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9. ABSTRACT

A catalog of methods for analyzing health sectors. It presents a selection of past analyses of health sector components and evaluates those analyses according to three criteria: (a) how well the analysis identifies choices in applying scarce resources among competing objectives; (b) the consequences of decisions in terms of health, economic improvement, and cost; and (c) the preferred alternatives, given the available information, skills, and resources. Those criteria are applied in settings widely varied in terms of the potential for successfully undertaking such studies and applying the results. Thus the catalog attempts to identify weaknesses where they exist, and offer some remedies. The reader is referred to cited literature where specified problems are analyzed and specified techniques applied. This catalog does not serve as a "cookbook" for directly solving health sector problems, but directs the reader to references where others with similar problems have analyzed them.

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SOME HEALTH SECTOR ANALYSIS METHODS FOR DEVELOPING NATIONS

Lawrence H. Stiffman
Program in Health Planning
School of Public Health
The University of Michigan
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Prepared with the Support of Agency for International Development
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A CATALOGUE OF HEALTH SECTOR ANALYSIS METHODS

The two purposes of this catalogue of health sector analysis methods are: (1) to present a selection of past analyses of components of the health sector; and (2) to evaluate these analyses in terms of their ability to illuminate choices on three levels:

a. the facility of the analysis in identifying choices in applying scarce resources among competing objectives, activities, or strategies;

b. the evaluation of the consequences of alternative decisions in general terms of health, economic improvement, and cost; and

c. the preferredness from among the alternatives, given the available quantity and quality of information, skills, resources.

These criteria are applied in settings widely varied as to the ability of successfully undertaking such studies as well as applying the results. Thus, the catalogue aims to identify weaknesses where they exist and offer some remedies. The reader is referred to cited literature where specified problems are analyzed and where specified techniques are applied. This catalogue does not serve as a "cookbook" for directly solving health sector problems, but aids the reader to references where others with similar problems have tread ground.

INTRODUCTION

A. The Scope of the Catalogue

The catalogue begins by discussing the boundaries or constraints in utilizing quantitative methods and techniques. The subjective nature of broad, national health planning choices and strategies limits the role of quantitative analyses for these purposes. Program budgeting applications are described in both the developed and in the developing country setting. Also, examples of cost-effectiveness analyses are offered for cholera and malaria.

At the "management" levels of health sector programs, forecasting and operations-research techniques are described. Examples are offered of identifying and organizing of data into information, and the analyzing and managing this information into description and prescription of health sector decisions. The examples are concerned with health resources planning in terms of forecasting demand for services with the applications oriented to the developed country but transferrable to the underdeveloped setting. Methods included are timeseries analysis, