent local experience at the kidney centre, St. Joseph's Hospital, Hamilton, Ontario. Table 10 summarizes the cost differences.
2. The health values obtained in this research are used to weight the life-years gained. The relevant health states are healthy, kidney transplant, home dialysis, hospital dialysis and dead with health values of 1.0, 0.83, 0.66, 0.53 and 0 respectively. The Gottschalk committee also used a weighting system for life-years gained. In their system a year gained on transplantation was weighted more heavily than a year gained on dialysis by a factor of 1.25.

TABLE 10

COSTS OF KIDNEY DIALYSIS AND TRANSPLANT

Item	Gottschalk Cost	Local Cost[a]
Home dialysis initial cost	$ 10,000	$ 10,000
Home dialysis annual operating costs	5,000	3,950
In-centre dialysis annual operating costs including amortized equipment	14,000	15,000
Transplant initial cost	13,000	20,000[b]
Annual drug costs for transplant patient	500	500

[a]Provided by Dr. A.G. Shimizu, Director, Dialysis Unit, St. Joseph's Hospital, Hamilton.

[b]The high cost of a transplant is primarily a result of the high quality of nursing care provided in the unit. Four nurses per shift are on duty for three transplant patients, for a total of thirty-two nursing hours per patient-day.

The report claims this value was selected for illustrative purposes only (p. 140). However, it is interesting to note that it is reasonably close to the more precise value determined in this research - the equivalent factor is the health value of a kidney transplant divided by the average health value for dialysis or

$$0.83/(0.66 + 0.53)/2 = 1.40$$

3. Both the health benefits (life-years gained) and the costs are converted to their present value equivalent. In the Gottschalk analysis, this was done only for costs.

4. An annual interest rate of 8 per cent is used rather than the Gottschalk figures of 4 and 5 per cent.

5. The indirect costs of chronic kidney disease are incorporated in the calculation, unlike the Gottschalk report which used a different cost model and excluded these costs. This requires data on the proportion of surviving patients who are able to return to work, their average earnings, and their remaining working years.

   a) The proportion of surviving patients able to return to work is estimated as: 90 per cent for patients with a kidney transplant; 80 per cent for patients on hospital-based dialysis, and 100 per cent for patients on

home dialysis.[1]

b) Their average earnings are assumed to be $4,191.85 per year.[2]

c) Their remaining working years are calculated using the Gottschalk assumption (p. 145) that all patients are 45, the median age of people suffering from chronic uremia. Then the expected life years gained per patient of 9 years on dialysis and 17.2 years with a transplant would all occur before retirement age. Thus, all the life-years gained would classify as working years. This assumption is convenient for calculation purposes and is believed to introduce little error since the inaccuracy occurs some years in the future (a few patients will reach age 65 and retire) where its effect is reduced by the discounting factor.

Health benefits

The Gottschalk report calculates two life tables for a cohort of 1000 people suffering from chronic kidney disease;

---

[1]Estimated by Dr. A. G. Shimizu, Director, Dialysis Unit, St. Joseph's Hospital, Hamilton.

[2]See footnote b on p. 166 above.

one assuming they enter a dialysis program and the other assuming a maximum transplantation route. The life expectancy for the dialysis cohort is 9.0 years while that for the transplantation cohort is 17.2 years - 13.3 additional years on a successful kidney and 3.9 years on dialysis subsequent to the failure of a transplanted kidney (p. 147). Using this data and equation (15), p. 64, the health benefits for the three programs can be calculated as follows:

(a) Home Dialysis Program

$$E = \sum_{n=1}^{9} \frac{365\ (.66 - 0)}{1.08^n}$$

= 1504.9 units of health benefit per patient.

(b) Hospital Dialysis Program

$$E = \sum_{n=1}^{9} \frac{365\ (.53 - 0)}{1.08^n}$$

= 1208.5 units of health benefit per patient.

(c) Kidney Transplant Program

$$E = \sum_{n=1}^{13} \frac{365\ (.83 - 0)}{1.08^n} + \frac{0.3(365)(.83 - 0)}{1.08^{14}} + \frac{0.7\ (365)(.53 - 0)}{1.08^{14}} + \sum_{n=15}^{17} \frac{365\ (.53 - 0)}{1.08^n} + \frac{0.2\ (365)(.53 - 0)}{1.08^{18}}$$

= 2650.9 units of health benefit per patient.

Costs

The total cost of a kidney program to society is the direct cost of the program (data from Table 10 above) less the indirect savings from the program (the additional earnings of the patients). The calculations for the three programs are shown below.

(a) Home Dialysis Program

$$C = 10{,}000 + \sum_{n=1}^{9} \frac{3950}{1.08^n} - \sum_{n=1}^{9} \frac{4191.85}{1.08^n}$$

$$= \$8{,}489.19 \text{ per patient.}$$

(b) Hospital Dialysis Program

$$C = \sum_{n=1}^{9} \frac{15{,}000}{1.08^n} - 0.8 \sum_{n=1}^{9} \frac{4191.85}{1.08^n}$$

$$= \$72{,}754.65 \text{ per patient.}$$

(c) Kidney Transplant Program

Patients in a transplant program will receive an average of 1.15 transplantations each (Gottschalk, p. 151). When their transplant fails they revert to dialysis (assumed hospital-based dialysis). Thus,

$$C = 20{,}000 \times 1.15 + \sum_{n=1}^{13} \frac{500}{1.08^n} + \frac{0.3 \times 500}{1.08^{14}} + \frac{0.7 \times 15000}{1.08^{14}}$$

$$+ \sum_{n=1}^{17} \frac{15000}{1.08^n} + \frac{0.2 \times 15000}{1.08^{14}}$$

$$- 0.9 \left[\sum_{n=1}^{13} \frac{4191.85}{1.08^n} + \frac{0.3 \times 4191.85}{1.08^{14}} \right]$$

$$- 0.8 \left[\frac{0.7 \times 4191.85}{1.08^{14}} + \sum_{n=15}^{17} \frac{4191.85}{1.08^n} + \frac{0.2 \times 4191.85}{1.08^{18}} \right]$$

$$= \$10{,}375.50 \text{ per patient.}$$

Effectiveness- cost ratios

The effectiveness-cost ratios for the three programs are shown below:

(a) Home Dialysis: $1000E/C = 1000 \times 1504.9/8489.19 = 177.3$

(b) Hospital Dialysis: $1000E/C = 1000 \times 1208.5/72{,}754.65 = 16.6$

(c) Kidney Transplant: $1000E/C = 1000 \times 2650.9/10{,}375.50 = 255.5$

Comparison to Gottschalk results

The Gottschalk results are given as costs per life-years gained (p. 154) and are summarized below:

(a) Home Dialysis - $4,200 per life-year gained.

(b) Hospital Dialysis - $11,600 per life-year gained.

(c) Kidney Transplant - $2,200 per life-year gained.

It can be seen that these results and those calculated for this project are comparable: in both cases the kidney transplant is the most cost-effective form of treatment, followed fairly closely by home dialysis, with hospital dialysis a poor third.

These results suggest that the best program for treatment of chronic kidney disease would be one aimed at maximum transplantation. Such a program would still require kidney dialysis centres, but their use would be primarily for patients waiting for a transplant or patients whose transplant had failed.

All the previous calculations have been performed on a per patient basis. To convert these results to a program basis, it is necessary to know how many patients would be treated by a given program. The Gottschalk report (p. 108) estimates that in 1964 there were 6,400 new candidates in the United States medically suitable for dialysis or transplant. This represents a rate of 3.35 new candidates per year per hundred thousand population. If we assume that this rate applies to Ontario, the number of new candidates expected in 1970 would be $3.35 \times 74.0553^{a} = 248$.

---

[a]The estimated 1970 Ontario population is 7,405,530. See Ontario Department of Treasury and Economics, 1968.

Now the question arises: can the previous results calculated on a per patient basis with data from a relatively small program be directly extrapolated to a large-scale program covering 248 patients per year? Probably not.

On a large-scale program the following changes might be expected: the health benefit per patient would decrease since a large-scale program could not be as selective in the patients it accepted; the indirect cost per patient would increase for the same reason (that is, a smaller proportion of these patients would be expected to return to work); and the direct cost per patient would decrease due to economies of scale.

No data were available on the magnitude of these changes, so the following assumptions were made for illustrative purposes: the total cost (direct cost plus indirect cost) per patient is constant with program size; the health benefit per patient, previously calculated, applies to a program treating one-quarter of the total cases and the incremental benefit decreases by five per cent for each additional quarter of the total cases treated. The results of these assumptions are summarized in Table 11 below.

TABLE 11

VARIOUS PROGRAMS FOR THE TREATMENT OF CHRONIC KIDNEY DISEASE CALCULATED FOR ONE YEAR

Program	E	C	1000E/C
Transplant Program			
25% coverage	164,356[a]	643,281[a]	255.5
50% coverage	320,494[b]	1,286,562	249.1
75% coverage	468,415[c]	1,929,843	242.7
100% coverage	608,117[d]	2,573,124	236.3
Home Dialysis Program			
25% coverage	93,303	526,330	177.3
50% coverage	181,941	1,052,660	172.8
75% coverage	265,914	1,578,990	168.4
100% coverage	345,221	2,105,330	164.0
Hospital Dialysis Program			
25% coverage	74,927	4,510,788	16.6
50% coverage	146,108	9,021,576	16.2
75% coverage	213,542	13,532,364	15.8
100% coverage	277,230	18,043,152	15.4

These results are for a single year of the program only. If the program is to be operated for N years, and assuming the population of the Province of Ontario is grow-

---

[a] The previous per case value x 62 cases.

[b] 320,494 = 164,356 + .95 (164,356).

[c] 468,415 = 164,356 + .95 (164,356) + .90 (164,356).

[d] 608,117 = 164,356 + .95 (164,356) + .90 (164,356) + .85 (164,356).

ing at a rate of 1.56 per cent per year,[1] the revised values can be calculated as follows:

Let E_1 and C_1 represent the effectiveness and cost respectively of a one-year program, and E_N and C_N the values for an N-year program, then

$$E_N = \sum_{n=1}^{N} \frac{E_1(1.0156)^n}{1.08^n}$$

$$= E_1 \sum_{n=1}^{N} (.94037)^n \text{ , and}$$

$$C_N = C_1 \sum_{n=1}^{N} (.94037)^n \text{ , and}$$

$$E_N/C_N = E_1 \sum_{n=1}^{N} (.94037)^n \; / \; C_1 \sum_{n=1}^{N} (.94037)^n$$

$$= E_1/C_1$$

The results are tabulated below for the transplant program at various coverages and various values of N.

---

[1] See assumption number 5, p. 138 above for the basis of this growth rate.

TABLE 12

TRANSPLANT PROGRAM AT VARIOUS DURATIONS AND COVERAGE

Program	E	C	1000E/C
25% Coverage			
N=1	164,356	643,281	255.5
N=10	1,190,348	4,658,963	255.5
N=50	2,578,943	10,093,851	255.5
N=100	2,591,368	10,142,483	255.5
N=∞	2,591,894	10,144,541	255.5
50% Coverage			
N=1	320,494	1,286,562	249.1
N=10	2,321,178	9,317,925	249.1
N=50	5,028,935	20,187,702	249.1
N=100	5,053,165	20,284,966	249.1
N=∞	5,054,190	20,289,083	249.1
75% Coverage			
N=1	468,415	1,929,843	242.7
N=10	3,392,496	13,976,888	242.7
N=50	7,349,993	30,281,552	242.7
N=100	7,385,406	30,427,449	242.7
N=∞	7,386,905	30,433,624	242.7
100% Coverage			
N=1	608,117	2,573,124	236.3
N=10	4,404,287	18,635,851	236.3
N=50	9,542,085	40,375,403	236.3
N=100	9,588,059	40,569,931	236.3
N=∞	9,590,009	40,578,165	236.3

Similar computations could be performed for the other two programs (home dialysis and hospital dialysis) but were not included since the results are not required in this project. That is, since the transplant program competes

with the other two for the same patients and since it is superior on a cost-effectiveness basis, there is no point in entering the two dialysis programs into the selection algorithm to compete for the limited funds available. This is not meant to imply that individual patients should always be treated by transplantation rather than dialysis. Obviously, a host of other factors enter the decision in each individual situation. However, it is meant to imply that if a patient is medically suitable for either transplantation or dialysis, transplantation is the more cost-effective treatment; and it is meant to imply that if a given level of resources are available to treat chronic kidney disease, a transplantation-oriented program will produce greater health improvement than a dialysis-oriented program.

This analysis has assumed that there will be no significant breakthrough in therapeutic procedures for the treatment of chronic kidney disease. That is, it has assumed that current procedures, costs, and results will continue to apply. If, on the other hand, costs decrease (with more experience and with economies of scale, both dialysis costs and transplantation costs could be expected to decrease) and prognoses improve (with improved dialysis equipment and procedures and with improved tissue matching and drug treatment for transplant patients it is quite possible that outcomes will continue to improve), the

effectiveness-cost ratios for the various programs will be higher than those calculated here.

The twenty variations of the transplantation program listed in Table 12 can be viewed as twenty different mutually exclusive programs. The four one-year programs are considered unreasonably short and are therefore excluded from further consideration. Within each coverage, the three programs for N=50, N=100 and N=∞ are almost identical, and so, to avoid unnecessarily lengthening the list of programs for consideration, the first two are dropped. This leaves eight different, mutually exclusive programs for final consideration by the optimization algorithms. For convenience, these are summarized below in Table 13.

TABLE 13

TRANSPLANT PROGRAMS FOR FINAL CONSIDERATION

Program Number	Program	E	C	1000E/C
56-1	25%, N=10	1,190,348	4,658,963	255.5
56-2	25%, N=∞	2,591,894	10,144,541	255.5
56-3	50%, N=10	2,321,178	9,317,925	249.1
56-4	50%, N=∞	5,054,190	20,289,083	249.1
56-5	75%, N=10	3,392,496	13,976,888	242.7
56-6	75%, N=∞	7,386,905	30,433,624	242.7
56-7	100%, N=10	4,404,287	18,635,851	236.3
56-8	100%, N=∞	9,590,009	40,578,165	236.3

Coronary Emergency Rescue Service

A coronary emergency rescue service (CERS) is a special-purpose ambulance, usually based at a hospital with a coronary care unit. It contains extensive equipment for cardiac resuscitation and is manned by a physician, a nurse or technician, a driver, and often a squad man. The objective is to provide sophisticated therapy to the victim at the site of the incident and during transportation to the coronary care unit, thereby saving time and lives.

A queuing model of this system was developed by Smith (1970) and simulated to determine the savings in time and lives from a coronary emergency rescue service as compared to a conventional ambulance system based at the same hospital. The data was obtained from Montgomery County, Maryland, a suburb of Washington, D.C. Smith found that a single CERS unit would save an average of two lives per year for an annual expenditure of $40,000.

To evaluate a CERS program by the model proposed in this research, the following additional data is required:

1. The life expectancy for those people whose lives are saved; that is, the life expectancy of people who survive a heart attack. This was determined to be 6.12 years.[1]

---

[1]See Appendix II, Exhibit 9 for the calculations.

2. The average annual earnings and working years gained for those people whose lives are saved. The average annual earnings are $5,506 for men and $2,878 for women.[1] The working years gained for each sex is the difference between the retirement age and the heart attack age or the total life-years gained, whichever is less. If we assume a retirement age of 65 and a heart attack age of 57 for men and 61 for women,[2] the working years gained are 6.12 and 4.0 respectively.

The health benefit from a coronary emergency rescue service operated for one year is the health value of the two lives saved. If we assume that these life-years gained are essentially healthy (have a health value of 1.0), the health benefit can be calculated from (15) p. 66 as follows:

$$E = \sum_{n=1}^{6} \frac{2 \times 365 \ (1.0 - 0)}{1.08^n} + \frac{2 \times 365 \times 0.12 \ (1.0 - 0)}{1.08^7}$$

$$= 3425.8 \text{ units of health.}$$

---

[1] See footnote b, p. 166 above for the basis of these figures.

[2] See Appendix II, Exhibit 9 for the derivation of these average ages for a heart attack.

The total cost to society of a CERS unit operated for one year is the direct cost of the program less the indirect savings from the program (the additional earnings from the two lives saved). Assuming that 1.2 of these lives are male and 0.8 are female,[1] the program cost for one year is

$$C = 40{,}000 - 1.2\left[\sum_{n=1}^{6}\frac{5506}{1.08^n} + \frac{0.12\times 5506}{1.08^7}\right] - 0.8\left[\sum_{n=1}^{4}\frac{2787}{1.08^n}\right]$$

$$= 1367.13$$

and the effectiveness-cost ratio is

$1000E/C = 1000 \times 3425.8/1367.13 = 2505.8$ units of health improvement per thousand dollars of cost.

The above calculations have been performed for a single CERS unit for a single year. To convert these results to a program basis we must make some assumptions about the number of units and number of years involved in each potential program. For illustrative purposes, let us consider four potential programs for the Province of Ontario; 5 units and 20 units at each of 5 years and 15 years. The program results are calculated by the method introduced previously[2] and are summarized below.

---

[1] See Appendix II, Exhibit 9 for an explanation of this 60/40 ratio.

[2] See p. 168 above.

TABLE 14

CORONARY EMERGENCY RESCUE SERVICE PROGRAM RESULTS

Program Number	Program	E	C	1000E/C
57-1	5 units, 5 years	71,501.6	28,534.06	2505.8
57-2	5 units, 15 years	162,722.1	64,937.32	2505.8
57-3	20 units, 5 years	286,066.4	114,136.23	2505.8
57-4	20 units, 15 years	650,888.4	259,749.27	2505.8

This analysis has assumed that there will be no significant breakthroughs in the treatment of heart attack victims. If there are, the relative merit of a coronary emergency rescue service would obviously increase -- since the direct costs would remain unchanged but the number of lives saved would increase. Even if there are no dramatic breakthroughs, it is expected that survivorship experience in coronary care units will continue to improve, and this will enhance the value (increase the effectiveness-cost ratio) of a CERS program.

CHAPTER V

OPTIMAL PROGRAM SELECTION

Four basic programs have been analyzed in the previous chapter: tuberculosis screening, prevention of hemolytic disease of the newborn, kidney dialysis and transplantation, and a coronary emergency rescue service. Each of these basic programs has been subdivided into a number of component programs; 657, 4, 8, and 4 respectively to give a total of 673 programs to be considered. These 673 programs belong to 57 program-sets, such that the members of any one program-set are mutually exclusive. The problem is to select the optimal sub-set of these 673 programs that will maximize the health benefit achieved for a given total cost to society. Two methods are used: cost-effectiveness ranking and mathematical programming.

Cost-Effectiveness Ranking

The cost-effectiveness ranking algorithm with mutually exclusive programs is described in detail in Chapter II.[1] It was programmed for computation on a G.E. 430 computer.[2] A partial listing of the output from this program is shown in Table 15.

The programs in Table 15 are listed in their cost-effectiveness priority sequence. This list may be used a number of ways:

1. If the objective is to produce the maximum health improvement for a given cost, locate this cost in the cumulative cost column and the set of programs down to this point will be the optimal set. That is, it will be the set which maximizes the health improvement for this cost. If the set contains a number of mutually exclusive programs, the last one listed supersedes all others. For example, the fifth program listed, 57-2, supersedes the previous program, 57-1.
2. If the objective is to produce a specified health improvement at minimum cost, locate this health improvement in the cumulative effectiveness column and the set of pro-

---

[1] See p. 74 above.

[2] The program, CERANK, written in BASIC through a remote time-sharing terminal, is listed in Appendix III, Exhibit 1.

TABLE 15[a]

PARTIAL LISTING OF THE COST-EFFECTIVENESS RANKING OUTPUT

COST EFFECTIVENESS RANKING

G W TORRANCE
AUGUST, 1970

PRIORITY RANKING	PROGRAM NUMBER	INCREMENTAL E/C X1000	CUMULATIVE E	CUMULATIVE C
1	55- 4	N.A.	12859036	-47299320
2	52- 1	N.A.	12860136	-47301616
3	47- 1	N.A.	12860545	-47302473
4	57- 1	2505.8	12932046	-47273939
5	57- 2	2505.8	13023267	-47237535
6	57- 3	2505.8	13146551	-47188336
7	57- 4	2505.8	13311433	-47042723
8	47- 4	991.8	13312617	-47041529
9	52- 4	978.1	13315810	-47038265
10	56- 1	255.5	14706158	-42379302
11	56- 2	255.5	16107704	-36893724
12	56- 4	242.7	18570000	-26749182
13	56- 6	229.9	20902715	-16604641
14	56- 8	217.2	23105819	-6460100
15	23-12	210.4	23107561	-6451823
16	23-11	210.4	23109302	-6443546
17	23-10	210.4	23112785	-6426992
18	23-13	109.5	23132989	-6242546
19	47- 7	80.7	23134229	-6227188
20	52- 7	80.6	23137573	-6185698
21	47-13	73.9	23139536	-6159127
22	51- 3	68.9	23139664	-6157274
23	51- 2	68.9	23139792	-6155421
24	51- 1	68.9	23140047	-6151716
25	48- 3	53.0	23140073	-6151218
26	48- 2	53.0	23140100	-6150719
27	48- 1	53.0	23140153	-6149721

[a]To interpret the program numbers shown in this Table, see the following locations:

a) For programs 1-1 to 54-9 see Appendix II, Exhibit 11;
b) For programs 55-1 to 55-4 see Table 9, p. 168;
c) For programs 56-1 to 56-8 see Table 13, p. 184; and
d) For programs 57-1 to 57-4 see Table 14, p. 188.

The complete output is shown in Appendix III, Exhibit 2.

grams down to this point will be the desired minimum-cost set. For example, the minimum-cost set of programs to produce 13,511,433 units of health improvement consists of programs 55-4, 52-1, 47-1 and 57-4.

3. If the objective is to compare two programs to decide which is more cost-effective, compare their positions on the list and the upper one is better unless both have the same incremental effectiveness-cost ratio in which case they are equivalent. All that really needs to be compared are the incremental effectiveness-cost ratios. However, if mutually exclusive programs are involved, the calculation of these incremental ratios is sufficiently complex that the ranking algorithm is a convenient tool to use.

The top program in the cost-effectiveness ranking of Table 15 is program 55-4, the continuing program for the prevention of hemolytic disease of the newborn in the Province of Ontario. This program is selected first by the algorithm since it has the largest economic return (negative cost) to society. The next two programs, 52-1 and 47-1, are the only others with a negative cost. These are single-year tuberculosis screening programs covering half the population of Kenora County and the City of Timmins, respectively.

It is interesting to note that if a cost-benefit analysis[1] had been performed on all of these programs, the

[1] That is, the productive resources version. See p. 8 above.

same three programs would have received top priority, in the same order, but no other programs would have been considered acceptable. This is because, in all the other cases, the dollar costs exceed the dollar benefits and such programs are rejected by the cost-benefit criterion. This displays an important advantage of cost-effectiveness over cost-benefit: it takes over at the point where cost-benefit leaves off, and most health programs are beyond this point.

The next best programs (ranked 4 to 7) in Table 15, are the four variations of the coronary emergency rescue service.[1] These all have the same incremental effectiveness-cost ratio, 2505.8, in which case the ranking algorithm breaks the tie by selecting the lower cost program first.

Following these, the two single-year tuberculosis screening programs are each increased to five-year programs (47-4 and 52-4). Then come the kidney programs, ranked 10 to 14, followed by a long list of tuberculosis screening programs.

All of these programs have been analyzed assuming that current methods and procedures will continue to be used. If, on the other hand, significant advances are made in the diagnostic or treatment procedures for any of

---

[1] See Table 14, p. 188 above for the definition of each of these four variations.

the diseases involved in these programs, the relative rankings of the various programs would undoubtedly change. If a decision-maker anticipates such advances, he can incorporate them into his decision two ways:

1) by specifying the anticipated advances, in which case an analyst can explicitly include them in the calculations, or
2) by determining the general effect of the anticipated advances on the programs, and incorporating these effects into his final deliberation as intangible factors.

Within any one type of program the cost-effective priority sequence provides few surprises. In the program for the prevention of hemolytic disease the variation with the largest economic return was ranked first. In the coronary emergency rescue service program, all the variations have a positive cost and the same effectiveness-cost ratio and are consequently ranked in increasing order of cost. In the kidney program, the variations with the smaller coverage are ranked above those with the larger coverage as a direct and obvious consequence of the assumptions made. In the tuberculosis screening program, the ranking is not quite so obvious. Generally, the different geographic regions are ranked in

decreasing sequence of their tuberculosis prevalence rate, as might be expected, but the interaction of program duration and the incremental concept provide some results which would have been difficult to predict in advance. For example, both the County of Kenora and the City of Timmins have a higher prevalence than the City of Toronto, and one might expect that all programs from these two areas would be exhausted before any from Toronto would be selected. This was not the case. If one were a little more perceptive and decided the ranking follows the individual effectiveness-cost ratios for each program,[1] he would be closer but still wrong. Program 23-13, for example, has an effectiveness-cost ratio of 124.9 and yet it is ranked above 47-7 which has a ratio of 180.5.

If these rankings within each type of program were the only benefit provided, the cost-effectiveness technique would be of dubious value. The real power of the technique comes from its ability to compare health programs of totally different types. This project has compared four health programs that cover a broad spectrum of the health services field -- two preventive programs, one for newborn and one for adults; a treatment program for a chronic disease, and an emergency treatment program for an acute ailment. There were

---

[1] See Appendix II, Exhibit 11 for these program effectiveness-cost ratios.

no technical difficulties[1] in handling these four widely diverse programs, and it would appear safe to conclude that a wide variety of health programs can be treated by this method.

The cost-effectiveness ranking technique provides an easy method for evaluating single programs on an interim basis. Suppose Table 15 represented an annual evaluation of potential health programs and it was decided to implement all programs down to 52-7 which is ranked twentieth and has an incremental effectiveness-cost ratio of 80.6. Then any individual program proposed before the next regular review would require an effectivness-cost ratio greater than 80.6 to be selected by this criterion. If the program had a number of mutually exclusive levels, it should be implemented up to the last level with an incremental ratio greater than 80.6.

Of course, the effectiveness-cost ratio is not the sole criterion for use in program selection. The intangible benefits must be included by the decision-maker in his final deliberations. The cost-effectiveness ranking technique provides assistance in the rational incorporation of these intangible benefits, again through the use of the incremental effectiveness-cost ratios. For example, consider the pro-

---

[1]Although there were no technical difficulties, there were certainly data acquisition difficulties, particularly in obtaining valid measures of the health benefits from the various programs.

gram for kidney transplantation on a continuing and province-wide basis, 56-8, versus the program for tuberculosis screening in the City of Toronto, 23-12. The former has an incremental effectiveness-cost ratio of 217.2 compared to 210.4 for the latter. Since these ratios are almost identical, the final relative priority of the two programs would likely be determined on the strength of the intangible benefits. On the other hand, if two programs had incremental effectiveness-cost ratios that were considerably different, the difference in their relative intangible benefits would have to be correspondingly greater to reverse their rankings.

A more rigorous approach to the inclusion of intangible benefits is provided by the implicit value method. In this method, the best solution is first obtained disregarding the intangible benefits. Then the intangible benefits are considered by the decision-maker and the solution modified according to his judgment. This second solution will either produce less health benefit, cost more money, or both; depending upon the changes made. In any event, these differences represent the implicit value attached to the intangible benefits by the decision-maker. This value is calculated, shown to the decision-maker, and he is given the opportunity to either agree with it or to modify his decision. The process continues until no further modifications are made.

Mathematical Programming

The mathematical programming approach to selecting the optimal sub-set of health programs is described in detail in Chapter III.[1] A major practical limitation of this method at the present time is the lack of an efficient 0-1 integer linear programming algorithm for large problems. In this project the algorithm developed by Lemke and Spielberg (1967) was used.[2] It was written to handle up to 150 variables and 50 constraints but the largest problem reported by the authors was 89 variables and 28 constraints, and this took 30 minutes of time on an IBM 7094. A full run to simultaneously optimize all the programs evaluated in this research would require 673 variables and 58 constraints. Since this is computationally infeasible, the problem was reduced by selecting, for input, only those programs that had ranked near the top in the cost-effectiveness ranking.

For a first optimization run, 61 programs were selected, which included all of those ranked in the top 24 on the cost-effectiveness ranking algorithm plus any

---

[1] See p. 78 above.

[2] See Appendix III, Exhibit 3 for further details on this algorithm and a description of how it was applied to the optimal selection of health programs.

others in the same geographic set.[1] The group of 61 programs contained 7 mutually exclusive sets, resulting in a 0-1 integer linear program with 61 variables and 8 constraints. This is a rather large program, and to reach the optimum, the algorithm required 139,879 iterations, it investigated 69,940 points, and it took 26 minutes of central processor time on a CDC 6400. At a cost of $300 per central processor hour[2] this amounts to $130 for a run which optimized only 61 programs. On the other hand, the cost-effectiveness algorithm optimized more than ten times as many programs, 673, in only 2 minutes of central processor time on a considerably slower computer, a G.E. 430. At the same charging rate, this would cost only $10. Thus, the cost-effectiveness algorithm written for this project, is a great deal more efficient computationally than the 0-1 integer linear programming algorithm. In fact, the latter is so poor that, at the present time, it cannot be recommended as a practical tool for other than trivial problems.

When the cost constraint was set at -6,151,716, the results from the mathematical programming approach were

---

[1]The 61 selected programs are 57-1 to 57-4, 55-1 to 55-4, 56-1 to 56-8, 52-1 to 52-9, 47-1 to 47-18, 23-10 to 23-18 and 51-1 to 51-9.

[2]The current charging rate for the CDC 6400 at McMaster University, Hamilton, Ontario.

identical to those from the cost-effectiveness ranking technique. That is, the optimal sub-set of programs was determined to consist of the following seven:

51-1, 47-13, 52-7, 23-13, 56-8, 55-4 and 57-4.

This provides a reassuring check that the cost-effectiveness ranking algorithm is indeed specifying the optimal sub-set of programs for any given cost.

Since the computer time for this first run was so long, a further reduced set of programs was created for additional experimentation. The set of programs was reduced from 61 to 10 by selecting a few programs only from a few of the more cost-effective mutually-exclusive sets. The selected programs are listed below in Table 16.

TABLE 16

REDUCED SET OF PROGRAMS

Reference Number	Program Number	E	C	1000E/C
1	23-11	3,482	16,553	210.4
2	23-15	6,792	54,388	124.9
3	47-1	408	-856	N.A.
4	47-7	2,832	15,695	180.5
5	52-1	1,100	-2,296	N.A.
6	52-4	4,294	968	4,434.9
7	52-5	2,147	484	179.9
8	57-1	71,502	28,534	2,505.8
9	57-2	162,722	64,937	2,505.8
10	51-1	510	7,410	68.9

For comparative purposes, this set was run through each algorithm. The results of the cost-effectiveness ranking are shown below.

TABLE 17

COST-EFFECTIVENESS RANKING OF THE REDUCED SET

COST EFFECTIVENESS RANKING

G W TORRANCE
AUGUST, 1970

PRIORITY RANKING	PROGRAM NUMBER	INCREMENTAL E/C X1000	CUMULATIVE E	CUMULATIVE C	OPTIMAL SET REF. NUMBERS
1	52- 1	N.A.	1100	-2296	5
2	47- 1	N.A.	1508	-3152	3,5
3	57- 1	2505.8	73009	25382	3,5,8
4	57- 2	2505.8	164230	61785	3,5,9
5	52- 4	978.6	167424	65049	3,6,9
6	23-11	210.4	170906	81602	1,3,6,9
7	47- 7	146.5	173330	98153	1,4,6,9
8	23-15	87.5	176640	135988	2,4,6,9
9	51- 1	68.9	177150	143398	2,4,6,9,10

The 0-1 integer programming algorithm was run at a number of different values for the cost constraint. When the cost constraint was incremented by $20,000 amounts, the following results were obtained:

TABLE 18

MATHEMATICAL PROGRAMMING OPTIMIZATION OF THE REDUCED SET

Optimal Set of Programs-Reference Numbers	Total Effectiveness of the Set	Total Cost of the Set	Cost Constraint
1,3,6	8,184	16,665	20,000
3,6,8,10	76,714	36,056	40,000
1,3,6,8,10	80,196	52,609	60,000
3,6,9,10	167,934	72,459	80,000
1,4,6,9	173,330	98,153	100,000
2,3,6,9	174,216	119,437	120,000
2,4,6,9	176,640	135,988	140,000
2,4,6,9,10	177,150	143,398	143,000

To facilitate the comparison of the results from the two algorithms, they have both been plotted on the same C-E graph, Figure 13 below.

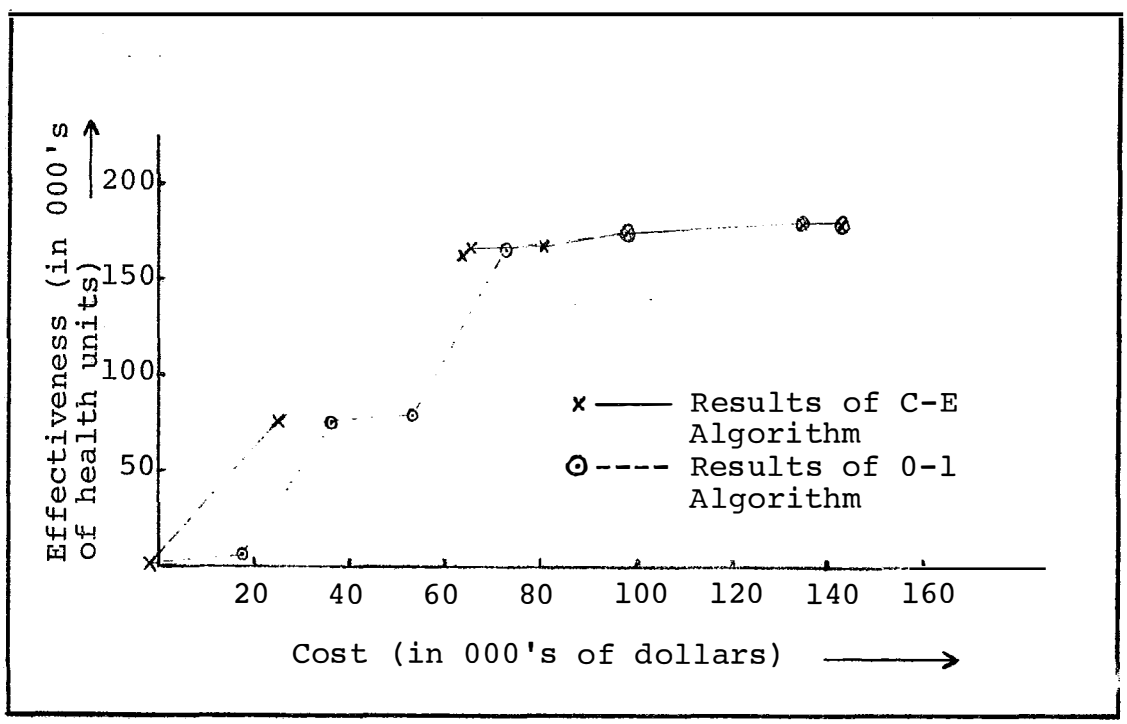

Fig. 12.--Plot of Specific C-E and 0-1 Results

It can be seen from this graph that each solution produced by the 0-1 algorithm had an effectiveness-cost ratio equal to or less than the effectiveness-cost ratio of the nearest solution produced by the C-E technique. (That is, the health benefit gained per dollar spent for each 0-1 solution was equal to or less than that for the nearest C-E solution.) For example, consider the solution generated by the 0-1 algorithm when the cost constraint was $40,000. Here, programs 3,6,8 and 10 are recommended for a total effectiveness of 76,714 units of health, a total cost of $36,056 and an effectiveness-cost ratio of 2,128 units of health per thousand dollars. While it is true that this is the best solution available with a total cost equal to or less than $40,000, it is still not a very good solution in terms of the health benefit gained per dollar spent. The two nearest solutions produced by the C-E algorithm are considerably better: one has an effectiveness of 73,009 and a cost of $25,382 for a ratio of 2,876 while the other has an effectiveness of 164,230, a cost of $61,785 and a ratio of 2,658.

The general structure of this situation is shown below in figure 14. Here, the 0-1 algorithm has been solved with the cost constraint as a running parameter and the resulting solutions plotted.[1] The points form a series

[1] See Appendix III, Exhibit 4 for a list of these solutions.

of peaks and valleys with each peak corresponding to one of the solutions from the C-E algorithm.

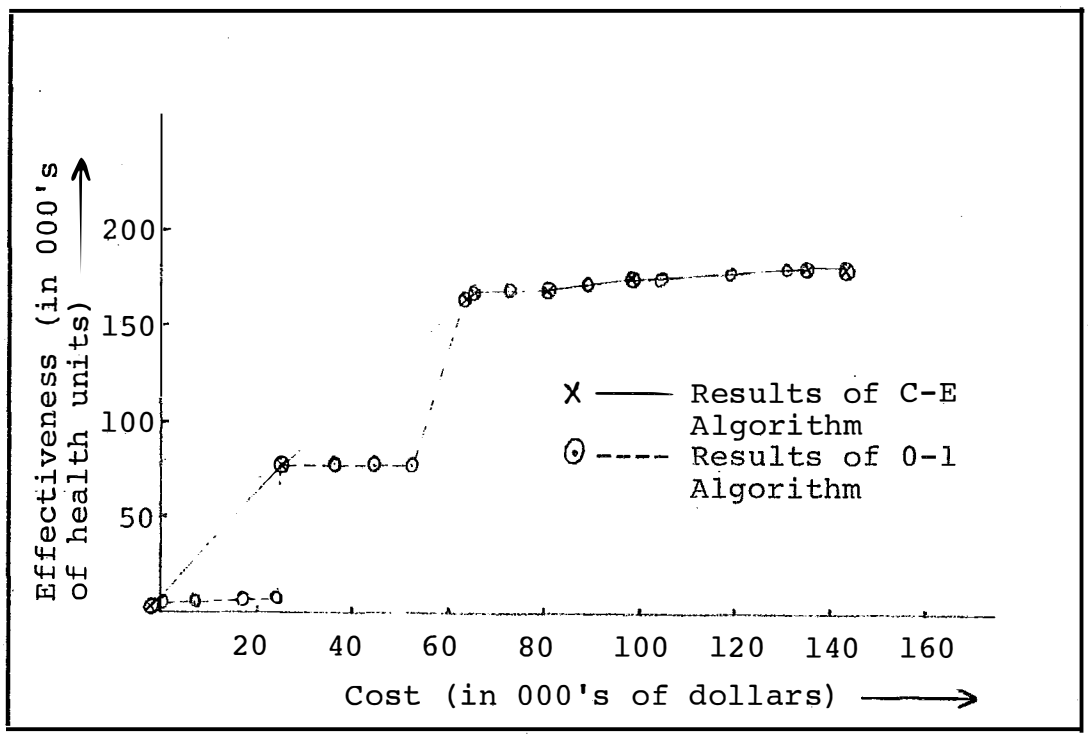

Fig. 13.--General Structure of C-E and 0-1 Results

The difference between the two techniques, then, is that the C-E algorithm produces only "peak" solutions while the 0-1 algorithm may produce any solution, at a peak or in a valley, depending upon the location of the cost constraint. Now, it cannot be denied that each 0-1 solution will always be the one that maximizes the health benefit while staying within the cost-constraint, but the point is that often there is a far better solution nearby which can be obtained by a slight change in the cost constraint. Since the cost constraint may well be rather

arbitrary to begin with, this is considered a serious disadvantage of the 0-1 method.

Another aspect of the same problem is that any of the "valley" solutions provided by the 0-1 algorithm will contain some poorer programs (lower effectiveness-cost ratio) at the expense of some better programs.

These problems with the 0-1 method can be overcome by making a number of runs while varying the cost constraint to explore the nearby solutions. However, given the earlier comments about the computational inefficiency of the 0-1 method, this could be an expensive solution.

In conclusion, then, the cost-effectiveness ranking algorithm is superior to the 0-1 integer linear programming algorithm for the type of application dealt with in this research -- an application with any number of programs, any number of mutual-exclusivity constraints, and one cost constraint. It can handle a larger set of programs; it provides more useful information (specifically the incremental effectiveness-cost ratios which are useful for the rational incorporation of the effect of the intangible benefits and also for interim single program evaluations); it is computationally more efficient; and it produces only "peak" solutions. The last characteristic, of course, would not be an advantage if a precise and inflexible cost constraint did indeed exist. However, it is contended that in most real problems in the health service system this is

not the case.

Although the cost-effectiveness algorithm is superior for most problems, as discussed above, it should be pointed out that it is not suited for applications with multiple resource constraints. These would have to be solved by the mathematical programming approach.

CHAPTER VI

CONCLUSIONS AND FURTHER RESEARCH

This research set out to investigate the problem of optimally allocating resources within the health service system. In particular, it was concerned with methods for selecting, within specified constraints, the optimal sub-set of health service programs from a set of feasible programs. Current approaches were reviewed and found inadequate. A generalized cost-effectiveness model based on a new morbidity-mortality health (utility) index was proposed, and was tested on four different types of health programs. As a result, the following conclusions can be stated:

1. The proposed model is feasible for application to health programs.
2. The model appears to be applicable to a wide variety of health programs -- perhaps all. In this research, it was applied to four different programs covering a broad spectrum of the health field, and no particular difficulties were encountered.
3. If the model is applicable to all programs, and this requires further research, it can be used to optimize the total health service system: that is, to allocate

the total health service resources to the health service activities and programs so as to maximize the overall health achieved. This, of course, would be a vast undertaking requiring extensive data gathering with serious data problems (see conclusion 7 below), but nevertheless, should be considered as an important long-term goal.

4. Two techniques were tested for measuring personal subjective utilities for various health states -- a time trade-off method and a von Neumann-Morgenstern standard gamble approach. Each technique was highly reliable on a stand-alone basis; and when combined, the two methods proved to be equivalent and quite reliable. The time trade-off technique was easier to administer and is recommended for this reason.
5. The utility of a day in a particular health condition (the health value of that condition) is not only a function of the condition itself and of the individual, but also a function of the duration that the individual has been in this particular condition. For confinement conditions, the utility was found to be a decreasing function of duration while the utility of chronic conditions was an increasing function. This conclusion must be considered tentative because of the small sample-size involved. Nevertheless, the result may be important to researchers interested in developing a set of universal utility weights for application to general health condi-

tions, since the implication here is that no such single value exists. That is, a general condition like bed-disability does not have a single utility value, but rather a value which is a function of the duration of time spent in the condition.

6. Two computational algorithms were investigated for analyzing a set of potential health programs to select the optimal sub-set: a cost-effectiveness ranking algorithm developed specifically for this research and a standard 0-1 integer linear programming algorithm. The cost-effectiveness algorithm is superior for those problems to which it is applicable -- an application with any number of programs, any number of mutual-exclusivity constraints, and one cost constraint. It has the following advantages: (1) simplicity, (2) computational efficiency, (3) the ability to handle larger sets of programs, (4) only "peak"[1] solutions are produced and these are normally to be preferred and (5) better information is provided along with the solution (specifically the incremental effectiveness cost ratios which are useful for the rational incorporation of the intangible benefits and also for interim single program evaluations). On the other hand, the 0-1 integer linear

---

[1]See p. 204 above for an elaboration on what is meant by "peak" solutions.

programming algorithm provides a great deal of flexibility for handling complicated problem structures (multiple resource constraints, time-streamed resource constraints) and in these cases, it would be the technique of choice.

7. The data gathering required to apply this generalized cost-effectiveness model to specific health programs is a time-consuming task. The health service system appears to contain a wealth of data -- a great deal is recorded and very little is thrown away -- but much of it is still in an unorganized raw state, and the required information must be tediously extracted by manually searching the appropriate data sources. In addition to this general problem of data gathering, there is the specific problem that the model requires data on the health benefits for the various programs, and valid health benefit data is particularly difficult to acquire. All four programs analyzed in this research had fairly clearly defined health benefits which minimized this problem; but in many, probably most, health programs this is not the case.[1]

8. From a strictly cost-effective point of view, the four programs analyzed in this project can be ranked as follows:

---

[1] See, for example, Sackett (1970).

(a) The program for the prevention of hemolytic disease of the newborn is an excellent venture which not only produces a substantial health benefit but also generates an economic return to society.

(b) Tuberculosis screening is an excellent program (ranked second) in a few areas of high prevalence and a mediocre program (ranked last) in most other areas.

(c) The program to provide coronary emergency rescue services ranked third.

(d) A program to treat chronic kidney disease by transplantation ranked fourth. The other two methods for treating this disease - home dialysis and hospital dialysis - were less cost-effective than this maximum transplantation approach.

These results must be regarded as preliminary: the health value sample was too small and non-random, and many assumptions were required in the calculations.

There are two major recommendations stemming from this research. First, it is recommended that the generalized cost-effectiveness model be applied by the decision-makers of the health service system, perhaps initially on a limited trial basis. This would provide an opportunity to further refine the technique and to determine its real value in providing assistance to the rational management of the system. Second, it is recommended that further

research be conducted on the approach to continue to improve and refine it. Specifically, the following items should be investigated:

1. Further application should be made of this approach to other health programs. This will uncover new problems which, when solved, will improve and further generalize the technique.
2. Additional research should be conducted on the health utility scale: a larger sample would be useful; the question of validation should be investigated; the application to general rather than specific health states should be examined; and, for comparative purposes, it would be useful to measure lay as well as physician utilities.
3. Research is required to determine the proper discount rate to apply to future health benefits.
4. Variations and sophistications of the basic model can be investigated. For example, research could be conducted into a continuous rather than discrete model, a stochastic rather than deterministic model, a model with interacting non-mutually-exclusive programs, and a model with multiple, distributional and time-streamed constraints.

This project has introduced a new approach to decision making in the health service system. Further research will be required to improve and refine the technique

so it can fulfil its potential of providing the basis for the rational evaluation and selection of health service programs, and eventually, for the overall optimization of the health service system.

APPENDIX I

HEALTH SCALE EXHIBITS

List of Exhibits

EXHIBIT 1

PAIRED DIFFERENCE TEST FOR TIME DEPENDENCY

In each pilot test of the measurement technique, each state that was valued at two different time durations was tested by a paired t-test to determine if the change in value with time was significant. The two time durations were: 1 year and life for version 1 confinement states and for version 2, 1 week and 1 year for version 1 chronic states, and 4 months and 10 years for version 3. For any one version and state, let

X = the long-term utility of this state for a specific individual and a specific measurement method.

Y = the short-term utility of the same state for the same individual and same measurement method.

Δ = X - Y

The results of the tests are tabulated below.[1]

---

[1]For the method of calculation see Appendix I, Exhibit 6 containing a detailed example.

State	Version	Observations	df	$\bar{\Delta}$	t_{calc}	$t_{.975}$	Conclusion
Confinement States:							
Home Bed	1	22	21	-.0477	.642	2.08	Not sig.
Home Confinement	3	4	3	-.203	2.294	3.18	Not sig.
Sanatorium Confinement	3	4	3	-.11	2.136	3.18	Not sig.
Chronic States:							
Mild Discomfort	1	22	21	.009	1.61	2.08	Not sig.
Reduced Activity	1	22	21	.011	1.07	2.08	Not sig.
Restricted Activity	1	22	21	.0268	1.52	2.08	Not sig.
Mild Discomfort	2	44	43	.0092	1.53	2.02	Not sig.
Ambulatory with drug Treatment	2	44	43	.0138	1.79	2.02	Not sig.
Hospital Dialysis	3	4	3	.2635	2.69	3.18	Not sig.
Home Dialysis	3	4	3	.2198	2.52	3.18	Not sig.
Kidney Transplant	3	4	3	-.0565	1.31	3.18	Not sig.

EXHIBIT 2

SIGN TEST FOR TIME DEPENDENCY

Let Δ be defined as in the previous Exhibit (Appendix I, Exhibit 1), and let p represent the true population proportion of non-zero Δ's which are greater than zero. It is hypothesized that p=0.5 for the aggregated confinement states and also for the aggregated chronic states, and these hypotheses are tested by the method outlined in Siegel (1956, pp. 68-75). The results are summarized below.

	Confinement States	Chronic States
Null Hypothesis	H_o: p = 0.5	H_o: p = 0.5
Alternate Hypothesis	H_1: p < 0.5	H_1: p > 0.5
Level of Significance	α = .05, 1-tail	α = .05, 1-tail
Number of non-zero Δ's (=n)	26	96
Number of Δ's > 0	7	59
Number of Δ's < 0	19	37
Mean = μ = np	13	48
Standard Deviation $\sigma = \sqrt{npq}$	2.55	4.90

	Confinement States	Chronic States
Test Statistic $(Z_{calc})^a$	$\frac{13-7.5}{2.55} = 2.16$	$\frac{58.5-48}{4.9} = 2.14$
Z_{tab}	1.64	1.64

Since $Z_{calc} > Z_{tab}$ in each case, the hypotheses H_o: p=0.5 are rejected, and the alternate hypotheses are accepted. That is, both the decrease in the health value of confinement states and the increase in the health value of chronic states with time are significant at the 5 per cent level.

---

[a] $Z_{calc} = \frac{|x - \mu| - 0.5}{\sigma}$. The factor 0.5 in the numerator is the correction for continuity, which improve the approximation to normality (Siegel, 1956, p. 72).

EXHIBIT 3

LETTER TO GENERAL PRACTITIONERS REQUESTING PARTICIPATION

McMASTER UNIVERSITY

HAMILTON, ONTARIO, CANADA

DEPARTMENT OF
CLINICAL EPIDEMIOLOGY & BIOSTATISTICS

Mailing Address:

Hamilton Health Association
Box 590
Hamilton, Ontario, Canada

June 9, 1970.

George Torrance of the Faculty of Business and I are involved in a research project which involves, among other things, the use of operations research techniques to quantitate how people feel about certain hypothetical situations in which they, as patients, would face alternative programmes of therapy.

If you agree to participate in this project, a member of the research team would conduct a 45-minute interview with you at a convenient time and place. In this interview you would be asked to imagine that you have a particular disability and to then choose (as a consumer, not a clinician) between two ficticious treatment plans. Of course, individual responses will be treated anonymously.

The objective of this phase of the project is to develop scale values for a health index. A brief overview of the total project is provided on the attached sheet if you are interested.

If you can spare 45 minutes to help out on this project please tell your secretary. We will contact her in the near future to arrange a suitable time.

Thanks very much. If you have any questions, please do not hesitate to call me at 383-2149.

Sincerely yours,

David L. Sackett, M.D.

DLS:js
Encl.(1)

EXHIBIT 4

HEALTH STATE DESCRIPTION SHEETS

Health States

Sheet 1, Randomization 1

May 27, 1970
G. W. Torrance

Home Confinement - You're restricted to your home in semi-isolation because you're contageous. Essentially you're quarantined - you may wander around your house and property but you should stay away from people. You have a cough, mild fatigue, no pain. Treatment consists of 2-3 pills/day and plenty of rest. There are no diet restrictions.

Sanitorium Confinement - You're confined to a sanitorium. You have a cough, mild fatigue and no pain. No diet restrictions. Treatment consists of plenty of rest, 2-3 pills/day and an average of 3 injections per week. You're not allowed any home visits and normal hospital visiting procedures apply; eg. no children allowed.

Health States

Sheet 2, Randomization 1

June 16, 1970
G. W. Torrance

Hospital Dialysis - two or three times/week you must travel to the hospital and spend about 8 hours hooked up to a dialysis machine. Working men generally go overnight; others go during the day. You're very anaemic and this may limit your activity. You're on a restricted diet (only 3 cups of fluid per day). There is a permanent shunt imbedded in your arm or leg which restricts your physical activities some - no swimming. You're geographically bound to your machine - vacations are difficult. There is no severe pain but chronic discomfort and for some people, emotional depression. You should be able to work full time but not on a physical job.

Home Dialysis - same as hospital dialysis (symptoms of anaemia, dietary restrictions, shunt, geographic restrictions) except you have dialysis equipment in your bedroom, and three nights a week you hook up for about 10 hours. You and another member of your family have learned how to hook up and operate the dialysis equipment. Occasionally you have to go to the hospital for dialysis.

Kidney Transplant - you have received a successful kidney transplant. Your anaemia from the kidney disease is better, and there are only minor restrictions on your diet and activities. You must take drugs against rejection which make you more susceptible to infections and other diseases. In addition the drugs will produce side-effects such as a strikingly Cushingoid appearance, and possibly other major effects (eg. diabetes).

EXHIBIT 5

RELIABILITY OF THE STANDARD GAMBLE

Data

X_i = the value obtained from the unmodified question

Y_i = the value obtained from the modified question for the same state and the same individual

Δ_i $X_i - Y_i$

X	.26	.27	1.0	.1	.82	.17	.55	.875	.98	.72	.86
Y	.11	.27	1.0	.1	.77	.33	.57	.875	.99	.86	.86
Δ	.15	0	0	0	.05	-.16	-.02	0	-.01	-.14	0

X	.5	.75	.9	.34	.62	.94	.96	.9	.95	.75
Y	.42	.55	.9	.21	.62	.98	.97	.9	.98	.75
Δ	.08	.2	0	.13	0	-.04	-.01	0	-.03	0

N = number of pairs of replicates = 21

Test for Significant Difference Between Replicates

$$\Sigma\Delta_i = .20$$

$$\bar{\Delta} = .0095$$

$$\Sigma\Delta_i^2 = .1366$$

$$S = \frac{\sqrt{\Sigma\Delta_i^2 - (\Sigma\Delta_i)^2/N}}{N - 1} = .0819$$

$$S_{\bar{\Delta}} = \frac{S}{\sqrt{N}} = .0179$$

$$t_{calc} = \frac{\bar{\Delta}}{S_{\bar{\Delta}}} = .5307$$

$$t^{20df}_{.975} = 2.09$$

Since .5307 < 2.09, the difference is not statistically significant at the 5 per cent level.

Coefficient of Correlation

$$\Sigma X_i = 14.215 \quad \Sigma X_i^2 = 11.341 \quad \Sigma X_i Y_i = 11.251$$

$$\Sigma Y_i = 14.015 \quad \Sigma Y_i^2 = 11.298$$

Then the coefficient of correlation ρ is estimated by the sample correlation coefficient r, given by[1]

$$r = \frac{N \Sigma X_i Y_i - (\Sigma X_i)(\Sigma Y_i)}{[N \Sigma X_i^2 - (\Sigma X_i)^2]^{1/2} [N \Sigma Y_i^2 - (\Sigma Y_i)^2]^{1/2}}$$
$$= .965$$

and the 95 per cent confidence limits for ρ are obtained by using the transformation

$$Z = \frac{1}{2} \ln \left(\frac{1+r}{1-r}\right)$$

which, for samples from bivariate normal populations, is approximately normally distributed with mean $\frac{1}{2} \ln \left(\frac{1+\rho}{1-\rho}\right)$ and variance $1/(N-3)$.[2] Hence 95 per cent confidence limits

---

[1] Freund, 1962, p. 310.

[2] Freund, 1962, p. 311.

for Z are

$$Z \pm 1.96\sigma_Z = \frac{1}{2} \ln \left(\frac{1+r}{1-r}\right) \pm \frac{1.96}{\sqrt{N-3}}$$

$$= 2.015 \pm .428$$

By means of the above transformation, the corresponding limits for ρ are .920 and .985.

EXHIBIT 6

RELIABILITY OF THE TIME TRADE-OFF[1]

Data[2]

X	.75	.79	.7	1.0	.17	.73	.84	.91	.5	.87	.92
Y	.88	.91	.85	1.0	.41	.82	.88	.94	.5	.87	.88
Δ	-.13	-.12	-.15	0	-.24	-.09	.04	-.03	0	0	.04

X	.91	.67	.95	.9	.64	.94	.61	.72	.86	1.0
Y	.94	.75	.97	.84	.67	.84	.34	.77	.86	1.0
Δ	-.03	-.08	-.02	.06	-.03	.10	.27	-.05	0	0

N = 21

Test for Significant Difference Between Replicates

$$\Sigma\Delta_i = -.540$$

$$\overline{\Delta} = -.0257$$

$$\Sigma\Delta_i^2 = .2212$$

$$S = .1020$$

$$S_{\overline{\Delta}} = .0223$$

$$t_{calc} = 1.153$$

$$t_{.975}^{20df} = 2.09$$

Since 1.153 < 2.09, the difference is not statistically significant at the 5 per cent level.

---

[1]See Appendix I, Exhibit 5, for a discussion of the notation and method.

[2]The omission of one pair of data is due to the missing observation of respondent number 3. See Appendix I, Exhibit 9 below.

Coefficient of Correlation

$\Sigma X_i = 16.380 \quad \Sigma X_i^2 = 13.538 \quad \Sigma X_i Y_i = 13.809$

$\Sigma Y_i = 16.920 \quad \Sigma Y_i^2 = 14.300$

$r = .858$

and 95 per cent confidence limits for ρ are .676 and .941.

EXHIBIT 7

TEST FOR SIGNIFICANT DIFFERENCE OF RELIABILITIES

To test for significant different between the reliabilities of the Standard Gamble ($r_1 = .965$)[1] and the Time Trade-Off ($r_2 = .858$)[2], compute

$$Z_1 = \frac{1}{2} \ln \left(\frac{1+r_1}{1-r_1}\right) = 2.014$$

$$Z_2 = \frac{1}{2} \ln \left(\frac{1+r_2}{1-r_2}\right) = 1.342$$

which are normally distributed with standard deviations $\sigma_{Z_1} = 1/\sqrt{N_1-3}$ and $\sigma_{Z_2} = 1/\sqrt{N_2-3}$.[3] Then

$\sigma_{Z_1 - Z_2} = \sqrt{\frac{1}{N_1-3} + \frac{1}{N_2-3}} = .333$ and, to test $H_o: \mu_{Z_1} = \mu_{Z_2}$ we have

$$Z = \frac{Z_1 - Z_2}{\sigma_{Z_1 - Z_2}} = 2.016 > 1.96$$

Hence there is a significant difference at the 5 per cent level.

---

[1] See Appendix I, Exhibit 5.

[2] See Appendix I, Exhibit 6.

[3] See, for example, Freund, 1962, p. 311.

EXHIBIT 8

EQUIVALENCE OF THE TWO TECHNIQUES

Data[1]

X_i = the mean value obtained by the Time Trade-Off Technique for a specific state and individual.

Y_i = the mean value obtained by the Standard Gamble Technique for the same state and individual.

$\Delta_i = X_i - Y_i$

$N = 54$

Test for Significant Difference Between Techniques[2]

$\Sigma\Delta_i = 1.975$

$\bar{\Delta} = .037$

$\Sigma\Delta_i^2 = 1.689$

$S = .175$

$S_{\bar{\Delta}} = .024$

---

[1]For the actual data see Appendix I, Exhibit 9. The omission of one pair of data is due to the missing observation of respondent number 3.

[2]See Appendix I, Exhibit 5 for a detailed example of the method.

$t_{calc} = 1.54$

$t^{53df}_{.975} = 2.01$

Since 1.54 < 2.01, the difference is not statistically significant at the 5 per cent level.

Coefficient of Correlation[1]

The coefficient of correlation was found to be r = .850 with 95 per cent confidence limits of .756 and .911.

---

[1]See Appendix I, Exhibit 5 for a detailed example of the method.

EXHIBIT 9

DATA MATRIX

	HEALTH STATES									
	Home Confinement (B)		Sanatorium Confinement (C)		Kidney Transplant (D)		Home Dialysis (E)		Hospital Dialysis (F)	
Subject	t	p	t	p	t	p	t	p	t	p
1	.61 .47	.26 .11	.02	.01	.61 .82	.43 .43	.55	.19	.10	.10
2	.47 .52	.31 .31	.50	.05	.94 .82	.84 .79	.39	.36	.40	.25
3	.33 .50	.17 .33	X	0.0	.85 .78	.66 .68	.61	.50	.50	.25
4	.50	.50	.67 .75	.88 .88	.96 .98	.96 .98	.93	.93	.80	.90
5	.86 .79	.72 .86	.75	.42	.78	.85	.88 .92	.87 .87	.80	.58
6	.50 .50	.50 .42	0.0	0.0	.88 .88	.72 .50	.05	.29	.10	0.0
7	.46 .56	X .70	.25	0.0	.91 .94	.90 .90	.86	.86	.80	.80
8	.12 .37	.37 .25	.11	.01	.63 .74	.70 .70	.55	.15	.38	.42
9	.81 .91	.89 .96	.11	.75	1.0 .97	.97 .99	.97	.91	.99	.90
10	.71 .85	.91 .91	.25	0.0	.84 .92	.93 .97	.63	.81	.50	.38
11	.88 .90	.88 .88	1.0	.75	.93 .92	.91 .91	.80	1.0	.92	.90

Notes:

1. t represents the time trade-off technique

   p represents the standard gamble.

2. X represents a missing value.[1]

3. The calculation of these values was performed with formulae (2) p. 96 and (8) p. 102, with h_{i+1} in each case equal to the mean of the two values of that state for that individual.

---

[1] The two missing values are explained on p. 112 above.

EXHIBIT 10

HEALTH STATE VALUE CALCULATIONS

Sample Calculation:[1] For state E (home dialysis).[2]

$$\bar{X}_E = \frac{15.87}{24} = .6613$$

The estimate of the variance in the population is

$$S^2 = \left[\frac{\sum_{i=1}^{k} \frac{n_i}{N} (\bar{X}_i - \bar{X})^2}{k-1} \right]$$

$$= \left[\frac{\sum_{i=1}^{k} \left(\frac{T_i^2}{n_i}\right) - \frac{T^2}{N}}{N(k-1)} \right]$$

where k is the number of subjects (=11)

n_i is the number of responses for subject i

T_i is the sum of the responses of subject i

$$N = \sum_{i=1}^{k} n_i$$

$$T = \sum_{i=1}^{k} T_i$$

and $\bar{X}_i = T_i/n_i$

---

[1]Method for homogeneous groups from Dixon and Massey, 1957, p. 129.

[2]For sample values see Appendix I, Exhibit 9.

$$\text{Then } S_E^2 = 11\left[\frac{\sum_{i=1}^{11}\left(\frac{T_i^2}{n_i}\right) - \frac{T^2}{24}}{24(10)}\right]$$

$$= \frac{11}{240}\ (12.2214 - 10.494)$$

$$= .079$$

The standard error of $\bar{X}_E$ is then

$$S_{\bar{X}_E} = S_E/\sqrt{k} = .085$$

and 95% confidence limits for μ_E are

$$\bar{X}_E \pm t^{10df}_{.975} S_{\bar{X}_E} = .661 \pm (2.228)\ (.0849) = .661 \pm .189$$

Summary of Results

State	$\bar{X}$	S^2	$S_{\bar{X}}$	$2.228S_{\bar{X}}$
B(Home Confinement)	.564	.060	.074	.164
C(Sanitorium Confinement)	.340	.117	.103	.230
D(Kidney Transplant)	.829	.017	.040	.089
E(Home Dialysis)	.661	.079	.085	.189
F(Hospital Dialysis)	.534	.102	.096	.215

EXHIBIT 11

REVIEW OF UTILITY MEASUREMENT TECHNIQUES

Six techniques for measuring utilities on an interval or ratio scale are reviewed below for their suitability to the health scale measurement task. Comments are inserted describing how each technique could be applied to health, or discussing some of the experimental experiences if it was so applied in this research.

1. Von Neumann-Morgenstern standard gamble

The standard gamble technique proposed by von Neumann and Morgenstern (1953) consists of the following steps:

(a) The events to be valued are first ranked by preference.

(b) Then two extreme events are taken from this list, one from each end, say event A and event Z.

(c) The subject is asked to choose between two alternatives;

Alternative 1: A 50-50 chance of either event A or event Z occurring, or

Alternative 2: An intermediate event, say M, occurring with certainty.

(d) The intermediate event or the probabilities are changed until the subject is indifferent between alternatives 1 and 2.

(e) The reference events, A and Z, can be arbitrarily assigned any value, since this is an interval scale, and the value

of the intermediate event can then be calculated under the assumption that the respondent is making rational choices (i.e., attempting to maximize his expected utility).

Von Neumann and Morgenstern established a set of consistent axioms upon which this method is based and showed that the method results in a linear interval scale.

Some of the pitfalls in the standard gamble technique are discussed by Dyckman, Smidt and McAdams (1969).

> [i] It may be necessary to simulate conditions similar to the ones under which the decision maker generally operates in order to approximate his utility function appropriately. Experiments with coins or other random devices may fail to do the job (p. 314).

This was one of the problems encountered when the standard gamble technique was used in this research to measure health values. A number of the respondents remarked on the unreality of the interview situation and were concerned that their responses might not be identical to what they would do if really faced with the situation. This is a general problem with any measurement taken in an artificial situation and the amount of error, if any, introduced can only be determined by a proper validation study.

> [ii] Before using this utility function, it is imperative that it be checked for consistency using several new gambles. If necessary, changes should be made until the decision maker is confident that it expresses his preferences (p. 316).

Consistency checks were performed in this research by repeating one of the measures in a disguised manner. In the early pilot versions, the respondent was confronted with serious inconsistencies and asked to reconcile them. However, as the interview technique improved this became increasingly unnecessary and on the final sample this was dropped altogether.

> [iii] An additional difficulty with the assumptions made in utility theory arises when extremely unfavourable outcomes (or payoffs) near the boundary of the utility function are involved. Examples might include war, bankruptcy or death. Near the lower end of the utility function, decision makers are likely to be unable to distinguish realistically between small differences in probabilities that produce substantial changes in the expected utility indices (p. 332).

What this means in actual practice is that the alternatives should be phrased so that the indifference probabilities are as near to 0.5 as possible. This suggestion was followed in this project.

> [iv] There is some evidence that individual managers may be considerably more conservative than their superiors would desire (p. 332).

The implication here is that when a professional (the manager) is making a decision for another person (the owner) he tends to be more conservative (less risk taking) than the individual would be for himself. The analogy in the health service system would suggest that a physician when advising a patient would be more conservative than the patient would be for himself. This hypothesis has not yet been tested,

but it would be possible and worthwhile to do so as a direct extension of this project by applying the value measuring instrument independently to a sample of physicians and a sample of patients.

2. Simplified von Neumann-Morgenstern standard gamble

Ackoff and Sasieni outline the following procedure which they describe as "a simplification of that proposed by von Neumann and Morgenstern" (1968, p. 49).

(a) Preference rank the outcomes- $0_1 > 0_2 > \cdots > 0_n$

(b) Let $U(0_n) = 1$, where $U(0_n)$ represents the utility of outcome n.

(c) Find α_1 such that the subject is indifferent between 0_n with certainty and 0_1 with probability α_1.

(d) Then $U(0_1) = 1/\alpha_1$.

(e) Repeat steps (c) and (d) for all remaining outcomes.

(f) Use other outcome pairs to check the reliability of the estimates.

This is called a simplification since it appears to require the subject to consider only 2 subjective values and 1 probability instead of 3 and 2 respectively as required by the von Neumann-Morgenstern standard gamble. But on closer investigation, this is not so. Step (c) above can be rephrased as follows: find α_1 such that the subject is indifferent between alternative 1 and 2, where alternative 1 is 0_n with certainty and alternative 2 is a gamble with probability α_1 of 0_1 and probability $(1-\alpha_1)$ of no change. No

change, by definition, has a utility of 0. Now it is apparent that this simplified version is really just a special case of the original version which can be used when one of the outcomes has a utility of 0.

3. Decision-theoretic method

At the International Conference on Operational Research and the Social Sciences in September 1964, Flagle reported that he and his colleagues had been unsuccessful with existing utility measurement techniques:

> Our efforts to estimate disutilities, losses, or costs directly or to apply standard gamble techniques to measure them...have not been successful. Sessions with clinicians and public health physicians have produced a consistent set of objections...(1966, p. 400).

Because of these difficulties, Flagle was experimenting with a decision-theoretic approach. The essence of this approach is as follows:

(a) Structure a realistic decision situation and let the decision maker select his strategy.

(b) Assuming his strategy is optimal for the utilities in his loss matrix, calculate bounds on the unknown utility.

(c) Repeat this process changing the decision situation (e.g., changing the probabilities) to tighten the bounds and provide an interval estimate of the utility. In the limit, the indifference point for the decision will provide a point estimate of the utility.

Computationally this limiting case for point estimates is identical to the von Neumann-Morgenstern standard gamble. So why should it work when the standard gamble did not? It would appear that the significant difference is the fact that the decision-theoretic method is framed as a realistic decision rather than an unnatural gamble.[1]

This approach was used as much as possible in the current research. That is, the decision situation posed to the subject was made as realistic as possible, given the unnatural environment of an interview setting.

4. Direct measurement

The direct measurement method was proposed by Stevens (1959) who noted the similarity between measuring utility and measuring perceptual responses such as brightness and loudness. The latter are measured directly on a ratio scale, by asking the subject, for example, to turn up the light until it is twice as bright or by changing the light and asking him to estimate the percentage change. Similarly Stevens suggests one can ask which event is twice as valuable (preferred twice as much) as a given event, and by repeating this procedure, develop a ratio scale. Then one must aggregate the different scales from different subjects into one common

---

[1]This is essentially the same observation as pitfall number [i] mentioned above on p. 235.

scale. In this regard, Stevens points out:

> If we are interested in standardizing a scale of brightness for a given condition of viewing, we must forego the hope that our scale will represent the visual responses of all citizens. We can, however, aspire to the less ambitious goal of erecting a scale that will describe the typical responses of the median observer in a population of interest. Having such a scale, we can then more effectively press the question of individual differences and idiosyncrasies, if the problem proves important (p. 52).

It is clear that a scale of subjective values involved in health would differ for each subject but, assuming there is reasonable consistency, we can, as Stevens says, develop the scale which represents the median subject.

This technique of directly measuring utilities by ratio estimation was further developed by Miller in 1966, although he called it "worth assessment".

In discussing the proper interpretation of worth, Miller points out:

(i) Worth is not an external property of the situation but is an internal property of the human decision maker (p. I-12).

(ii) Worth judgements made by different people will be different (p. I-15).

(iii) Worth judgements made by the same person over time will be different (p. I-15).

Miller's worth scale varies from 0 (no worth) to 1 (maximum worth), is a ratio scale, and all normal arithmetic operations are valid (p. I-24).

The part of his method which is applicable to this research is the following procedure for measuring the weights (worth) of his sub-criteria.

> 1. All sub-criteria subsumed under a given higher level criterion are ranked in order of ascending perceived importance (p. II-46).

Successive pair-wise comparisons are made to achieve this ranking.

> 2. Then starting with the most important pair of sub-criteria appearing at the head of the list, successive pair-wise comparisons are made between contiguous sub-criteria, and decision makers are asked to indicate in terms of a ratio the degree of perceived relative importance of the two. Stated alternatively, decision makers are asked to indicate the rate at which they would be willing to accept reduced satisfaction of one sub-criterion in return for increased satisfaction of the other (p. II-46).

In each pair-wise comparison, the top item of the pair is given a value of 1 and the decision maker assigns an appropriate fraction to the other item indicating its relative value. Then sequential multiplication provides the appropriate weights.

If a group of decision makers is involved, their individual answers must be aggregated into a single common scale. Miller recommends a discussion among the decision makers to reduce the variation in the answers, followed by a simple arithmetic mean to provide the required single number (p. II-49).

Stimson (1969) reported an application of this direct measurement technique in the health area. He used it as a second measuring technique along with the Churchman-Ackoff method (see below) to measure the utilities of objectives of decision-makers in a public health agency.

In this research project, the direct measurement technique was used as one of the methods in the early pilot studies. However, as the project progressed, the technique was modified and evolved into a time trade-off method.

5. Churchman-Ackoff method

This method was developed by Churchman and Ackoff (1954) to apply to qualitative outcomes with additive independent utilities. For example, if 0_j and 0_k have utilities U_j and U_k respectively, the utility of the combined outcome 0_j and 0_k must be $U_j + U_k$. Since health states are mutually exclusive, combined outcomes are impossible and the method is not applicable.

6. Method of indifference curves

The indifference curve technique is used by economists to determine utility functions. Given two commodities, A and B, and a family of indifference curves (lines of constant utility) as shown in figure 14 below, one can solve for the utility functions f(A) and f(B) by fitting the curves $f(A) + f(B) = k_i$, $i = 1,2,\ldots,n$.

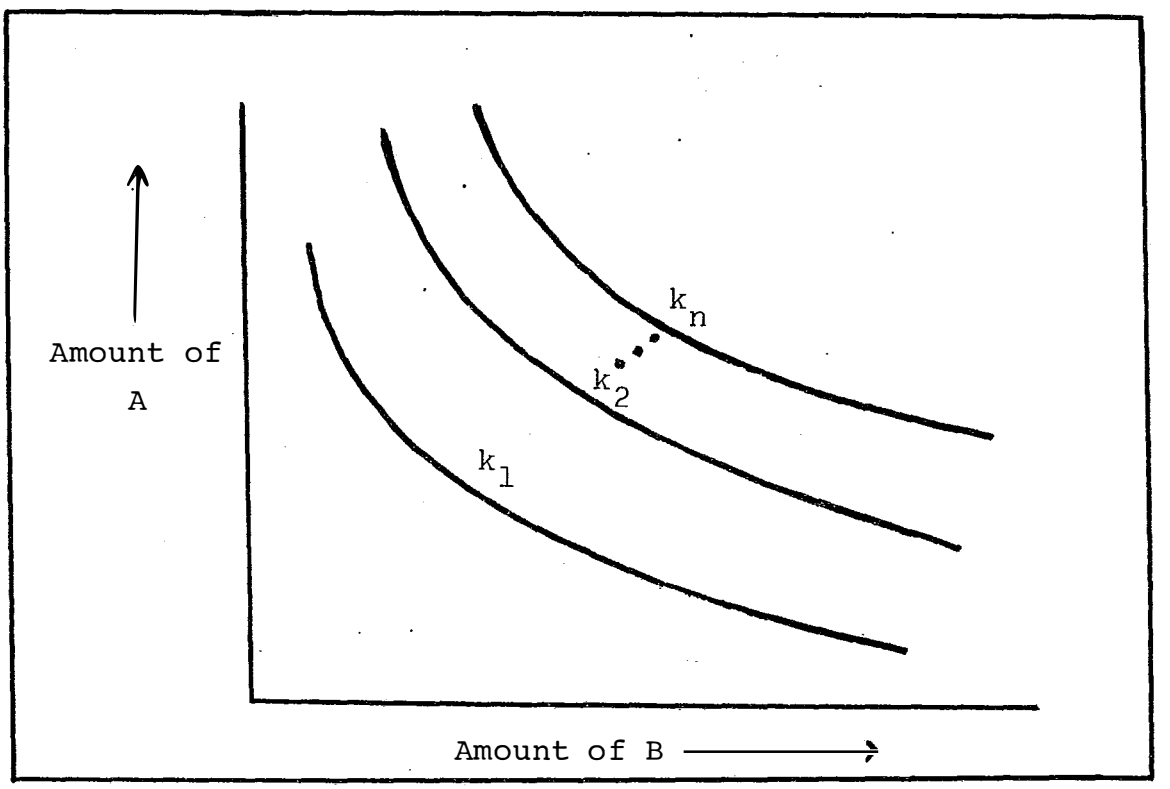

Fig. 14.--Family of Indifference Curves

As an example of how this technique could be applied to health states, consider a situation where the amount of A represented time in one particular health state (for example, months of home confinement under treatment for tuberculosis) while the amount of B represented time in a different state (for example, months of sanitorium confinement under treatment for tuberculosis). Then, if a respondent were indifferent between 6 months of A and 4 months of B, the two points (0,6) and (4,0) would represent two points on a single indifference curve.

This variation on the indifference curve method (obtaining intersects only) was used in this research although it was developed as an outgrowth of the direct measurement technique rather than of the indifference curve technique.

7. Summary

The following six utility measuring techniques have been reviewed:

1. Von Neumann-Morgenstern standard gamble.
2. Simplified von Neumann-Morgenstern standard gamble.
3. Decision-theoretic method.
4. Direct measurement method.
5. Churchman-Ackoff method.
6. Method of indifference curves.

Number 5 was determined to be unsuitable. Numbers 2 and 3 were found to be variations on number 1, the standard gamble. The standard gamble (1) was selected as one of the methods to be used, with the alternatives phrased as realistically as possible as suggested by Flagle's decision-theoretic approach. The direct measurement method was the other technique selected for use, and this approach evolved, in application, into a time trade-off technique which had some aspects in common with the method of indifference curves.

APPENDIX II

HEALTH PROGRAM EXHIBITS

List of Exhibits

EXHIBIT 1

PROJECTION OF TUBERCULOSIS PREVALENCE

The incidence of active tuberculosis in Ontario for the years 1960-1968 is summarized below:

Year	Rate per 100,000 Population[1]
1960	33.3
1961	27.3
1962	27.8
1963	26.4
1964	22.9
1965	20.9
1966	20.3
1967	19.5
1968	18.3

The prevalence rate has declined steadily since 1960 (with the exception of 1962). By the method of least squares, the best-fitting[2] exponential function was found to be

$$R(X) = 33.7452\ e^{-.0711081\,X}$$

where R(X) is the active tuberculosis rate in year X (X=0 for 1960).

This function is plotted in figure 15.

Since $e^{-.0711081} = 0.931$, the annual decrease in the incidence rate of tuberculosis is 1-0.931 = .069 or 6.9

---

[1] Ontario Department of Health, 1969c, p. 4.

[2] Index of Determination = .9437.

per cent. This figure is verified by Hawthorne who cites a figure of 7 per cent in a study of tuberculosis in Scotland (1969, p. 223).

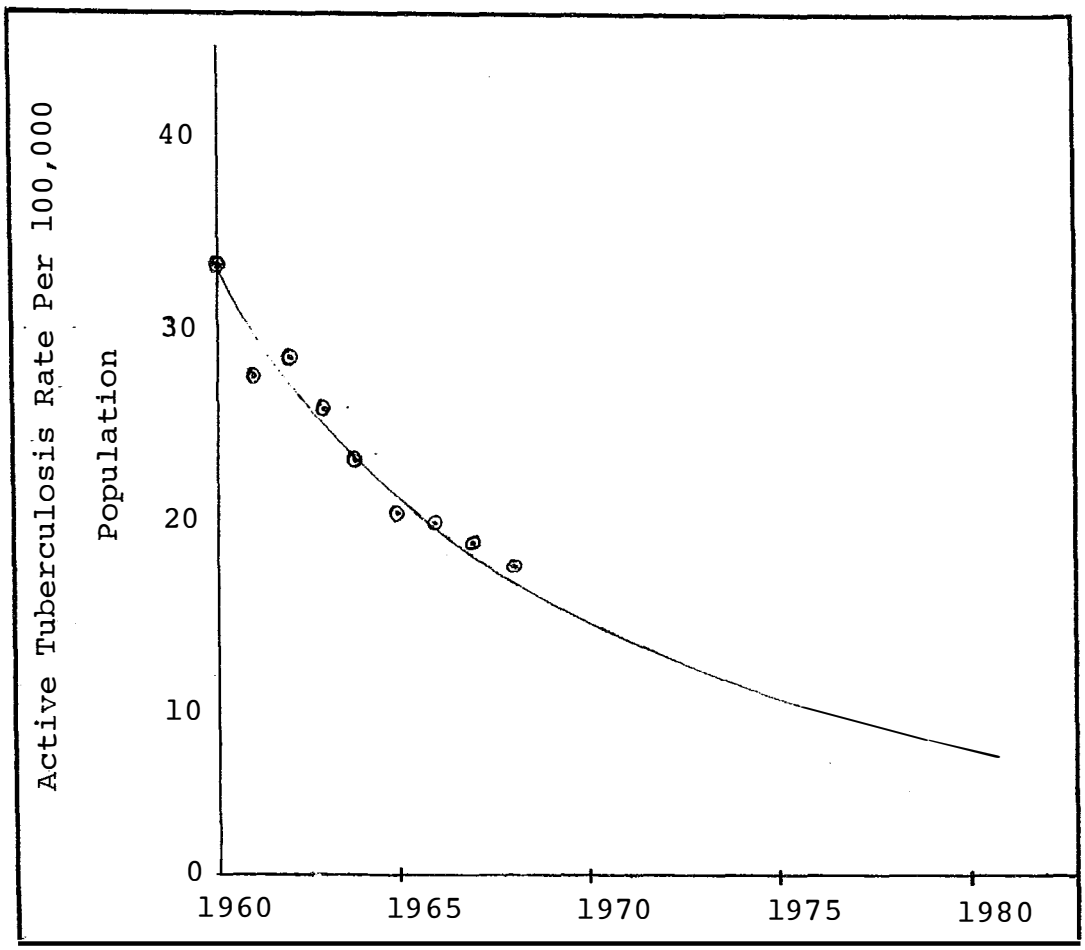

Fig. 15.-- Active Tuberculosis Rate, 1960-1968, with Projections to 1980

EXHIBIT 2

METHOD OF DETECTION VERSUS EXTENT

Data (1967-1968)[a]

Method of Detection	Extent of Disease: Advanced		Moderately Advanced		Minimal	
	Number	%	Number	%	Number	%
Mass Survey	4	4.6	28	32.2	55	63.2
Symptoms	227	29.5	297	38.6	245	31.9
Contact Follow-Up	4	6.8	12	20.3	43	72.9
Routine X-Ray	25	12.4	74	36.6	103	51.0
Survey of Special Groups	40	15.3	86	33.0	135	51.7
Total	300	21.8	497	36.1	581	42.1

[a]Source: Wigle, 1970.

EXHIBIT 3

FEREBEE EPIDEMIOLOGICAL MODEL

The future course of tuberculosis was analyzed using the epidemiological model by Shirley H. Ferebee (1967). The analysis was required to determine the decrease in future cases from the elimination of one case now.

The Ferebee model is based on five assumptions:

1) That the present population [of the United States] contains approximately 25 million truly infected persons who harbor living tubercle bacilli;

2) That, each year, one of every 625 previously infected persons will develop active tuberculosis;

3) That, on the average, each new case will infect 3 persons among the 165 million uninfected;

4) That one of every 12 new infections will progress to clinical disease during the first year of infection; and

5) That the infected and uninfected populations are subject to the same age specific death rates from all causes (p. 4).

Note that this model breaks the infected population into two categories: new infections and old infections. When a person is first infected he enters the category of new infections. One-twelfth of these people progress to

active disease in the first year (assumption number 4 above). The remaining eleven-twelfths, who do not activate, move to the category of old infections at the end of the year. In this category, their chance of activation in any one year is only 1 in 625 (assumption number 2 above).

A tuberculosis screening program discovers active cases earlier than they would have been discovered otherwise (assumed to be one year earlier). Let F(N) represent the number of these cases discovered in year N. Without the screening program, these F(N) cases would have initiated a chain of future infections and activations as outlined by the Ferebee model. We wish to calculate the size of this chain, and particularly the number of new active cases created each year as a direct result of this chain. To do this, two additional assumptions are required:

(6) All infections from an active case are assumed to occur at the mid-point of the infectious period. For the original F(N) cases, this would be six months after the time they would have been discovered had there been a screening program. For subsequent cases infected from the chain reaction, this would be six months following activation.

(7) All new infections that are going to activate do so at the mid-point of their time period -- that is, six months after infection.

The chain of infections and activations initiated in year N by the F(N) cases can be computed as follows. Let

$V_N(J)$ = the number of new active cases arising in year J as a result of the chain of infections initiated in year N by the F(N) cases.

$W_N(J)$ = the number of old infected persons existing at the end of year J, as a result of the chain of infections initiated in year N by the F(N) cases.

New active cases in year J come from two sources: from the pool of new infections and from the pool of old infections. From assumption 3, the size of the pool of new infections in year J is three times the number of new active cases in year J-1. From assumption 4, one out of every twelve of these will activate in year J. Combining these two assumptions, the number of new active cases in year J from the pool of new infections is $3 \times 1/12\ V_N(J-1) = 0.25\ V_N(J-1)$. The number of new active cases in year J coming from the pool of old infections is 1/625 times the size of the pool, or $.0016\ W_N(J-1)$. Thus

$$V_N(J) = .25V_N(J-1) + .0016\ W_N(J-1), \quad J = N + 1, N + 2,... \qquad (1)$$

$$V_N(N) = F(N) \qquad (2)$$

The size of the old infected pool is required to solve equation (1). The old infected pool at the end of year J, $W_N(J)$, is the previous pool $W_N(J-1)$, plus net additions minus deaths. The net additions are the new infec-

tions from the previous year, $3V_N(J-1)$, less all activations, $V_N(J)$. The deaths are removed by multiplying by .9788, the age-specific survival rate for infected persons.[1] Thus,

$$W_N(J) = .9788\ [W_N(J-1)+3V_N(J-1)-V_N(J)],$$
$$J = N+1,\ N+2,\ldots \qquad (3)$$

In the first year, year N, there is no pool of old infections resulting from the F(N) cases. Thus

$$W_N(N) = 0 \qquad (4)$$

In summary, then, the number of new active cases arising in year J as a direct result of the chain of infections initiated in year N by the F(N) cases can be calculated from the recursive formulae, (1) and (3), using the initial conditions expressed by (2) and (4).

---

[1] Calculated from Ferebee (1967, p. 5) who uses an age-specific death rate of 530,000/25,000,000 = .0212.

EXHIBIT 4

EFFECT OF TUBERCULOSIS ON LIFE EXPECTANCY

Introduction

Only two studies could be located which measured the reduction in life expectancy from tuberculosis. Unfortunately, neither represented local experience. Trauger (1966) reported a Hawaiian study that determined the average reduction in life expectancy for a patient with active tuberculosis to be 11.6 years. He estimated the comparable figure for the United States to be 8.2 years. (The figure calculated below for Ontario is 7.8 years.) Trauger's data also showed that essentially all of this reduction in life expectancy came from patients on the active tuberculosis registry. Those people who had been cured and placed on the inactive registry exhibited normal mortality rates.

Iversen (1967a and 1967b) studied the progress of Danish patients who suffered from active tuberculosis during a four year period (1961 to 1964 inclusive). Based on their cure and death rates he was able to calculate life-tables for these patients which would assess their prognosis according to the severity of their disease. That is, it would show, for a given cohort, how many patients would be cured and how many would die each year until they had all done one or the other. The following tables and calculations are based on the application of Iversen's cure and death rates to the Ontario tuberculosis population.

Life Tables for Tuberculosis Patients

Year	Advanced		Moderately Advanced		Minimal	
	l_x	d_x	l_x	d_x	l_x	d_x
0	100	4	100	3	100	2
1	96.00	2.88	97.00	2.33	98.00	1.76
2	91.20	2.74	92.73	2.23	94.28	1.70
3	75.70	2.42	76.13	1.90	76.55	1.38
4	52.08	1.77	44.54	1.20	33.84	.68
5	35.73	1.36	26.86	.83	16.92	.41
6	22.94	1.10	16.15	.61	9.32	.26
7	14.95	.85	9.85	.45	5.19	.18
8	9.62	.63	6.25	.33	3.25	.13
9	6.30	.41	4.20	.22	2.57	.10
10	4.13	.27	2.83	.15	2.03	.08
11	2.70	.18	1.90	.10	1.60	.06
12	1.77	.12	1.28	.07	1.27	.05
13	1.16	.08	.86	.05	1.00	.04
14	.76	.05	.58	.03	.79	.03
15	.50	.03	.39	.02	.62	.02
16	.33	.02	.26	.01	.49	.02
17	.21	.01	.18	.01	.39	.02
18	.14	.01	.12	.01	.31	.01
19	.09	.01	.08	.00	.24	.01
20	.06	.00	.05	↓	.19	.01
21	.04	↓	.03		.15	.01
22	.03		.02		.12	.00
23	.02		.01		.09	↓
24	.01		.01		.07	
25	.01		.00		.05	
26	.00		↓		.04	
27	↓				.02	
28					.01	
29					.01	
30					.00	
					↓	

Notes:

1) The life tables were compiled by applying the cure and death rates cited by Iversen (1969b, p. 899) to cohorts of 100 cases. Iversen gives four rates -- for bilateral and unilateral lesions both with and without cavity. Although these four categories are not precisely equivalent to the categories advanced, moderately advanced and minimal, it was felt that an approximate equivalence did exist;[1] with advanced equivalent to bilateral lesion with cavity, minimal equivalent to unilateral lesion without cavity, and moderately advanced encompassing Iversen's remaining two categories.

2) For durations of disease exceeding ten years, the rates were assumed constant at Iversen's ten year level.

3) The tables are compiled by deducting the number of deaths, d_x, and number of cures during year x from the cases in the cohort, l_x, at the beginning of the year to give the cohort, l_{x+1}, at the beginning of the next year.

Years of Life Lost

The following two assumptions are required to compute the years of life lost from these life tables:

---

[1] Wigle, 1970.

1. Trauger discovered that only active tuberculosis patients have excess mortality; cured patients have normal mortality. This finding is assumed to apply to Iversen's data. Thus the entire excess mortality is represented by the deaths of active cases, d_x, in the life tables.

2. It is assumed that all patients with active tuberculosis are diagnosed at age 44, the average age for the active tuberculosis population of Ontario.[1] This would give them a normal life expectancy of 30 additional years.[2]

Since a person who dies in year n loses 30-n years of life, the years lost by the cohort is $\sum_{n=0}^{30} d_{x_n} (30-n)$. For example, for the cohort of 11 advanced cases, the years of life lost is

$$4(30-0) + 2.88\ (30-1) + \text{---} + .01\ (30-19)$$
$$= 913.55$$

Similarly, for the moderately advanced and minimal cohorts, the life years lost are 800.56 and 700.43 respectively.

Discounting at 8 per cent, the present value of life years lost for the advanced, moderately advanced and minimal cohorts are 166.73, 122.49 and 82.44 years respectively.

---

[1] Ontario Department of Health, 1969c, p. 6.

[2] Dominion Bureau of Statistics, 1964, pp. 12-15.

Years of Working Life Lost

To determine the years of working life lost the following additional assumptions are required:

1) Men retire at age 65.
2) Housewives never retire and working women retire to become housewives.

Based on these assumptions, the average remaining working years for a patient diagnosed with active tuberculosis is 25. The working years lost to the cohort of 100 through death is $\sum_{n=0}^{25} d_{x_n} (25-n)$. The results are: advanced, 414 years; moderate, 301 years; and minimal, 200 years. On a present value basis at 8 per cent these figures are respectively 156, 115 and 77 years.

Summary of Results

Extent of Disease on Diagnosis	Years of Life Lost Per Patient		Years of Working Life Lost Per Patient	
	Years	PV Years	Years	PV Years
Far Advanced	9.14	1.67	4.14	1.56
Moderately Advanced	8.01	1.22	3.01	1.15
Minimal	7.00	0.82	2.00	0.77
All Cases[1]	7.83	1.15	2.83	1.08

[1]Weighted average based on the number of cases in each extent -- see Appendix II, Exhibit 2.

EXHIBIT 5

AVERAGE ANNUAL EARNINGS FOR TUBERCULOSIS PATIENTS

Occupational Category	Number of Patients[1]	Average Income[2]	Total Income[3]
Employees of Businesses	161	$ 5,565.38	$ 896,026.18
Employees of Institutions	56	4,035.42	225,983.52
Teachers and Professors	12	6,824.22	81,890.64
Federal Employees	9	6,146.65	55,319.85
Provincial Employees	6	5,850.03	35,100.18
Muncipal Employees	6	5,679.12	34,074.72
Unclassified Employees[4]	325	3,723.73	1,210,212.25
Farmers	13	5,887.17	76,533.21
Fishermen	10	4,768.84	47,688.40
Accountants	1	15,464.30	15,464.30
Physicians	5	30,973.86	154,869.30
Dentists	1	19,957.61	19,957.61
Lawyers	2	26,089.41	52,178.82
Engineers & Architects	13	21,594.24	280,725.12
Entertainers & Artists	3	6,170.82	18,512.46
Other Professionals	2	7,569.21	15,138.42
Salesmen	31	7,446.07	230,828.17
Forestry Operators	11	5,771.26	63,483.86
Manufacturers	62	7,139.38	442,641.56
Construction	33	6,520.39	215,172.87
Public Utility	1	5,603.19	5,603.19
Retailers	3	6,983.64	20,950.92
Insurance & Real Estate	25	10,414.97	260,374.25
Service Operators	66	5,546.34	366,058.44
Non-Earners[5]	420	----	----
	1,277		$4,824,788.24

The average annual income for a patient with active tuberculosis is $4,824,788.24/1,277 = $3,778.22.

---

[1] Ontario Department of Health, 1969c, p. 56.

[2] The Department of National Revenue, Taxation, 1969, Table 9.

[3] Calculated by multiplying the number of patients by average income.

[4] Housewives are included in this category, with an income equal to that of domestic servants.

[5] This category includes 44 pre-school children, 191 retired, 73 unemployed and 112 students.

EXHIBIT 6

SENSITIVITY OF RESULTS TO NUMBER OF YEARS CALCULATED

In the analysis of the tuberculosis screening program the present value of the health improvement created by the program is calculated from

$$E = \sum_{n=1}^{\infty} \frac{m'(n)-m(n)}{(1+i)^n} h \qquad \text{(from equation 9, p. 64)}$$

and the present value of the cost of the program to society is

$$C = \sum_{n=1}^{\infty} \frac{C(n)}{(1+i)^n} \qquad \text{(from equation 27, p. 152)}$$

In both cases, due to the effect of the discounting, the computation can be truncated after a finite number of years (N) with a known loss in accuracy. To determine the effect of N on the results, a number of sensitivity runs were made. The results of these runs for three of the programs are tabulated below. It can be seen that, if the summations are truncated after 75 years, the maximum error is approximately 0.1 per cent and many of the values have considerably less error than this. Hence, a value of N=75 was selected as a reasonable balance between computational cost and accuracy.

		N=50		N=75		N=100		N=150	
		Result	%Δ	Result	%Δ	Result	%Δ	Result	%Δ
Program 23-1	E	10,706	N.A.	10,722	.15	10,723	.01	10,723	0
	C	253,135	N.A.	252,848	-.11	252,821	-.01	252,818	0
	1000E/C	42.3	N.A.	42.4	.24	42.4	0	42.4	0
Program 23-14	E	13,561	N.A.	13,584	.17	13,586	.02	13,587	.01
	C	109,208	N.A.	108,777	-.39	108,735	-.04	108,731	0
	1000E/C	124.2	N.A.	124.9	.56	125.0	.08	125.0	0
Program 28-9	E	2,165	N.A.	2,171	.28	2,171	0	2,171	0
	C	138,907	N.A.	138,810	-.07	138,801	-.01	138,800	0
	1000E/C	15.6	N.A.	15.6	0	15.6	0	15.6	0

EXHIBIT 7

FREQUENCIES OF HEMOLYTIC DISEASE AND ITS OUTCOMES

Year	Deliveries	Newborn with Hemolytic Disease				
		Total	Still-born	Neonatal Death	Exchange Trans-fusion	No Exchange Trans-fusion
1966	3,504	33	1	1	18	13
1967	3,413	37	3	1	13	20
1968	3,228	26	3	3	9	11
1969	3,377	23	6	1	9	7
TOTAL	13,522	119 (.88%)	13 (10.9%)	6 (5.0%)	49 (41.2%)	51 (42.9%)

Notes:

1. Cases referred from areas normally serviced by other hospitals are excluded.

2. Source of data was a manual study of all files of Rh cases for Henderson General Hospital, Hamilton.

EXHIBIT 8

ADDITIONAL TREATMENT COSTS FOR A CASE OF HEMOLYTIC DISEASE OF THE NEWBORN

A case of hemolytic disease of the newborn creates additional treatment costs in two ways: (1) additional days stay in the hospital for the baby and mother, and (2) additional tests and procedures performed on the baby and mother. The data to determine these additional costs was obtained from a study of the Henderson General Hospital, Hamilton, Ontario for the period 1966 to 1969 inclusive. Much of the study consisted of a laborious manual search of the charts for all cases of hemolytic disease of the newborn during this period.

Additional Days Stay:

The average length of stay for all babies delivered at Henderson General Hospital is 7.8 days, while the mother averages 7.1 days stay. The additional days stay for babies with hemolytic disease are a cost of the disease. For mild cases of hemolytic disease (no exchange transfusion required), the days stay are 9.1 for the baby and 7.2 for the mother. The corresponding figures for a severe case are 9.65 and 9.37 days. At a per diem gross operating cost of $47.64,[1]

[1] Ontario Hospital Services Commission, 1969, pp. 103-109. This figure is an average for 229 hospitals in Ontario and is used in preference to the corresponding figure for Henderson General ($44.09) as the latter includes costs of Chronic and Convalescent Units.

the additional costs of a case of hemolytic disease are summarized below:

	Severe		Mild	
	Additional Days	Cost	Additional Days	Cost
Baby	1.85	$ 88.13	1.3	$ 61.93
Mother	2.27	108.14	.1	4.76
Total	4.12	$196.27	1.4	$ 66.69

Additional Tests and Procedures:

The frequencies of tests and procedures performed on babies with hemolytic disease were compiled by a manual search of the charts. Because of the difficulties in obtaining corresponding data for well babies, it was assumed that the observed tests and procedures are all additional to those required by well babies.[1] In the following discussion, all costs, except where noted, were obtained from the Ontario Medical Association (1969).

Additional tests for babies with hemolytic disease are summarized below:

---

[1]This is a reasonable assumption, according to Dr. A. Zipursky, Chairman, Department of Pediatrics, McMaster University.

Test	Cost/ Test	Per Severe Case		Per Mild Case	
		Frequency	Cost	Frequency	Cost
Amnioscentesis - Initial	$20.00	.50	$10.00	.40	$ 8.00
- Repeat	10.00	1.57	15.70	.85	8.50
Bacteriology	6.00	.13	.78	.40	2.40
Bicarbonate	4.00	.37	1.48	.05	.20
Bilirubin - Direct	2.00	5.82	11.64	.40	.80
- Total	2.00	11.49	22.98	6.00	12.00
Blood Films	2.00	.19	.38	.15	.30
Blood Gases	10.00	.03	.30	---	---
Blood Smear	5.00	.01	.05	.05	.25
Calcium	2.00	.25	.50	.20	.40
Chloride	2.00	.40	.80	---	---
CO_2 Combining	5.00	.03	.15	---	---
Coombs Test	3.00	.07	.21	1.00	3.00
Cross Match	10.00	.84	8.40	---	---
Cultures	6.00	.57	3.42	---	---
Differential	2.00	.19	.38	.15	.30
Electrocardiogram	10.00	.09	.90	.05	.50
Electrolytes	5.00	.01	.05	.10	.50
Gastric Aspiration	10.00	---	---	.05	.50
Glucose	2.00	.46	.92	.25	.50
Hemoglobin & Hematocrit	2.00	7.75	15.50	3.75	7.50
Magnesium	4.00	.12	.48	.05	.20
PCO_2	5.00	.06	.30	.05	.25
pH	5.00	1.94	9.70	.70	3.50
Phosphorus	3.50	.12	.42	.05	.18
Platelets	3.00	.13	.39	---	---
Potassium	1.50	.40	.60	---	---
Prothrombin Time	2.00	.12	.24	---	---
RBC	2.00	.04	.08	---	---
Reticulocytes	3.00	.13	.39	.15	.45
Sodium	1.50	.40	.60	---	---
Thromboplastin	3.00	.10	.30	---	---
Total Protein Electrophoresis	15.00	.32	4.80	.15	2.25
Urea N	2.00	.44	.88	.25	.50
Urinalysis	2.00	.03	.06	---	---
WBC	1.00	.21	.21	.15	.15
X-rays - Abdomen	10.00	.02	.20	---	---
- Chest	6.00	.26	1.56	---	---
- Lumbar Spine	15.00	---	---	.05	.75
Total			$115.75		$50.88

Additional procedures required by a case of hemolytic disease are summarized below:

Procedure	Cost	Per Severe Case		Per Mild Case	
		Frequency	Cost	Frequency	Cost
Intra-Uterine Transfusion	$140.25[a]	.19	$ 26.65	---	---
Induction of Labor	37.55[b]	.56	21.03	.05	$ 1.88
Caesarian Delivery	238.00	.04	9.52	.30	71.40
Sterilization	98.00	.19	18.62	.35	34.30
Exchange Transfusion:					
- Initial	160.25[c]	.82	131.41	---	---
- Subsequent	110.25	.40	44.10	---	---
Total			$251.33		$107.58

[a] Includes $100 for a specialist and $30 for radiological control (Ontario Medical Association, 1969) and 1.25 units of blood (estimated by Dr. A. Zipursky, Chairman, Department of Pediatrics, McMaster University) at a cost of $8.20 per unit (Dr. Tieman, National Director, Canadian Red Cross.

[b] Dr. D.L. Sackett, Chairman, Department of Clinical Epidemiology and Biostatistics, McMaster University, estimates that 60 per cent of these inductions are surgical (at $39.25) and 40 per cent medical. The figure used is a weighted average of the cost of each.

[c] Includes specialist at $150 ($100 for subsequent transfusion) plus $10.25 for blood.

Summary

These additional costs for a case of hemolytic disease of the newborn may be summarized as follows:

	Severe Case	Mild Case
Additional days stay	$ 196.27	$ 66.69
Additional tests	115.75	50.88
Additional procedures	251.33	107.58
Total	$ 563.35	$ 225.15

EXHIBIT 9

LIFE EXPECTANCY FOR HEART ATTACK SURVIVORS

The average age of a person with definite heart disease is 57 for males and 61 for females. This was calculated by assuming that the age-specific rates for definite heart disease found by the President's Commission on Heart Disease, Cancer and Stroke[1] apply to Ontario, and by determining from this, how many people in each age category have definite heart disease and hence their average age. Since these are the people who take heart attacks, it can reasonably be assumed that the average age of a person taking an attack is also 57 for males and 61 for females.

For those who survive an attack a life table can be computed to determine their remaining life expectancy.

---

[1] The President's Commission on Heart Disease, Cancer and Stroke, 1965, p. 25.

LIFE TABLE FOR MALE SURVIVORS

Year After Attack	Normal Death Rate[1]	Mortality Ratio[2]	Coronary Death Rate[3]	Number Alive	Number of Deaths
1	.01631	13.8	.22508	100	22.51
2	.01796	5.3	.09519	77.49	7.38
3	.01973	6.8	.13416	70.12	9.41
4	.02161	5.4	.11669	60.71	7.08
5	.02359	5.0	.11795	53.62	6.32
6	.02567	5.7	.14632	47.30	6.92
7	.02775	↓	.15818	40.38	6.39
8	.02985		.17015	33.99	5.78
9	.03209		.18291	28.21	5.16
10	.03458		.19711	23.05	4.54
11	.03747		.21358	18.51	3.95
12	.04071		.23205	14.55	3.38
13	.04425		.25223	11.18	2.82
14	.04809		.27411	8.36	2.29
15	.05227		.29794	6.07	1.81
16	.05682		.32387	4.26	1.38
17	.06166		.35146	2.88	1.01
18	.06679		.38070	1.87	.71
19	.07230		.41211	1.16	.48
20	.07828		.44620	.68	.30
21	.08483		.48353	.38	.18
22	.09190		.52383	.19	.10
23	.09940		.56658	.09	.05
24	.10745		.61247	.04	.02
25	.11613		.66194	.02	.01
26	.12554		.71558	.01	.01
				0	

[1]From Dominion Bureau of Statistics, 1964, pp. 12-15. This is the mortality rate in the general population, commencing at age 57 for males and 61 for females.

[2]The ratio of observed deaths in the population of heart attack survivors to the normal expected deaths. This ratio is assumed constant at 5.7 after 5 years subsequent to attack (Pell and D'Alonzo, 1964, pp. 919-920).

[3]Coronary Death Rate = Normal Death Rate x Mortality Ratio.

LIFE TABLE FOR FEMALE SURVIVORS[1]

Year After Attack	Normal Death Rate[1]	Mortality Ratio[2]	Coronary Death Rate[3]	Number Alive	Number of Deaths
1	.01167	13.8	.16105	100	16.11
2	.01291	5.3	.06842	83.89	5.74
3	.01431	6.8	.09731	78.15	7.61
4	.01584	5.4	.08554	70.55	6.03
5	.01753	5.0	.08765	64.52	5.65
6	.01939	5.7	.11052	58.86	6.51
7	.02142	↓	.12209	52.35	6.39
8	.02351		.13401	45.96	6.16
9	.02564		.14615	39.80	5.82
10	.02800		.15960	33.99	5.42
11	.03079		.17550	28.56	5.01
12	.03421		.19500	23.55	4.59
13	.03818		.21763	18.96	4.13
14	.04258		.24271	14.83	3.60
15	.04750		.27075	11.23	3.04
16	.05306		.30244	8.19	2.48
17	.05935		.33830	5.71	1.93
18	.06629		.37785	3.78	1.43
19	.07384		.42089	2.35	.99
20	.08208		.46786	1.36	.64
21	.09112		.51938	.72	.38
22	.10106		.57604	.35	.20
23	.11183		.63743	.15	.09
24	.12337		.70321	.06	.04
25	.13577		.77389	.02	.02
				0	

[1] See footnotes under Life Table for Male Survivors.

Assuming that all deaths occur at the mid-point of the year (a person dying in year n has survived his heart attack for n - 1/2 years), the expected life of survivors is 5.549 years for males and 6.981 for females. As 60 per cent of heart fatalities in Ontario occur in males,[1] the average life expectancy for a fatality avoided by a coronary emergency rescue service is

$$0.6\ (5.549) + 0.4\ (6.981) = 6.12 \text{ years}$$

---

[1] Dominion Bureau of Statistics, 1968a. This figure has remained constant (within 1 per cent) since 1965.

EXHIBIT 10

LISTING OF THE TUBERCULOSIS CALCULATION PROGRAM (TBCALC)

```
TBCALC     13:58  PC-TOR TUE.  11/08/70


100 '---PARAMETER DATA---
110 DATA .034,.119,.243,3778,7,6
120 DATA 1,.56,.34,0
130 '
140 '---M. E. SET TABLE DATA---
150 DATA 23,23,28,1,30,33,47,3,49,26,50,54,11,38,24,46,21,17,35
160 DATA 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23
170 DATA 24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43
180 DATA 44,45,46,47,48,49,50,51,52,53,54
190 '
200 '---BASIC PROGRAM DATA---
210 DATA .4, 1847359, 27.2, .4, 667571, 48.9
220 DATA .4, 288993, 20.3, .4, 289414, 26.4
230 DATA .4, 196420, 21.5, .4, 191762, 23.9
240 DATA .4, 27769, 68.9, .4, 54665, 30.0
250 DATA .4, 43716, 24.5, .4, 98059, 23.3
260 DATA .4, 84361, 21.9, .4, 94921, 21.1
270 DATA .4, 44744, 20.3, .4, 94956, 17.8
280 DATA .4, 59150, 16.0, .4, 74791, 15.3
290 DATA .4, 79769, 14.6, .4, 54454, 13.2
300 DATA .4, 55393, 12.8
310 DATA .465, 433200, 20.7, .6, 17200, 14.0
320 DATA .49, 102300, 22.0, .6, 18200, 24.2
330 DATA .53, 23800, 25.6, .5, 41800, 14.0
340 DATA .5, 50000, 7.3, .53, 27100, 17.7
350 DATA .52, 90500, 10.1, .6, 15200, 7.6
360 DATA .45, 60800, 19.1, .52, 46400, 9.0
370 DATA .6, 8300, 10.3, .49, 95600, 13.0
380 DATA .6, 26000, 10.3, .53, 46800, 10.6
390 DATA .47, 84400, 12.9, .6, 21200, 12.2
400 DATA .52, 32000, 23.9, .42, 171000, 12.8
410 DATA .45, 183500, 12.1, .44, 215100, 10.1
420 DATA .41, 2102700, 26.5, .46, 94700, 13.6
430 DATA .57, 31100, 17.3, .45, 155200, 19.6
440 DATA .45, 186700, 22.4, .44, 397900, 17.1
450 DATA .52, 62200, 12.9, .45, 269300, 18.9
460 DATA .55, 52300, 7.9, .5, 78600, 12.6
470 DATA .45, 292500, 20.9, .5, 101500, 17.8
480 DATA .5, 114800, 9.4, .6, 56500, 6.2
490 DATA .5, 62000, 7.6, .44, 234100, 13.4
```

```
500 DATA .48, 100800, 10.6, .6, 43900, 6.0
510 DATA .53, 18400, 4.7, .53, 63200, 8.6
520 DATA .6, 29000, 18.1, .6, 28000, 10.6
530 DATA .51, 156800, 10.7, .45, 117900, 19.5
540 DATA .5, 97100, 44.2, .6, 10800, 28.5
550 DATA .48, 80700, 15.7, .49, 184700, 21.5
560 DATA .6, 46100, 32.2, .55, 54500, 64.1
570 DATA .6, 25300, 13.2, .47, 145600, 27.6
580 '
590 '---INITIALIZATION---
600 DIM P(200), R(200), A(200), B(200), F(200), V(200), W(200), X(200)
610 DIM K(80), L(60)
620 DIM T(200,3), M(200,5), C(200,5), E(200), D(200)
630 PRINT "                              TUBERCULOSIS SCREENING PROGRAM"
640 PRINT "                                                    G W TORRANCE"
650 PRINT "                                                    AUGUST, 1970"
660 PRINT "                    F"
670 PRINT "                D   R"
680 PRINT "                U   E"
690 PRINT "          R     R   O"
700 PRINT "          E     A   U        E                C"
710 PRINT "          G     T   E  PRESENT VALUE  PRESENT VALUE      1000E/C"
720 PRINT "          I     I   N    OF HEALTH          OF          EFFECTIVENE
730 PRINT "PROGRAM   O     O   C    BENEFITS          COSTS          COST RATIO
740 PRINT "NUMBER    N     N   Y (UNITS OF HEALTH) (DOLLARS)        (X1000)"
750:##-##    ##   ##   #  ########    ############        ######.#
760 READ B1, B2, B3, K, X, Y
770 READ H(1), H(2), H(3), H(4)
780 FOR I=1 TO 73
790 READ K(I)
800 NEXT I
810 FOR I=1 TO 60
820 L(I)=0
830 NEXT I
840 '
850 '---MAJOR LOOP FOR EACH REGION---
860 P=1
870 Q=19
880 FOR L=P TO Q
890 S=K(L)
900 PRINT
910 READ A, P(X), R(Y)
920 FOR T=1 TO 3
930 ON T GO TO 940,960,980
940 T1=1
950 GO TO 990
960 T1=5
970 GO TO 990
980 T1=15
990 FOR J=1 TO 10
```

```
1000 FOR I=1 TO 3
1010 T(J,I)=0
1020 NEXT I
1030 NEXT J
1040 F(10)=0
1050 FOR J=1 TO 200
1060 X(J)=0
1070 NEXT J
1080 C=0
1090 E=0
1100 Z=0
1110 '
1120 '---LOOP FOR EACH YEAR---
1130 G=11
1140 H=10+T1
1150 FOR N=G TO H
1160 IF Z=2 GO TO 1800
1170 P(N)=1.0156↑(N-X)*P(X)
1180 B(N)=A*P(N)/2
1190 R(N)=.931↑(N-Y)*R(Y)
1200 A(N)=.802*R(N)
1210 F(N)=.69*A(N)*B(N)/100000
1220 V(N)=F(N)
1230 W(N)=0
1240 IF Z=2 GO TO 1300
1250 FOR J=N+1 TO 85
1260 V(J)=.25*V(J-1)+.0016*W(J-1)
1270 W(J)=.9788*(W(J-1)+3*V(J-1)-V(J))
1280 X(J)=X(J)+V(J)
1290 NEXT J
1300 T(N,1)=.046*F(N)-.295*(F(N-1)+X(N))
1310 T(N,2)=.322*F(N)-.386*(F(N-1)+X(N))
1320 T(N,3)=.632*F(N)-.319*(F(N-1)+X(N))
1330 M(N,2)=93*B1*T(N,1)+73*B2*T(N,2)+44*B3*T(N,3)
1340 B=182.5*T(N,1)+86.2*T(N-1,1)
1350 M(N,3)=B*(1-B1)+179.3*(1-B2)*T(N,2)+130.2*(1-B3)*T(N,3)
1360 M(N,4)=365*(1.67*T(N,1)+1.22*T(N,2)+.82*T(N,3))
1370 M(N,1)=0-M(N,2)-M(N,3)-M(N,4)
1380 E(N)=M(N,1)*H(1)+M(N,2)*H(2)+M(N,3)*H(3)+M(N,4)*H(4)
1390 D=1.08↑(N-10)
1400 E=E+E(N)/D
1410 C(N,1)=1.25*B(N)
1420 C(N,2)=23.56*M(N,3)
1430 S1=0
1440 S2=0
1450 S3=0
1460 FOR I=1 TO 3
1470 S1=S1+T(N,I)
1480 S2=S2+T(N-1,I)
1490 S3=S3+(4-I)*T(N-2,I)
```

```
1500 NEXT I
1510 S4=0.5*S1+S2+0.25*S3
1520 C(N,3)=22.77*S4+45.76*M(N,3)/365
1530 C(N,4)=17.35*(S4-M(N,3)/365)
1540 M(N,5)=365*(1.56*T(N,1)+1.15*T(N,2)+.77*T(N,3))
1550 C(N,5)=(K/365)*(M(N,2)+M(N,3)+M(N,5))
1560 D(N)=C(N,1)+C(N,2)+C(N,3)+C(N,4)+C(N,5)
1570 C=C+D(N)/D
1580 NEXT N
1590 IF Z=2 GO TO 1660
1600 G=H+1
1610 H=85
1620 Z=2
1630 GO TO 1150
1640 '
1650 '---PRINT ROUTINE---
1660 FOR M=1 TO 3
1670 L(S)=L(S)+1
1680 WRITE:ECFILE:LNM(101);S;L(S);E;C
1690 PRINT USING 750,S,L(S),L,T1,2↑M,E,C,1000*E/C
1700 E=E/2
1710 C=C/2
1720 NEXT M
1730 NEXT T
1740 NEXT L
1750 IF L=73 GO TO 1820
1760 P=20
1770 Q=73
1780 Y=7
1790 GO TO 880
1800 B(N)=0
1810 GO TO 1190
1820 END
```

EXHIBIT 11

OUTPUT OF THE TUBERCULOSIS CALCULATION PROGRAM

TUBERCULOSIS SCREENING PROGRAM
G W TORRANCE
AUGUST, 1970

PROGRAM NUMBER	REGION	DURATION	FREQUENCY	E PRESENT VALUE OF HEALTH BENEFITS (UNITS OF HEALTH)	C PRESENT VALUE OF COSTS (DOLLARS)	1000E/C EFFECTIVENESS-COST RATIO (X1000)
23- 1	1	1	2	10722	252848	42.4
23- 2	1	1	4	5361	126424	42.4
23- 3	1	1	8	2680	63212	42.4
23- 4	1	5	2	41820	1230893	34.0
23- 5	1	5	4	20910	615446	34.0
23- 6	1	5	8	10455	307723	34.0
23- 7	1	15	2	74388	3193662	23.3
23- 8	1	15	4	37194	1596831	23.3
23- 9	1	15	8	18597	798415	23.3
23-10	2	1	2	6965	33107	210.4
23-11	2	1	4	3482	16553	210.4
23-12	2	1	8	1741	8276	210.4
23-13	2	5	2	27169	217554	124.9
23-14	2	5	4	13584	108777	124.9
23-15	2	5	8	6792	54388	124.9
23-16	2	15	2	48327	749863	64.4
23-17	2	15	4	24163	374931	64.4
23-18	2	15	8	12081	187465	64.4
28- 1	3	1	2	1251	47574	26.3
28- 2	3	1	4	625	23787	26.3
28- 3	3	1	8	312	11893	26.3
28- 4	3	5	2	4882	223836	21.8
28- 5	3	5	4	2441	111918	21.8
28- 6	3	5	8	1220	55959	21.8
28- 7	3	15	2	8684	555243	15.6
28- 8	3	15	4	4342	277621	15.6
28- 9	3	15	8	2171	138810	15.6

1- 1	4	1	2	1630	40543	40.2
1- 2	4	1	4	815	20271	40.2
1- 3	4	1	8	407	10135	40.2
1- 4	4	5	2	6359	196468	32.4
1- 5	4	5	4	3179	98234	32.4
1- 6	4	5	8	1589	49117	32.4
1- 7	4	15	2	11311	506791	22.3
1- 8	4	15	4	5655	253395	22.3
1- 9	4	15	8	2827	126697	22.3
30- 1	5	1	2	901	31387	28.7
30- 2	5	1	4	450	15693	28.7
30- 3	5	1	8	225	7846	28.7
30- 4	5	5	2	3514	148437	23.7
30- 5	5	5	4	1757	74218	23.7
30- 6	5	5	8	878	37109	23.7
30- 7	5	15	2	6251	370805	16.9
30- 8	5	15	4	3125	185402	16.9
30- 9	5	15	8	1562	92701	16.9
33- 1	6	1	2	977	28791	34.0
33- 2	6	1	4	488	14395	34.0
33- 3	6	1	8	244	7197	34.0
33- 4	6	5	2	3814	137697	27.7
33- 5	6	5	4	1907	68848	27.7
33- 6	6	5	8	953	34424	27.7
33- 7	6	15	2	6784	349170	19.4
33- 8	6	15	4	3392	174585	19.4
33- 9	6	15	8	1696	87292	19.4
47- 1	7	1	2	408	-856	-476.7
47- 2	7	1	4	204	-428	-476.7
47- 3	7	1	8	102	-214	-476.7
47- 4	7	5	2	1592	337	4720.6
47- 5	7	5	4	796	168	4720.6
47- 6	7	5	8	398	84	4720.6
47- 7	7	15	2	2832	15695	180.5
47- 8	7	15	4	1416	7847	180.5
47- 9	7	15	8	708	3923	180.5
3- 1	8	1	2	349	6866	51.0
3- 2	8	1	4	174	3433	51.0
3- 3	8	1	8	87	1716	51.0
3- 4	8	5	2	1364	34022	40.1
3- 5	8	5	4	682	17011	40.1
3- 6	8	5	8	341	8505	40.1
3- 7	8	15	2	2427	90232	26.9
3- 8	8	15	4	1213	45116	26.9
3- 9	8	15	8	606	22558	26.9

49- 1	9	1	2	228	6458	35.4
49- 2	9	1	4	114	3229	35.4
49- 3	9	1	8	57	1614	35.4
49- 4	9	5	2	891	30979	28.8
49- 5	9	5	4	445	15489	28.8
49- 6	9	5	8	222	7744	28.8
49- 7	9	15	2	1585	78868	20.1
49- 8	9	15	4	792	39434	20.1
49- 9	9	15	8	396	19717	20.1
26- 1	10	1	2	487	14959	32.6
26- 2	10	1	4	243	7479	32.6
26- 3	10	1	8	121	3739	32.6
26- 4	10	5	2	1901	71335	26.7
26- 5	10	5	4	950	35667	26.7
26- 6	10	5	8	475	17833	26.7
26- 7	10	15	2	3382	180192	18.8
26- 8	10	15	4	1691	90096	18.8
26- 9	10	15	8	845	45048	18.8
50- 1	11	1	2	394	13344	29.5
50- 2	11	1	4	197	6672	29.5
50- 3	11	1	8	98	3336	29.5
50- 4	11	5	2	1537	63223	24.3
50- 5	11	5	4	768	31611	24.3
50- 6	11	5	8	384	15805	24.3
50- 7	11	15	2	2735	158316	17.3
50- 8	11	15	4	1367	79158	17.3
50- 9	11	15	8	683	39579	17.3
54- 1	12	1	2	427	15320	27.9
54- 2	12	1	4	213	7660	27.9
54- 3	12	1	8	106	3830	27.9
54- 4	12	5	2	1666	72328	23.0
54- 5	12	5	4	833	36164	23.0
54- 6	12	5	8	416	18082	23.0
54- 7	12	15	2	2965	180253	16.4
54- 8	12	15	4	1482	90126	16.4
54- 9	12	15	8	741	45063	16.4
11- 1	13	1	2	193	7365	26.3
11- 2	13	1	4	96	3682	26.3
11- 3	13	1	8	48	1841	26.3
11- 4	13	5	2	755	34656	21.8
11- 5	13	5	4	377	17328	21.8
11- 6	13	5	8	188	8664	21.8
11- 7	13	15	2	1344	85966	15.6
11- 8	13	15	4	672	42983	15.6
11- 9	13	15	8	336	21491	15.6

38- 1	14	1	2	360	16586	21.7
38- 2	14	1	4	180	8293	21.7
38- 3	14	1	8	90	4146	21.7
38- 4	14	5	2	1406	77271	18.2
38- 5	14	5	4	703	38635	18.2
38- 6	14	5	8	351	19317	18.2
38- 7	14	15	2	2502	189063	13.2
38- 8	14	15	4	1251	94531	13.2
38- 9	14	15	8	625	47265	13.2
24- 1	15	1	2	201	10760	18.8
24- 2	15	1	4	100	5380	18.8
24- 3	15	1	8	50	2690	18.8
24- 4	15	5	2	787	49803	15.8
24- 5	15	5	4	393	24901	15.8
24- 6	15	5	8	196	12450	15.8
24- 7	15	15	2	1401	120742	11.6
24- 8	15	15	4	700	60371	11.6
24- 9	15	15	8	350	30185	11.6
46- 1	16	1	2	244	13816	17.7
46- 2	16	1	4	122	6908	17.7
46- 3	16	1	8	61	3454	17.7
46- 4	16	5	2	952	63794	14.9
46- 5	16	5	4	476	31897	14.9
46- 6	16	5	8	238	15948	14.9
46- 7	16	15	2	1694	154130	11.0
46- 8	16	15	4	847	77065	11.0
46- 9	16	15	8	423	38532	11.0
21- 1	17	1	2	248	14960	16.6
21- 2	17	1	4	124	7480	16.6
21- 3	17	1	8	62	3740	16.6
21- 4	17	5	2	969	68916	14.1
21- 5	17	5	4	484	34458	14.1
21- 6	17	5	8	242	17229	14.1
21- 7	17	15	2	1724	165947	10.4
21- 8	17	15	4	862	82973	10.4
21- 9	17	15	8	431	41486	10.4
17- 1	18	1	2	153	10519	14.6
17- 2	18	1	4	76	5259	14.6
17- 3	18	1	8	38	2629	14.6
17- 4	18	5	2	598	48241	12.4
17- 5	18	5	4	299	24120	12.4
17- 6	18	5	8	149	12060	12.4
17- 7	18	15	2	1064	115410	9.2
17- 8	18	15	4	532	57705	9.2
17- 9	18	15	8	266	28852	9.2

35- 1	19	1	2	151	10789	14.0
35- 2	19	1	4	75	5394	14.0
35- 3	19	1	8	37	2697	14.0
35- 4	19	5	2	590	49421	11.9
35- 5	19	5	4	295	24710	11.9
35- 6	19	5	8	147	12355	11.9
35- 7	19	15	2	1049	118019	8.9
35- 8	19	15	4	524	59009	8.9
35- 9	19	15	8	262	29504	8.9
1-10	20	1	2	2389	78985	30.2
1-11	20	1	4	1194	39492	30.2
1-12	20	1	8	597	19746	30.2
1-13	20	5	2	9319	374774	24.9
1-14	20	5	4	4659	187387	24.9
1-15	20	5	8	2329	93693	24.9
1-16	20	15	2	16576	940380	17.6
1-17	20	15	4	8288	470190	17.6
1-18	20	15	8	4144	235095	17.6
2- 1	21	1	2	82	4793	17.3
2- 2	21	1	4	41	2396	17.3
2- 3	21	1	8	20	1198	17.3
2- 4	21	5	2	322	22112	14.6
2- 5	21	5	4	161	11056	14.6
2- 6	21	5	8	80	5528	14.6
2- 7	21	15	2	574	53358	10.8
2- 8	21	15	4	287	26679	10.8
2- 9	21	15	8	143	13339	10.8
3-10	22	1	2	631	18951	33.3
3-11	22	1	4	315	9475	33.3
3-12	22	1	8	157	4737	33.3
3-13	22	5	2	2464	90516	27.2
3-14	22	5	4	1232	45258	27.2
3-15	22	5	8	616	22629	27.2
3-16	22	15	2	4383	229127	19.1
3-17	22	15	4	2191	114563	19.1
3-18	22	15	8	1095	57281	19.1
4- 1	23	1	2	151	3869	39.1
4- 2	23	1	4	75	1934	39.1
4- 3	23	1	8	37	967	39.1
4- 4	23	5	2	590	18706	31.6
4- 5	23	5	4	295	9353	31.6
4- 6	23	5	8	147	4676	31.6
4- 7	23	15	2	1050	48114	21.8
4- 8	23	15	4	525	24057	21.8
4- 9	23	15	8	262	12028	21.8

5- 1	24	1	2	185	4278	43.2
5- 2	24	1	4	92	2139	43.2
5- 3	24	1	8	46	1069	43.2
5- 4	24	5	2	721	20864	34.6
5- 5	24	5	4	360	10432	34.6
5- 6	24	5	8	180	5216	34.6
5- 7	24	15	2	1283	54255	23.7
5- 8	24	15	4	641	27127	23.7
5- 9	24	15	8	320	13563	23.7
6- 1	25	1	2	167	9707	17.3
6- 2	25	1	4	83	4853	17.3
6- 3	25	1	8	41	2426	17.3
6- 4	25	5	2	653	44783	14.6
6- 5	25	5	4	326	22391	14.6
6- 6	25	5	8	163	11195	14.6
6- 7	25	15	2	1163	108060	10.8
6- 8	25	15	4	581	54030	10.8
6- 9	25	15	8	290	27015	10.8
7- 1	26	1	2	104	13420	7.8
7- 2	26	1	4	52	6710	7.8
7- 3	26	1	8	26	3355	7.8
7- 4	26	5	2	407	60624	6.7
7- 5	26	5	4	203	30312	6.7
7- 6	26	5	8	101	15156	6.7
7- 7	26	15	2	725	141809	5.1
7- 8	26	15	4	362	70904	5.1
7- 9	26	15	8	181	35452	5.1
8- 1	27	1	2	145	6097	23.9
8- 2	27	1	4	72	3048	23.9
8- 3	27	1	8	36	1524	23.9
8- 4	27	5	2	568	28537	19.9
8- 5	27	5	4	284	14268	19.9
8- 6	27	5	8	142	7134	19.9
8- 7	27	15	2	1010	70279	14.4
8- 8	27	15	4	505	35139	14.4
8- 9	27	15	8	252	17569	14.4
9- 1	28	1	2	272	23840	11.4
9- 2	28	1	4	136	11920	11.4
9- 3	28	1	8	68	5960	11.4
9- 4	28	5	2	1062	108568	9.8
9- 5	28	5	4	531	54284	9.8
9- 6	28	5	8	265	27142	9.8
9- 7	28	15	2	1889	257068	7.4
9- 8	28	15	4	944	128534	7.4
9- 9	28	15	8	472	64267	7.4

10- 1	29	1	2	39	4866	8.2
10- 2	29	1	4	19	2433	8.2
10- 3	29	1	8	9	1216	8.2
10- 4	29	5	2	154	22000	7.0
10- 5	29	5	4	77	11000	7.0
10- 6	29	5	8	38	5500	7.0
10- 7	29	15	2	275	51527	5.3
10- 8	29	15	4	137	25763	5.3
10- 9	29	15	8	68	12881	5.3
11-10	30	1	2	299	11200	26.7
11-11	30	1	4	149	5600	26.7
11-12	30	1	8	74	2800	26.7
11-13	30	5	2	1167	52747	22.1
11-14	30	5	4	583	26373	22.1
11-15	30	5	8	291	13186	22.1
11-16	30	15	2	2077	131005	15.9
11-17	30	15	4	1038	65502	15.9
11-18	30	15	8	519	32751	15.9
12- 1	31	1	2	124	12509	9.9
12- 2	31	1	4	62	6254	9.9
12- 3	31	1	8	31	3127	9.9
12- 4	31	5	2	485	56781	8.5
12- 5	31	5	4	242	28390	8.5
12- 6	31	5	8	121	14195	8.5
12- 7	31	15	2	863	133789	6.5
12- 8	31	15	4	431	66894	6.5
12- 9	31	15	8	215	33447	6.5
13- 1	32	1	2	29	2512	11.7
13- 2	32	1	4	14	1256	11.7
13- 3	32	1	8	7	628	11.7
13- 4	32	5	2	114	11446	10.0
13- 5	32	5	4	57	5723	10.0
13- 6	32	5	8	28	2861	10.0
13- 7	32	15	2	203	27129	7.5
13- 8	32	15	4	101	13564	7.5
13- 9	32	15	8	50	6782	7.5
14- 1	33	1	2	348	22263	15.7
14- 2	33	1	4	174	11131	15.7
14- 3	33	1	8	87	5565	15.7
14- 4	33	5	2	1361	102347	13.3
14- 5	33	5	4	680	51173	13.3
14- 6	33	5	8	340	25586	13.3
14- 7	33	15	2	2420	245710	9.9
14- 8	33	15	4	1210	122855	9.9
14- 9	33	15	8	605	61427	9.9

15- 1	34	1	2	92	7869	11.7
15- 2	34	1	4	46	3934	11.7
15- 3	34	1	8	23	1967	11.7
15- 4	34	5	2	359	35857	10.0
15- 5	34	5	4	179	17928	10.0
15- 6	34	5	8	89	8964	10.0
15- 7	34	15	2	638	84982	7.5
15- 8	34	15	4	319	42491	7.5
15- 9	34	15	8	159	21245	7.5
16- 1	35	1	2	150	12431	12.1
16- 2	35	1	4	75	6215	12.1
16- 3	35	1	8	37	3107	12.1
16- 4	35	5	2	587	56700	10.4
16- 5	35	5	4	293	28350	10.4
16- 6	35	5	8	146	14175	10.4
16- 7	35	15	2	1045	134564	7.8
16- 8	35	15	4	522	67282	7.8
16- 9	35	15	8	261	33641	7.8
17-10	36	1	2	293	18895	15.5
17-11	36	1	4	146	9447	15.5
17-12	36	1	8	73	4723	15.5
17-13	36	5	2	1143	86835	13.2
17-14	36	5	4	571	43417	13.2
17-15	36	5	8	285	21708	13.2
17-16	36	15	2	2034	208367	9.8
17-17	36	15	4	1017	104183	9.8
17-18	36	15	8	508	52091	9.8
18- 1	37	1	2	88	6155	14.4
18- 2	37	1	4	44	3077	14.4
18- 3	37	1	8	22	1538	14.4
18- 4	37	5	2	346	28219	12.3
18- 5	37	5	4	173	14109	12.3
18- 6	37	5	8	86	7054	12.3
18- 7	37	15	2	616	67482	9.1
18- 8	37	15	4	308	33741	9.1
18- 9	37	15	8	154	16870	9.1
19- 1	38	1	2	227	5949	38.3
19- 2	38	1	4	113	2974	38.3
19- 3	38	1	8	56	1487	38.3
19- 4	38	5	2	888	28715	31.0
19- 5	38	5	4	444	14357	31.0
19- 6	38	5	8	222	7178	31.0
19- 7	38	15	2	1580	73691	21.5
19- 8	38	15	4	790	36845	21.5
19- 9	38	15	8	395	18422	21.5

20- 1	39	1	2	526	34288	15.4
20- 2	39	1	4	263	17144	15.4
20- 3	39	1	8	131	8572	15.4
20- 4	39	5	2	2054	157521	13.0
20- 5	39	5	4	1027	78760	13.0
20- 6	39	5	8	513	39380	13.0
20- 7	39	15	2	3654	377792	9.7
20- 8	39	15	4	1827	188896	9.7
20- 9	39	15	8	913	94448	9.7
21-10	40	1	2	572	40047	14.3
21-11	40	1	4	286	20023	14.3
21-12	40	1	8	143	10011	14.3
21-13	40	5	2	2233	183544	12.2
21-14	40	5	4	1116	91772	12.2
21-15	40	5	8	558	45886	12.2
21-16	40	15	2	3972	438697	9.1
21-17	40	15	4	1986	219348	9.1
21-18	40	15	8	993	109674	9.1
22- 1	41	1	2	547	47945	11.4
22- 2	41	1	4	273	23972	11.4
22- 3	41	1	8	136	11986	11.4
22- 4	41	5	2	2136	218344	9.8
22- 5	41	5	4	1068	109172	9.8
22- 6	41	5	8	534	54586	9.8
22- 7	41	15	2	3800	517000	7.4
22- 8	41	15	4	1900	258500	7.4
22- 9	41	15	8	950	129250	7.4
23-19	42	1	2	13090	284035	46.1
23-20	42	1	4	6545	142017	46.1
23-21	42	1	8	3272	71008	46.1
23-22	42	5	2	51058	1393316	36.6
23-23	42	5	4	25529	696658	36.6
23-24	42	5	8	12764	348329	36.6
23-25	42	15	2	90820	3649949	24.9
23-26	42	15	4	45410	1824974	24.9
23-27	42	15	8	22705	912487	24.9
24-10	43	1	2	339	20421	16.6
24-11	43	1	4	169	10210	16.6
24-12	43	1	8	84	5105	16.6
24-13	43	5	2	1324	94075	14.1
24-14	43	5	4	662	47037	14.1
24-15	43	5	8	331	23518	14.1
24-16	43	15	2	2355	226536	10.4
24-17	43	15	4	1177	113268	10.4
24-18	43	15	8	588	56634	10.4

25- 1	44	1	2	175	7601	23.1
25- 2	44	1	4	87	3800	23.1
25- 3	44	1	8	43	1900	23.1
25- 4	44	5	2	685	35519	19.3
25- 5	44	5	4	342	17759	19.3
25- 6	44	5	8	171	8879	19.3
25- 7	44	15	2	1219	87271	14.0
25- 8	44	15	4	609	43635	14.0
25- 9	44	15	8	304	21817	14.0
26-10	45	1	2	784	28214	27.8
26-11	45	1	4	392	14107	27.8
26-12	45	1	8	196	7053	27.8
26-13	45	5	2	3059	133173	23.0
26-14	45	5	4	1529	66586	23.0
26-15	45	5	8	764	33293	23.0
26-16	45	15	2	5441	331792	16.4
26-17	45	15	4	2720	165896	16.4
26-18	45	15	8	1360	82948	16.4
27- 1	46	1	2	1078	31400	34.3
27- 2	46	1	4	539	15700	34.3
27- 3	46	1	8	269	7850	34.3
27- 4	46	5	2	4205	150293	28.0
27- 5	46	5	4	2102	75146	28.0
27- 6	46	5	8	1051	37573	28.0
27- 7	46	15	2	7481	381508	19.6
27- 8	46	15	4	3740	190754	19.6
27- 9	46	15	8	1870	95377	19.6
28-10	47	1	2	1715	75455	22.7
28-11	47	1	4	857	37727	22.7
28-12	47	1	8	428	18863	22.7
28-13	47	5	2	6690	352278	19.0
28-14	47	5	4	3345	176139	19.0
28-15	47	5	8	1672	88069	19.0
28-16	47	15	2	11901	864539	13.8
28-17	47	15	4	5950	432269	13.8
28-18	47	15	8	2975	216134	13.8
29- 1	48	1	2	239	15406	15.5
29- 2	48	1	4	119	7703	15.5
29- 3	48	1	8	59	3851	15.5
29- 4	48	5	2	932	70803	13.2
29- 5	48	5	4	466	35401	13.2
29- 6	48	5	8	233	17700	13.2
29- 7	48	15	2	1658	169895	9.8
29- 8	48	15	4	829	84947	9.8
29- 9	48	15	8	414	42473	9.8

30-10	49	1	2	1312	49873	26.3
30-11	49	1	4	656	24936	26.3
30-12	49	1	8	328	12468	26.3
30-13	49	5	2	5118	234652	21.8
30-14	49	5	4	2559	117326	21.8
30-15	49	5	8	1279	58663	21.8
30-16	49	15	2	9105	582076	15.6
30-17	49	15	4	4552	291038	15.6
30-18	49	15	8	2276	145519	15.6
31- 1	50	1	2	130	15255	8.5
31- 2	50	1	4	65	7627	8.5
31- 3	50	1	8	32	3813	8.5
31- 4	50	5	2	507	69026	7.4
31- 5	50	5	4	253	34513	7.4
31- 6	50	5	8	126	17256	7.4
31- 7	50	15	2	903	161872	5.6
31- 8	50	15	4	451	80936	5.6
31- 9	50	15	8	225	40468	5.6
32- 1	51	1	2	283	18847	15.1
32- 2	51	1	4	141	9423	15.1
32- 3	51	1	8	70	4711	15.1
32- 4	51	5	2	1106	86526	12.8
32- 5	51	5	4	553	43263	12.8
32- 6	51	5	8	276	21631	12.8
32- 7	51	15	2	1968	207317	9.5
32- 8	51	15	4	984	103658	9.5
32- 9	51	15	8	492	51829	9.5
33-10	52	1	2	1576	51326	30.7
33-11	52	1	4	788	25663	30.7
33-12	52	1	8	394	12831	30.7
33-13	52	5	2	6148	243778	25.2
33-14	52	5	4	3074	121889	25.2
33-15	52	5	8	1537	60944	25.2
33-16	52	15	2	10936	612497	17.9
33-17	52	15	4	5468	306248	17.9
33-18	52	15	8	2734	153124	17.9
34- 1	53	1	2	517	21488	24.1
34- 2	53	1	4	258	10744	24.1
34- 3	53	1	8	129	5372	24.1
34- 4	53	5	2	2018	100619	20.1
34- 5	53	5	4	1009	50309	20.1
34- 6	53	5	8	504	25154	20.1
34- 7	53	15	2	3591	247945	14.5
34- 8	53	15	4	1795	123972	14.5
34- 9	53	15	8	897	61986	14.5

35-10	54	1	2	309	29512	10.5
35-11	54	1	4	154	14756	10.5
35-12	54	1	8	77	7378	10.5
35-13	54	5	2	1205	134115	9.0
35-14	54	5	4	602	67057	9.0
35-15	54	5	8	301	33528	9.0
35-16	54	15	2	2144	316562	6.8
35-17	54	15	4	1072	158281	6.8
35-18	54	15	8	536	79140	6.8
36- 1	55	1	2	120	18601	6.5
36- 2	55	1	4	60	9300	6.5
36- 3	55	1	8	30	4650	6.5
36- 4	55	5	2	469	83777	5.6
36- 5	55	5	4	234	41888	5.6
36- 6	55	5	8	117	20944	5.6
36- 7	55	15	2	835	195087	4.3
36- 8	55	15	4	417	97543	4.3
36- 9	55	15	8	208	48771	4.3
37- 1	56	1	2	135	16541	8.2
37- 2	56	1	4	67	8270	8.2
37- 3	56	1	8	33	4135	8.2
37- 4	56	5	2	526	74782	7.0
37- 5	56	5	4	263	37391	7.0
37- 6	56	5	8	131	18695	7.0
37- 7	56	15	2	936	175146	5.3
37- 8	56	15	4	468	87573	5.3
37- 9	56	15	8	234	43786	5.3
38-10	57	1	2	790	48509	16.3
38-11	57	1	4	395	24254	16.3
38-12	57	1	8	197	12127	16.3
38-13	57	5	2	3084	223313	13.8
38-14	57	5	4	1542	111656	13.8
38-15	57	5	8	771	55828	13.8
38-16	57	15	2	5486	537198	10.2
38-17	57	15	4	2743	268599	10.2
38-18	57	15	8	1371	134299	10.2
39- 1	58	1	2	293	24249	12.1
39- 2	58	1	4	146	12124	12.1
39- 3	58	1	8	73	6062	12.1
39- 4	58	5	2	1146	110603	10.4
39- 5	58	5	4	573	55301	10.4
39- 6	58	5	8	286	27650	10.4
39- 7	58	15	2	2038	262488	7.8
39- 8	58	15	4	1019	131244	7.8
39- 9	58	15	8	509	65622	7.8

40- 1	59	1	2	90	14509	6.2
40- 2	59	1	4	45	7254	6.2
40- 3	59	1	8	22	3627	6.2
40- 4	59	5	2	353	65315	5.4
40- 5	59	5	4	176	32657	5.4
40- 6	59	5	8	88	16328	5.4
40- 7	59	15	2	628	151976	4.1
40- 8	59	15	4	314	75988	4.1
40- 9	59	15	8	157	37994	4.1
41- 1	60	1	2	26	5508	4.8
41- 2	60	1	4	13	2754	4.8
41- 3	60	1	8	6	1377	4.8
41- 4	60	5	2	102	24716	4.1
41- 5	60	5	4	51	12358	4.1
41- 6	60	5	8	25	6179	4.1
41- 7	60	15	2	182	57216	3.2
41- 8	60	15	4	91	28608	3.2
41- 9	60	15	8	45	14304	3.2
42- 1	61	1	2	165	17511	9.4
42- 2	61	1	4	82	8755	9.4
42- 3	61	1	8	41	4377	9.4
42- 4	61	5	2	643	79392	8.1
42- 5	61	5	4	321	39696	8.1
42- 6	61	5	8	160	19848	8.1
42- 7	61	15	2	1145	186739	6.1
42- 8	61	15	4	572	93369	6.1
42- 9	61	15	8	286	46684	6.1
43- 1	62	1	2	180	7311	24.7
43- 2	62	1	4	90	3655	24.7
43- 3	62	1	8	45	1827	24.7
43- 4	62	5	2	703	34278	20.5
43- 5	62	5	4	351	17139	20.5
43- 6	62	5	8	175	8569	20.5
43- 7	62	15	2	1251	84618	14.8
43- 8	62	15	4	625	42309	14.8
43- 9	62	15	8	312	21154	14.8
44- 1	63	1	2	102	8419	12.1
44- 2	63	1	4	51	4209	12.1
44- 3	63	1	8	25	2104	12.1
44- 4	63	5	2	397	38403	10.4
44- 5	63	5	4	198	19201	10.4
44- 6	63	5	8	99	9600	10.4
44- 7	63	15	2	707	91141	7.8
44- 8	63	15	4	353	45570	7.8
44- 9	63	15	8	176	22785	7.8

45- 1	64	1	2	490	39992	12.3
45- 2	64	1	4	245	19996	12.3
45- 3	64	1	8	122	9998	12.3
45- 4	64	5	2	1912	182466	10.5
45- 5	64	5	4	956	91233	10.5
45- 6	64	5	8	478	45616	10.5
45- 7	64	15	2	3401	433236	7.9
45- 8	64	15	4	1700	216618	7.9
45- 9	64	15	8	850	108309	7.9
46-10	65	1	2	592	21490	27.6
46-11	65	1	4	296	10745	27.6
46-12	65	1	8	148	5372	27.6
46-13	65	5	2	2312	101390	22.8
46-14	65	5	4	1156	50695	22.8
46-15	65	5	8	578	25347	22.8
46-16	65	15	2	4112	252449	16.3
46-17	65	15	4	2056	126224	16.3
46-18	65	15	8	1028	63112	16.3
47-10	66	1	2	1229	6714	183.1
47-11	66	1	4	614	3357	183.1
47-12	66	1	8	307	1678	183.1
47-13	66	5	2	4795	42266	113.5
47-14	66	5	4	2397	21133	113.5
47-15	66	5	8	1198	10566	113.5
47-16	66	15	2	8530	141160	60.4
47-17	66	15	4	4265	70580	60.4
47-18	66	15	8	2132	35290	60.4
48- 1	67	1	2	105	1994	53.0
48- 2	67	1	4	52	997	53.0
48- 3	67	1	8	26	498	53.0
48- 4	67	5	2	412	9926	41.6
48- 5	67	5	4	206	4963	41.6
48- 6	67	5	8	103	2481	41.6
48- 7	67	15	2	734	26463	27.7
48- 8	67	15	4	367	13231	27.7
48- 9	67	15	8	183	6615	27.7
49-10	68	1	2	348	17280	20.2
49-11	68	1	4	174	8640	20.2
49-12	68	1	8	87	4320	20.2
49-13	68	5	2	1359	80226	16.9
49-14	68	5	4	679	40113	16.9
49-15	68	5	8	339	20056	16.9
49-16	68	15	2	2417	195344	12.4
49-17	68	15	4	1208	97672	12.4
49-18	68	15	8	604	48836	12.4

50-10	69	1	2	1114	34704	32.1
50-11	69	1	4	557	17352	32.1
50-12	69	1	8	278	8676	32.1
50-13	69	5	2	4348	165330	26.3
50-14	69	5	4	2174	82665	26.3
50-15	69	5	8	1087	41332	26.3
50-16	69	15	2	7735	417073	18.5
50-17	69	15	4	3867	208536	18.5
50-18	69	15	8	1933	104268	18.5
51- 1	70	1	2	510	7410	68.9
51- 2	70	1	4	255	3705	68.9
51- 3	70	1	8	127	1852	68.9
51- 4	70	5	2	1990	38062	52.3
51- 5	70	5	4	995	19031	52.3
51- 6	70	5	8	497	9515	52.3
51- 7	70	15	2	3540	105292	33.6
51- 8	70	15	4	1770	52646	33.6
51- 9	70	15	8	885	26323	33.6
52- 1	71	1	2	1100	-2296	-479.4
52- 2	71	1	4	550	-1148	-479.4
52- 3	71	1	8	275	-574	-479.4
52- 4	71	5	2	4294	968	4434.9
52- 5	71	5	4	2147	484	4434.9
52- 6	71	5	8	1073	242	4434.9
52- 7	71	15	2	7638	42458	179.9
52- 8	71	15	4	3819	21229	179.9
52- 9	71	15	8	1909	10614	179.9
53- 1	72	1	2	114	7181	16.0
53- 2	72	1	4	57	3590	16.0
53- 3	72	1	8	28	1795	16.0
53- 4	72	5	2	447	33038	13.6
53- 5	72	5	4	223	16519	13.6
53- 6	72	5	8	111	8259	13.6
53- 7	72	15	2	796	79395	10.0
53- 8	72	15	4	398	39697	10.0
53- 9	72	15	8	199	19848	10.0
54-10	73	1	2	1082	21733	49.8
54-11	73	1	4	541	10866	49.8
54-12	73	1	8	270	5433	49.8
54-13	73	5	2	4221	107427	39.3
54-14	73	5	4	2110	53713	39.3
54-15	73	5	8	1055	26856	39.3
54-16	73	15	2	7508	284084	26.4
54-17	73	15	4	3754	142042	26.4
54-18	73	15	8	1877	71021	26.4

APPENDIX III

OPTIMIZATION EXHIBITS

List of Exhibits

1. Listing of the Cost-Effectiveness Ranking Program (CERANK)

2. Complete Cost-Effectiveness Priority Ranking

3. Mathematical Programming Application

4. Selected Results from the Mathematical Programming Algorithm

EXHIBIT 1

LISTING OF THE COST-EFFECTIVENESS RANKING PROGRAM (CERANK)

```
CERANK     13:39  PC-TOR FRI.  18/09/70

100 DIM A(60),B(60),C(60,30),D(60),E(60,30),F(60)
110: ####      ##-##    ######.#  ############ ############
120: ####      ##-##       N.A.   ############ ############
130 L=0
140 G=0
150 H=0
160 PRINT "              COST EFFECTIVENESS RANKING"
170 PRINT "                                          G W TORRANCE"
180 PRINT "                                          AUGUST, 1970"
190 PRINT "                     INCREMENTAL"
200 PRINT "PRIORITY PROGRAM      E/C       CUMULATIVE   CUMULATIVE"
210 PRINT "RANKING  NUMBER      X1000          E             C"
220 PRINT
230 '
240 '---LOAD DATA---
250 FOR I=1 TO 60
260 FOR J=1 TO 30
270 E(I,J)=0
280 C(I,J)=0
290 NEXT J
300 NEXT I
310 INPUT:ECFILE:END=370,I,J,E,C
320 E(I,J)=E
330 C(I,J)=C
340 GO TO 310
350 '
360 '---INITIAL LIST---
370 FOR I=1 TO 60
380 W=0
390 X=0
400 Y=0
410 FOR J=1 TO 30
420 IF C(I,J)>X GO TO 490
430 IF C(I,J)=X GO TO 450
440 GO TO 460
450 IF E(I,J)<=W GO TO 490
460 W=E(I,J)
470 X=C(I,J)
480 Y=J
490 NEXT J
```

```
500 IF X<0 GO TO 620
510 FOR J=1 TO 30
520 IF C(I,J)=0 GO TO 610
530 T=INT(10000*E(I,J)/C(I,J)+.5)
540 IF T<X GO TO 610
550 IF T=X GO TO 570
560 GO TO 580
570 IF C(I,J)>=W GO TO 610
580 W=C(I,J)
590 X=T
600 Y=J
610 NEXT J
620 A(I)=Y
630 IF A(I)=0 GO TO 670
640 B(I)=E(I,Y)
650 D(I)=C(I,Y)
660 F(I)=INT(10000*E(I,Y)/C(I,Y)+.5)/10
670 NEXT I
680 '
690 '---SELECT FROM THE LIST---
700 W=0
710 X=0
720 Y=0
730 FOR I=1 TO 60
740 IF A(I)=0 GO TO 820
750 IF D(I)>X GO TO 820
760 IF D(I)=X GO TO 780
770 GO TO 790
780 IF B(I)<=W  GO TO 820
790 W=B(I)
800 X=D(I)
810 Y=I
820 NEXT I
830 IF X<0 GO TO 950
840 FOR I=1 TO 60
850 IF A(I)=0 GO TO 930
860 IF F(I)<X GO TO 930
870 IF F(I)=X GO TO 890
880 GO TO 900
890 IF D(I)>=W GO TO 930
900 W=D(I)
910 X=F(I)
920 Y=I
930 NEXT I
940 IF X=0 GO TO 1290
950 L=L+1
960 G=G+B(Y)
970 H=H+D(Y)
980 IF F(Y)<0 GO TO 1010
990 PRINT USING 110,L,Y,A(Y),F(Y),G,H
```

```
1000 GO TO 1020
1010 PRINT USING 120,L,Y,A(Y),G,H
1020 '
1030 '---UPDATE LIST---
1040 I=Y
1050 R=A(I)
1060 W=0
1070 X=0
1080 Y=0
1090 FOR J=1 TO 30
1100 IF E(I,J)-E(I,R)<=0 GO TO 1200
1110 S=(E(I,J)-E(I,R))/(C(I,J)-C(I,R))
1120 S=INT(10000*S+.5)/10
1130 IF S<X GO TO 1200
1140 IF S=X GO TO 1160
1150 GO TO 1170
1160 IF C(I,J)-C(I,R)>=W GO TO 1200
1170 W=C(I,J)-C(I,R)
1180 X=S
1190 Y=J
1200 NEXT J
1210 IF X=0 GO TO 1270
1220 A(I)=Y
1230 B(I)=E(I,Y)-E(I,R)
1240 D(I)=C(I,Y)-C(I,R)
1250 F(I)=X
1260 GO TO 700
1270 A(I)=0
1280 GO TO 700
1290 END
```

EXHIBIT 2

COMPLETE COST-EFFECTIVENESS PRIORITY RANKING

COST EFFECTIVENESS RANKING

G. W TORRANCE
AUGUST, 1970

PRIORITY RANKING	PROGRAM NUMBER	INCREMENTAL E/C X1000	CUMULATIVE E	CUMULATIVE C
1	55- 4	N.A.	12859036	-47299320
2	52- 1	N.A.	12860136	-47301616
3	47- 1	N.A.	12860545	-47302473
4	57- 1	2505.8	12932046	-47273939
5	57- 2	2505.8	13023267	-47237535
6	57- 3	2505.8	13146551	-47188336
7	57- 4	2505.8	13511433	-47042723
8	47- 4	991.8	13512617	-47041529
9	52- 4	978.1	13515810	-47038265
10	56- 1	255.5	14706158	-42379302
11	56- 2	255.5	16107704	-36893724
12	56- 4	242.7	18570000	-26749182
13	56- 6	229.9	20902715	-16604641
14	56- 8	217.2	23105819	-6460100
15	23-12	210.4	23107561	-6451823
16	23-11	210.4	23109302	-6443546
17	23-10	210.4	23112785	-6426992
18	23-13	109.5	23132989	-6242546
19	47- 7	80.7	23134229	-6227188
20	52- 7	80.6	23137573	-6185698
21	47-13	73.9	23139536	-6159127
22	51- 3	68.9	23139664	-6157274
23	51- 2	68.9	23139792	-6155421
24	51- 1	68.9	23140047	-6151716
25	48- 3	53.0	23140073	-6151218
26	48- 2	53.0	23140100	-6150719
27	48- 1	53.0	23140153	-6149721
28	3- 3	51.0	23140240	-6148005
29	3- 2	51.0	23140328	-6146288
30	3- 1	51.0	23140503	-6142855
31	54-12	49.8	23140773	-6137422
32	54-11	49.8	23141044	-6131988
33	54-10	49.8	23141585	-6121122

34	51- 4	48.3	23143065	-6090470
35	5- 3	43.2	23143111	-6089400
36	5- 2	43.2	23143158	-6088331
37	5- 1	43.2	23143250	-6086192
38	1- 3	40.2	23143658	-6076056
39	1- 2	40.2	23144065	-6065920
40	1- 1	40.2	23144880	-6045648
41	23-16	39.7	23166038	-5513338
42	4- 3	39.1	23166076	-5512371
43	4- 2	39.1	23166114	-5511404
44	4- 1	39.1	23166190	-5509469
45	48- 4	38.7	23166497	-5501537
46	19- 3	38.3	23166554	-5500050
47	19- 2	38.3	23166611	-5498562
48	19- 1	38.3	23166724	-5495588
49	47-16	37.8	23170459	-5396694
50	3- 4	37.4	23171474	-5369538
51	54-13	36.6	23174613	-5283844
52	49- 3	35.4	23174670	-5282230
53	49- 2	35.4	23174727	-5280615
54	49- 1	35.4	23174842	-5277386
55	27- 3	34.3	23175111	-5269536
56	27- 2	34.3	23175381	-5261686
57	27- 1	34.3	23175920	-5245986
58	33- 3	34.0	23176165	-5238788
59	33- 2	34.0	23176409	-5231590
60	33- 1	34.0	23176898	-5217194
61	26- 3	32.6	23177020	-5213454
62	26- 2	32.6	23177142	-5209715
63	26- 1	32.6	23177386	-5202235
64	5- 4	32.4	23177922	-5185649
65	50-12	32.1	23178201	-5176972
66	50-11	32.1	23178480	-5168296
67	50-10	32.1	23179037	-5150944
68	1- 4	30.3	23183766	-4995019
69	4- 4	29.6	23184205	-4980182
70	19- 4	29.0	23184866	-4957415
71	30- 3	28.7	23185091	-4949569
72	30- 2	28.7	23185317	-4941722
73	30- 1	28.7	23185767	-4926028
74	46-12	27.6	23185915	-4920656
75	46-11	27.6	23186064	-4915283
76	46-10	27.6	23186360	-4904538
77	49- 4	27.0	23187023	-4880016
78	11-12	26.7	23187098	-4877216
79	11-11	26.7	23187173	-4874416

80	11-10	26.7	23187322	-4868816
81	33-10	26.6	23187921	-4846280
82	28- 3	26.3	23188234	-4834387
83	28- 2	26.3	23188547	-4822493
84	28- 1	26.3	23189173	-4798706
85	27- 4	26.3	23192300	-4679813
86	33- 4	25.9	23194538	-4593442
87	26- 4	25.1	23195952	-4537066
88	50-13	24.8	23199186	-4406440
89	43- 3	24.7	23199231	-4404612
90	43- 2	24.7	23199276	-4402784
91	43- 1	24.7	23199367	-4399128
92	34- 3	24.1	23199496	-4393756
93	34- 2	24.1	23199625	-4388384
94	34- 1	24.1	23199884	-4377639
95	8- 3	23.9	23199921	-4376115
96	8- 2	23.9	23199957	-4374591
97	8- 1	23.9	23200030	-4371542
98	25- 3	23.1	23200074	-4369642
99	25- 2	23.1	23200118	-4367741
100	25- 1	23.1	23200206	-4363940
101	51- 7	23.1	23201756	-4296710
102	30- 4	22.3	23204369	-4179659
103	33-13	22.0	23206703	-4073578
104	38- 3	21.7	23206793	-4069432
105	38- 2	21.7	23206883	-4065285
106	38- 1	21.7	23207064	-4056992
107	46-13	21.5	23208783	-3977092
108	11-13	20.9	23209652	-3935545
109	28- 4	20.6	23213282	-3759283
110	3-13	19.5	23214382	-3702789
111	48- 7	19.4	23214704	-3686252
112	43- 4	19.4	23215227	-3659285
113	34- 4	19.0	23216728	-3580154
114	24- 3	18.8	23216779	-3577464
115	24- 2	18.8	23216829	-3574774
116	24- 1	18.8	23216930	-3569394
117	8- 4	18.8	23217353	-3546953
118	26-13	18.7	23218511	-3485116
119	30-13	18.6	23220115	-3398901
120	54-16	18.6	23223402	-3222244

121	25- 4	18.3	23223912	-3194326
122	2- 3	17.3	23223932	-3193128
123	2- 2	17.3	23223953	-3191929
124	2- 1	17.3	23223994	-3189533
125	6- 3	17.3	23224036	-3187106
126	6- 2	17.3	23224078	-3184679
127	6- 1	17.3	23224162	-3179825
128	38- 4	17.2	23225208	-3119141
129	5- 7	16.8	23225770	-3085750
130	21- 3	16.6	23225832	-3082010
131	21- 2	16.6	23225894	-3078270
132	21- 1	16.6	23226019	-3070790
133	1-13	16.6	23228979	-2892483
134	53- 3	16.0	23229007	-2890687
135	53- 2	16.0	23229036	-2888892
136	53- 1	16.0	23229093	-2885301
137	14- 3	15.7	23229181	-2879735
138	14- 2	15.7	23229268	-2874169
139	14- 1	15.7	23229442	-2863038
140	4- 7	15.6	23229902	-2833630
141	29- 3	15.5	23229962	-2829778
142	29- 2	15.5	23230022	-2825926
143	17-12	15.5	23230095	-2821202
144	17-11	15.5	23230168	-2816478
145	29- 1	15.5	23230288	-2808775
146	17-10	15.5	23230435	-2799327
147	20- 3	15.4	23230566	-2790755
148	20- 2	15.4	23230698	-2782183
149	20- 1	15.4	23230961	-2765038
150	19- 7	15.4	23231653	-2720062
151	32- 3	15.1	23231724	-2715350
152	32- 2	15.1	23231795	-2710638
153	32- 1	15.1	23231937	-2701214
154	1- 7	15.1	23233929	-2569198
155	24- 4	15.0	23234515	-2530155
156	23-25	14.7	23277008	369930
157	49- 7	14.5	23277702	417819
158	18- 3	14.4	23277724	419358
159	18- 2	14.4	23277747	420897
160	18- 1	14.4	23277791	423975

161	27- 7	14.2	23281066	655191
162	28-13	14.1	23282875	783632
163	35- 3	14.0	23282913	786329
164	35- 2	14.0	23282950	789026
165	35- 1	14.0	23283026	794421
166	2- 4	13.9	23283266	811741
167	6- 4	13.9	23283752	846817
168	3-16	13.8	23285672	985428
169	50-16	13.5	23289058	1237171
170	21- 4	13.4	23289779	1291127
171	33-16	13.0	23294567	1659845
172	53- 4	12.9	23294900	1685701
173	14- 4	12.6	23295912	1765785
174	29- 4	12.5	23296605	1821181
175	17-13	12.5	23297456	1889121
176	20- 4	12.4	23298984	2012353
177	45- 3	12.3	23299106	2022351
178	45- 2	12.3	23299229	2032350
179	45- 1	12.3	23299474	2052346
180	32- 4	12.2	23300297	2120025
181	44- 3	12.1	23300322	2122130
182	44- 2	12.1	23300348	2124235
183	16- 3	12.1	23300385	2127343
184	16- 2	12.1	23300423	2130451
185	44- 1	12.1	23300474	2134661
186	39- 3	12.1	23300548	2140723
187	39- 2	12.1	23300621	2146785
188	16- 1	12.1	23300696	2153001
189	39- 1	12.1	23300843	2165126
190	24-13	12.1	23301380	2209398
191	1-16	12.1	23306645	2642988
192	26-16	12.0	23309027	2841608
193	46-16	11.9	23310828	2992666
194	13- 3	11.7	23310835	2993294
195	13- 2	11.7	23310843	2993922
196	13- 1	11.7	23310857	2995178
197	15- 3	11.7	23310880	2997145
198	15- 2	11.7	23310903	2999112
199	15- 1	11.7	23310949	3003047
200	18- 4	11.7	23311207	3025111

201	11-16	11.6	23312117	3103370
202	38-13	11.5	23313795	3249412
203	30-16	11.5	23317781	3596836
204	9- 3	11.4	23317849	3602796
205	9- 2	11.4	23317917	3608756
206	9- 1	11.4	23318053	3620676
207	22- 3	11.4	23318190	3632662
208	22- 2	11.4	23318327	3644649
209	22- 1	11.4	23318601	3668621
210	35- 4	11.4	23319040	3707253
211	21-13	11.0	23320304	3821881
212	43- 7	10.9	23320852	3872221
213	34- 7	10.7	23322424	4019547
214	8- 7	10.6	23322866	4061290
215	25- 7	10.3	23323400	4113042
216	28-16	10.2	23328611	4625303
217	45- 4	10.0	23330033	4767776
218	12- 3	9.9	23330064	4770904
219	12- 2	9.9	23330095	4774031
220	12- 1	9.9	23330157	4780286
221	44- 4	9.9	23330453	4810270
222	16- 4	9.9	23330890	4854539
223	39- 4	9.9	23331742	4940892
224	13- 4	9.5	23331828	4949827
225	15- 4	9.5	23332095	4977816
226	42- 3	9.4	23332136	4982194
227	42- 2	9.4	23332177	4986572
228	42- 1	9.4	23332260	4995328
229	9- 4	9.3	23333050	5080056
230	22- 4	9.3	23334638	5250455
231	31- 3	8.5	23334671	5254269
232	31- 2	8.5	23334703	5258083
233	31- 1	8.5	23334769	5265711
234	10- 3	8.2	23334778	5266927
235	10- 2	8.2	23334788	5268144
236	10- 1	8.2	23334808	5270577
237	37- 3	8.2	23334842	5274712
238	37- 2	8.2	23334876	5278848
239	37- 1	8.2	23334943	5287118
240	12- 4	8.2	23335304	5331390
241	2- 7	8.0	23335556	5362635
242	6- 7	8.0	23336065	5425912
243	7- 3	7.8	23336091	5429267

244	7- 2	7.8	23336117	5432623
245	7- 1	7.8	23336169	5439333
246	24-16	7.8	23337200	5571794
247	42- 4	7.7	23337679	5633675
248	38-16	7.7	23340081	5947560
249	53- 7	7.5	23340430	5993918
250	14- 7	7.4	23341490	6137281
251	35-13	7.3	23342106	6221975
252	29- 7	7.3	23342832	6321068
253	17-16	7.3	23343723	6442599
254	20- 7	7.3	23345323	6662871
255	49-16	7.1	23346155	6779347
256	32- 7	7.1	23347016	6900138
257	31- 4	7.0	23347394	6953910
258	18- 7	6.9	23347664	6993172
259	21-16	6.8	23349403	7248325
260	10- 4	6.7	23349518	7265460
261	37- 4	6.7	23349910	7323700
262	36- 3	6.5	23349940	7328351
263	36- 2	6.5	23349970	7333001
264	36- 1	6.5	23350030	7342302
265	7- 4	6.4	23350334	7389505
266	40- 3	6.2	23350356	7393132
267	40- 2	6.2	23350379	7396760
268	40- 1	6.2	23350424	7404015
269	44- 7	5.9	23350734	7456753
270	16- 7	5.9	23351192	7534616
271	39- 7	5.9	23352084	7686502
272	45- 7	5.9	23353574	7937272
273	13- 7	5.7	23353663	7952954
274	15- 7	5.7	23353942	8002078
275	9- 7	5.6	23354770	8150579
276	22- 7	5.6	23356433	8449234
277	36- 4	5.4	23356783	8514410
278	40- 4	5.2	23357045	8565216
279	35-16	5.1	23357984	8747663
280	12- 7	4.9	23358362	8824672
281	41- 3	4.8	23358369	8826049
282	41- 2	4.8	23358375	8827426
283	41- 1	4.8	23358389	8830181
284	42- 7	4.7	23358890	8937527
285	31- 7	4.3	23359285	9030373
286	10- 7	4.1	23359406	9059900
287	37- 7	4.1	23359816	9160265
288	41- 4	4.0	23359892	9179472
289	7- 7	3.9	23360210	9260657
290	36- 7	3.3	23360576	9371968
291	40- 7	3.2	23360851	9458628
292	41- 7	2.5	23360931	9491129

EXHIBIT 3

MATHEMATICAL PROGRAMMING APPLICATION

This project used the 0-1 integer linear programming algorithm developed by Lemke and Spielberg.[1] It is a direct search algorithm for the solution of problems of the form:

$$\text{Min} \quad Z = \underline{c}\,\underline{y}$$

$$A\underline{y} \leqslant \underline{b}$$

$$y_i = 0 \text{ or } 1, \; i = 1,2,\ldots n.$$

Here, $\underline{c}$, (the cost vector) and $\underline{y}$ (the vector of variables y_i) are n-component vectors, $\underline{b}$ (the right-hand side vector) is an m-component vector, and A (the matrix of constraint coefficients) is an mxn matrix. The elements of $\underline{c}$, $\underline{b}$ and A are integers unrestricted in sign. The program is written for $m \leqslant 50$ and $n \leqslant 150$.

The following example shows how this algorithm was applied to the optimal selection of health programs. Consider the following four health programs:

---

[1] See Lemke and Spielberg (1967) for a description of this algorithm. A more detailed operations-oriented description plus a FORTRAN source deck may be obtained from IBM by requesting a copy of 360-15.2.001, Direct Search Zero-One Integer Programming 1-DZIP1.

i	Program Number	E	C
1	52-1	1,100	- 2,296
2	52-4	4,294	968
3	57-1	71,502	28,534
4	57-2	162,722	64,937

Since the problem is to select that sub-set of programs which will maximize the health benefits for a given cost, this leads to the following 0-1 integer linear program with four variables and three constraints:

$$\text{Min } Z = -1100\,y_1 - 4294\,y_2 - 71502\,y_3 - 162722\,y_4 \qquad (1)$$

$$-2296\,y_1 + 968\,y_2 + 28534\,y_3 + 64937\,y_4 \leq K \qquad (2)$$

$$y_1 + y_2 \leq 1 \qquad (3)$$

$$y_3 + y_4 \leq 1 \qquad (4)$$

Here, (2) is the cost constraint, K is the total cost not to be exceeded, and (3) and (4) are the constraints to ensure that only one program from each mutually exclusive set is in solution at any one time.

In this project, the 0-1 integer linear programming algorithm was applied in exactly this manner, except, of course, the number of programs was considerably larger.

EXHIBIT 4

SELECTED RESULT FROM THE MATHEMATICAL PROGRAMMING ALGORITHM

Optimal Set of Programs	Effectiveness	Cost	Cost Constraint
3,5	1,508	-3,152	-1,000
3,7	2,555	- 372	0
3,6	4,702	112	1,000
3,6,10	5,212	7,522	10,000
1,3,6	8,184	16,665	20,000
1,3,6,10	8,694	24,075	25,000
3,5,8	73,010	25,382	25,500
3,6,8	76,204	28,646	30,000
3,6,8,10	76,714	36,056	40,000
1,3,6,8	79,686	45,199	50,000
1,3,6,8,10	80,196	52,609	60,000
3,5,9	164,230	61,785	65,000
3,6,9	167,424	65,049	70,000
3,6,9,10	167,934	72,459	80,000
1,3,6,9	170,906	81,602	85,000
1,3,6,9,10	171,416	89,012	90,000
1,4,6,9	173,330	98,153	100,000
1,4,6,9,10	173,840	105,563	110,000
2,3,6,9	174,216	119,437	120,000
2,3,6,9,10	174,726	126,847	130,000
2,4,6,9	176,640	135,988	140,000
2,4,6,9,10	177,150	143,398	145,000

LIST OF REFERENCES

Ackoff, Russell L. 1961. Progress in Operations Research, Volume I. New York: John Wiley and Sons.

Ackoff, Russell L., Gupta, Shiv K. and Minas, J. Sayer. 1962. Scientific Method: Optimizing Applied Research Decisions. New York: John Wiley and Sons.

Ackoff, Russell L. and Sasieni, Maurice W. 1968. Fundamentals of Operations Research. New York: John Wiley and Sons.

Adams, Ernest W. 1960. "Survey of Bernouillian Utility Theory" in Solomon, Herbert (Ed.) Mathematical Thinking in the Measurement of Behavior. Glencoe, Illinois: Free Press of Glencoe.

Anthony, Robert N. 1965. Planning and Control Systems: A Framework for Analysis. Boston: Harvard University Press.

Arrow, Kenneth J. 1963. Social Choice and Individual Values. New York: John Wiley and Sons.

Arrow, Kenneth J. 1969. "The Social Discount Rate" in Somers, G.G. and Wood, W.D. (Eds.) Cost Benefit Analysis of Manpower Policies. Kingston, Ontario: Industrial Relations Center, Queen's University.

Baumol, William J. 1968. "On the Social Rate of Discount", The American Economic Review, Volume 58, Number 4, September, pp. 788-802.

Bower, Joseph L. 1969. "Systems Analysis for Social Decisions", Operations Research, Volume 17, Number 6, November-December, pp. 927-940.

Bush, J.W. 1970. Private Letter. Professor of Health Planning. New York University, New York City.

Chase, Samuel B. (Ed.). 1968. Problems in Public Expenditure Analysis. Washington: The Brookings Institute.

Chiang, C.L. 1965. An Index of Health: Mathematical Models, Series 2, Number 5. Washington: Public Health Service.

Churchman, C. West and Ackoff, Russell L. 1954. "An Approximate Measure of Value", Operations Research, Volume 2, Number 2, May, pp. 172-187.

The Department of National Revenue, Taxation. 1969. Taxation Statistics (Annual). Ottawa: Queen's Printer.

Dixon, Wilfrid J. and Massey, Frank J. Jr. 1957. Introduction to Statistical Analysis, Second Edition. New York: McGraw-Hill.

Dominion Bureau of Statistics. 1964. Provincial and Regional Life Tables, 1960-1962, Publication Number 84-517. Ottawa: Queen's Printer.

Dominion Bureau of Statistics. 1968a. Causes of Death (Annual) Publication Number 84-203. Ottawa: Queen's Printer.

Dominion Bureau of Statistics. 1968b. Vital Statistics (Annual) Publication Number 84-202. Ottawa: Queen's Printer.

Dominion Bureau of Statistics. 1969. Seasonally Adjusted Labour Force Statistics, 1953-1968, Publication Number 71-201. Ottawa: Queen's Printer.

Donabedian, Avedis. 1966. "Evaluating the Quality of Medical Care" in Mainland, Donald (Ed.), Health Services Research I. New York: Milbank Memorial Fund, pp. 166-207.

Donabedian, Avedis. 1968. "Promoting Quality Through Evaluating the Process of Patient Care", Medical Care, Volume 6, Number 3, May-June, pp. 181-202.

Donabedian, Avedis. 1969. A Guide to Medical Care Administration, Volume II: Medical Care Appraisal. New York: The American Public Health Association, Inc.

Dyckman, T.R., Smidt, S. and McAdams, A.K. 1969. Management Decision Making Under Uncertainty: An Introduction to Probability and Statistical Decision Theory. London: The MacMillan Company, Collier-MacMillan Limited.

English, J. Morley (Editor). 1968. Cost-Effectiveness: The Economic Evaluation of Engineered Systems. New York: John Wiley and Sons.

Fein, Rashi. 1958. Economics of Mental Illness. New York: Basic Books, Inc.

Fein, Rashi. 1967a. "Definition and Scope of the Problem: Economic Aspects in Assessing the Effectiveness of Child Health Services" in Bergman, Abraham (Ed.), Report on the Fifty-Sixth Ross Conference on Pediatric Research. Columbus: Ross Laboratories, pp. 44-53.

Fein, Rashi. 1967b. The Doctor Shortage: An Economic Diagnosis. Washington, D.C.: The Brookings Institute.

Feldstein, Martin S. 1964. "The Social Time Preference Discount Rate in Cost Benefit Analysis", Economic Journal, Volume 74, June.

Feldstein, Martin S. 1965. "The Derivation of Social Preference Rates", Kyklos, Volume 18, pp. 277-287.

Feldstein, Martin S. 1967. Economic Analysis for Health Service Efficiency: Econometric Studies of the British National Health Service. Amsterdam: North-Holland Publishing Company.

Ferebee, Shirley H. 1967. "An Epidemiological Model of Tuberculosis in the United States", National Tuberculosis Association Bulletin, Volume 53, Number 1, pp. 4-7.

Flagle, Charles D. 1966. "A Threshold Method for Utility Estimation and Resolution of Conflict" in Lawrence, J.R. (Ed.), Operational Research and the Social Sciences. London: Tavistock Publications, pp. 399-407.

Flagle, Charles D. and Young, J.P. 1966. "Application of Operations Research and Industrial Engineering to Problems of Health Sciences, Hospitals and Public Health", Journal of Industrial Engineering, November.

Freund, John E. 1962. Mathematical Statistics. Englewood Cliffs: Prentice-Hall, Inc.

Freund, John E. 1967. Modern Elementary Statistics, Third Edition. Englewood Cliffs: Prentice-Hall, Inc.

Fuchs, Victor R. 1966. "The Contribution of Health Services to the American Economy", The Milbank Memorial Fund Quarterly, Volume 44, Number 4, Part 2, October, pp. 65-103.

Goldman, Thomas A. (Ed.). 1967. Cost-Effectiveness Analysis: New Approaches in Decision Making. New York: Frederick A. Praeger, Publishers.

Gorham, William. 1966. "Allocating Federal Resources Among Competing Social Needs". Health, Education and Welfare Indicators, August, pp. 1-13.

Gottschalk, Carl W. 1967. Report of the Committee on Chronic Kidney Disease. Washington: Bureau of the Budget.

Guion, Robert M. 1965. Personnel Testing. New York: McGraw-Hill Book Company.

Hadley, G. 1961. Linear Algebra. Reading, Massachusetts: Addison-Wesley.

Hadley, G. 1964. Nonlinear and Dynamic Programming. Reading, Massachusetts: Addison-Wesley.

Harberger, Arnold C. 1965. Survey of Literature on Cost-Benefit Analysis for Industrial Project Evaluation. Paper presented at the Inter-Regional Symposium in Industrial Project Evaluation, October. Prauge.

Harper, W.H. 1969. Private Communication. Toronto: Research and Planning Branch, Ontario Department of Health.

Hatry, Harry P. 1967. Criteria for Evaluation in Planning State and Local Programs. A study submitted by the Subcommittee on Inter-Governmental Relations, to the Committee on Government Operations. U.S. Senate, July 21. Washington: U.S. Government Printing Office.

Hawthorne, V.M. 1969. "An Epidemiological Method to Improve Tuberculosis Control", Scottish Medical Journal, Volume 14, pp. 222-227.

Helmer, Olaf. 1969. "The Application of Cost-Effectiveness to Non-Military Government Problems" in Cleland, David I. and King, William R., Systems, Organizations, Analysis Management: A Book of Readings. New York: McGraw-Hill Book Company, pp. 265-271.

Iversen, E. 1967a. "Epidemiological Basis of Tuberculosis Eradication 7. Application of Life-Table Methods for Assessing the Prognosis for Tuberculosis Patients", Bulletin of the World Health Organization, Volume 36, pp. 733-746.

Iversen, E. 1967b. "Epidemiological Basis of Tuberculosis Eradication 8. Some Factors of Significance for the Prognosis for a Tuberculosis Patient", Bulletin of the World Health Organization, Volume 37, pp. 893-906.

Kandle, Roscoe, P. 1961. "Report of the Chairman of the Technical Development Board to the Governing Council at the Eighty-Eighth Annual Meeting of the American Public Health Association in San Francisco, California, October 30, 1960," Journal of Public Health, Volume 51, Number 2, February, pp. 287-294.

Kelman, H.R. and Elinson, Jack. 1969. "Strategy and Tactics of Evaluating a Large-Scale Medical Program," Medical Care, Volume 7, Number 2, March-April, pp. 79-85.

Kennedy, F.D. 1969. The Maternal and Infant Care Simulation Model. A Paper presented at the Joint National Meeting of the American Astronautical Society and the Operations Research Society of America, June 17-20. Denver, Colorado.

Kisch, Arnold I. et. al. 1969. "A New Proxy Measure for Health Status", Health Services Research, Volume 4, Number 3, Fall, pp. 223-230.

Kissick, William L. 1967. "Planning, Programming and Budgeting in Health", Medical Care, Volume 5, Number 4, July-August, pp. 201-220.

Kissick, William L. 1969. "Cost/Benefit Studies in Health Planning in the U.S.A." Health Economics, Regional Office for Europe, W.H.O. Copenhagen: (Euro 0339), pp. 39-44.

Klarman, Herbert E. 1965a. The Economics of Health. New York: Columbia University Press.

Klarman, Herbert E. 1965b. "Syphilis Control Programs" in Dorfman, Robert (Ed.), Measuring Benefits of Government Investments. Washington: The Brookings Institute, pp. 367-410.

Klarman, Herbert E. 1965c. "Socioeconomic Impact of Heart Disease" in The Heart and Circulation. Second National Conference on Cardiovascular Diseases. Washington, D.C.

Klarman, Herbert E. 1966. Present Status of Cost-Benefit Analysis in the Health Field. Paper presented at the 94th Annual Meeting, American Public Health Association, November 1. San Francisco.

Klarman, Herbert E., Francis, J. and Rosenthal, G.O. 1968. "Cost-Effectiveness Analysis Applied to the Treatment of Chronic Renal Disease", Medical Care, Volume 6, Number 1, January-February, pp. 48-54.

Kohn, Robert. 1966a. "Health Objectives for the Evaluation of Health Services and Operational Research", The Canadian Journal of Public Health, January, pp. 13-17.

Kohn, Robert. 1966b. Royal Commission on Health Services: The Health of the Canadian People. Ottawa: Queen's Printer.

Kohn, Robert. 1967. Royal Commission on Health Services: The Health of the Canadian People. Ottawa: Queen's Printer.

Lemke, C.E. and Spielberg, K. 1967. "Direct Search Algorithm for Zero-One and Mixed-Integer Programming", Operations Research, September-October, pp. 892-915.

Lipworth, Leslie. 1969. "Cost Effectiveness of a Preventive Program in Renal Disease", Milbank Memorial Fund Quarterly, July, pp. 70-74.

Little, Arthur D. Inc. 1968. Cost-Effectiveness in Traffic Safety. New York: Frederick A. Praeger, Inc.

Mao, James C.T. 1969. Quantitative Analysis of Financial Decisions. London: The MacMillan Company.

Marshall, A.W. 1965. Cost/Benefit Analysis in Health, Rand Corporation, Report No. P.-3274.

McCaffree, Kenneth M. 1968. "The Economic Basis for the Development of Community Mental Health Programs", Medical Care, Volume 6, Number 4, July-August, pp. 286-299.

McKean, Roland N. 1958. Efficiency in Government Systems Analysis: With Emphasis on Water Resources Development. New York: John Wiley and Sons.

McKean, Roland N. 1968. Public Spending. New York: McGraw-Hill Book Company.

Miller, James E. 1970a. Performance Indices for Community Health Programs. Presented at the 37th National Meeting of ORSA, April 20-22. Washington, D.C.

Miller, James E. 1970b. Private Letter. Tucson, Arizona: U.S. Public Health Service.

Miller, J.R. III. 1966. The Assessment of Worth: A Systematic Procedure and Its Experimental Validation. Doctoral Dissertation, M.I.T.

Modi, Jamshed A. 1969. Cost-Effectiveness Analysis of Artificial Kidney Systems. Paper presented at the Joint National Meeting of the American Astronautical Society and the Operations Research Society of America, June 17-20. Denver, Colorado.

Mushkin, Selma. 1962. "Health as an Investment", Journal of Political Economy, Volume 70, Number 5, Part 2, Supplement, October, pp. 129-157.

Naddor, Eliezor, Shuman, L.J. and Young, J.P. 1969. A Planning Model for Regional Health Services. Paper delivered at the 36th National Meeting of the Operations Research Society of American, November 10-12. Miami Beach.

Natrella, Mary G. 1963. Experimental Statistics, National Bureau of Standards Handbook 91. Washington, D.C.: U.S. Government Printing Office.

Neenan, William B. 1967. Normative Evaluation of a Public Health Program. Ann Arbor: The University of Michigan.

Neumann, John von and Morgenstern, Oskar. 1953. Theory of Games and Economic Behaviour, Third Edition. New York: John Wiley and Sons.

Niskanen, William A. 1967. "Measures of Effectiveness", Chapter 2 in Goldman, Thomas A. (Ed.), Cost Effectiveness Analysis. New York: Frederick A. Praeger, Publishers.

Ontario Department of Health. 1969a. Annual Report - 1968 - Tuberculosis Prevention. Toronto: Tuberculosis Prevention Service, Special Health Services Branch, Public Health Division, Ontario Department of Health.

Ontario Department of Health. 1969b. Statistical Report of Sanitoria in the Province of Ontario for the Year Ending December 31, 1968 - Medical Statistics. Toronto: Chronic Disease Section, Epidemiology Service, Special Health Services Branch, Ontario Department of Health.

Ontario Department of Health. 1969c. Tuberculosis in Ontario, 1968. Toronto: Tuberculosis Prevention Service, Special Health Services Branch, Public Health Division, Ontario Department of Health.

Ontario Department of Treasury and Economics. 1968. Ontario Population, 1966 and 1967 and Short Term Projections, 1967-1973. Toronto: Economic Planning Branch, Policy Planning Division, Ontario Department of Treasury and Economics.

Ontario Hospital Services Commission. 1969. Statistical Supplement to 1968 Annual Report. Toronto: O.H.S.C.

Ontario Medical Association. 1969. Schedule of Fees, April 1. Toronto: O.M.A.

Packer, Arnold H. 1968. "Applying Cost-Effectiveness Concepts to the Community Health System", Operations Research, Volume 16, Number 2, March-April, pp. 227-253.

Packer, Arnold H. 1969. Modelling the Community Health Service System. A paper presented at the Joint National Meeting of the American Astronautical Society and the Operations Research Society of America, June 17-20. Denver, Colorado.

Pell, S. and D'Alonzo, C.A. 1964. "Immediate Mortality and Five-Year Survival of Employed Men with a First Myocardial Infraction", New England Journal of Medicine, Volume 270, Number 18, pp. 915-922.

Piot, Maurice and Sundaresan, T.K. 1967. A Linear Program Decision Model for Tuberculosis Control: Progress Report on the First Test Runs, WHO/TB/TECHN. Information/67.55. Geneva: World Health Organization.

The President's Commission on Heart Disease, Cancer and Stroke. 1965. A National Program to Conquer Heart Disease, Cancer and Stroke. Washington, D.C.: United States Government Printing Office.

Prest, A.R. and Turvey, R. 1965. "Cost-Benefit Analysis: A Survey", The Economic Journal, Volume 75, December, pp. 683-735.

Quade, Edward S. 1967. "Introduction and Overview", Chapter 1 in Goldman, Thomas A. (Ed.), Cost Effectiveness Analysis. New York: Frederick A. Praeger, Publishers.

Quade, E.S. and Boucher, W.I. (Eds.). 1968. Systems Analysis and Policy Planning, Applications in Defense. New York: American Elsevier Publishing Co.

Race, R.R. and Sanger, Ruth. 1968. Blood Groups in Man. Oxford: Blackwell Scientific Publications.

Revelle, Charles S., Lynn, Walter R. and Feldman, Floyd M. 1967. Mathematical Models for the Economic Allocation of Tuberculosis Control Activities in Developing Nations. Geneva: WHO, WHO/TB/TECH. Information/67.59. Also published in the American Review of Respiratory Diseases, Volume 96, Number 5, November, pp. 893-909.

Revelle, Charles, Feldman, Floyd and Lynn, Walter. 1969. "An Optimization Model of Tuberculosis Epidemiology", Management Science, Volume 16, Number 4, December, pp. 190-211.

Rice, Dorothy P. 1966. Estimating the Cost of Illness, Health Economic Series Number 6. Washington, D.C.: U.S. Government Printing Office.

Rice, Dorothy P. 1967a. "Estimating the Cost of Illness", American Journal of Public Health, Volume 57, Number 3, March, pp. 424-440.

Rice, Dorothy P. 1967b. "The Economic Value of Human Life", American Journal of Public Health, Volume 57, Number 11, November, pp. 1954-1966.

Rice, Dorothy P. 1969. "Measurement and Application of Illness Costs", Public Health Reports, Volume 84, Number 2, February, pp. 95-101.

Robertson, Robert L. 1967. "Issues in Measuring the Economic Effects of Personal Health Services", Medical Care, Volume 5, Number 6, November-December, pp. 362-368.

Sackett, D.L. 1970. "Can Screening Programs for Serious Diseases Really Improve Health?", Science Forum, Volume 15, June, pp. 9-13.

Sanazaro, Paul J. and Williamson, John W. 1968. "End Results of Patient Care: A Provisional Classification Based on Reports by Internists", Medical Care, Volume 6, Number 2, March-April, pp. 123-130.

Sanders, Barker S. 1964. "Measuring Community Health Levels", American Journal of Public Health, Volume 54, July, pp. 1063-1070.

Sanders, J.L. 1970a. Models for the Description and Evaluation of Acute and Chronic Disease Programs. Presented at the 37th Annual Meeting of ORSA, April 20-22. Washington, D.C.

Sanders, J.L. 1970b. Private Letter. Professor of Systems Engineering, University of Arizona, Tucson, June 16.

Schelling, Thomas. 1968. "The Life You Save May Be Your Own" in Chase, Samuel B. Jr. (Ed.), Problems in Public Expenditure Analysis. Washington: The Brookings Institute.

Schwartz, Eli. 1970. "The Cost of Capital and Investment Criteria in the Public Sector", The Journal of Finance, Volume 25, Number 1, March, pp. 135-142.

Siegel, Sidney. 1956. Nonparametric Statistics for the Behavioral Sciences. New York: McGraw-Hill.

Sinclair, Craig. 1969. "Costing the Hazards of Technology", New Scientist, Volume 16, October, pp. 120-122.

Sinclair, Craig. 1970. Private Letter. Falmer, Brighton, England: Science Policy Research Unit, University of Sussex.

Smith, B. Gordon. 1970. Coronary Emergency Rescue Services Treated as a Queueing System - A Cost Effectiveness Analysis. Presented at the 37th National Meeting of ORSA, April 20-22. Washington, D.C.

Smith, Warren F. 1968. "Cost-Effectiveness and Cost-Benefit Analyses for Public Health Programs", Public Health Reports, Volume 83, Number 11, November, pp. 899-906.

Somers, Herman M. and Somers, Anne R. 1967. A Program for Research in Health Economics, Health Economics Series No. 7, January. Arlington, Virginia: U.S. Department of Health, Education and Welfare, Public Health Service.

Stern, Curt. 1960. Principles of Human Genetics, Second Edition. San Francisco: W.H. Freeman and Company, pp. 342-347.

Stevens, S.S. 1959. "Measurement, Psychophysics and Utility" in Churchman, C. West and Ratoosh, Philburn, Measurement: Definitions and Theories, pp. 18-63. New York: John Wiley and Sons.

Stewart, William H. 1967. "The Challenging Need for Assessment" in Assessing the Effectiveness of Child Health Services. Report of the Fifty-sixth Ross Conference on Pediatric Research, Bergman, Abraham B. (Ed.). Columbus: Ross Laboratories. pp. 9-23.

Stimson, David H. 1969. "Utility Measurement in Public Health Decision Making", Management Science, Volume 16, Number 2, October, pp. B-17 to B-30.

Sullivan, Donald F. 1966. Conceptual Problems in Developing an Index of Health, Vital and Health Statistics, National Centre for Health Statistics, Series 2, Number 17, Public Health Service Publications No. 1000, May.

Swaroop, S. and Uemura, K. 1957. "Proportional Mortality of 50 Years and Above", Bulletin of the World Health Organization, Volume 17, Number 3, pp. 439-481.

Thedie, Jacques and Abraham, Claude. 1961. "Economic Aspects of Road Accidents", Traffic Engineering and Control, Volume 2, Number 10, February, pp. 589- 595.

Thomas, Warren H. 1968. "A Model for Predicting Recovery Progress of Coronary Patients", Health Services Research, Volume 3, Fall, pp. 185-213.

Trauger, D.A. 1966. "Tuberculosis and Life Expectancy in Hawaii", American Review of Respiratory Diseases, Volume 93, pp. 284-287.

Weingartner, H.M. 1967. Mathematical Programming and the Analysis of Capital Budgeting Problems. Chicago: Markham Publishing Company.

Weisbrod, Burton A. 1962. Economics of Public Health: Measuring the Economic Impact of Diseases. Philadelphia: University of Pennsylvania Press.

White, Kerr L. 1967a. "Definition and Scope of Problems" in Assessing the Effectiveness of Child Health Services. Report of the Fifty-sixth Ross Conference on Pediatric Research, Bergman, Abraham B. (Ed.), pp. 24-33. Columbus: Ross Laboratories.

White, Kerr L. 1967b. "Primary Medical Care for Families: Organization and Evaluation", New England Journal of Medicine, Volume 277, October 19, pp. 847-852.

White, Kerr L. 1968. "Research in Medical Care and Health Services Systems", Medical Care, Volume 6, Number 2, March-April, pp. 95-100.

Wigle, W.D. A series of interviews, telephone conversations and letters during 1969 and 1970 with Dr. W.D. Wigle, Tuberculosis Prevention Service, Ontario Department of Health.

Wiseman, Jack. 1963. "Cost-Benefit Analysis and Health Service Policy", Scottish Journal of Political Economy, Volume 10, February, pp. 128-145.

World Health Organization. 1957. Measurements of Levels of Health. Report by a Study Group, WHO, Technical Report Series No. 137. Geneva.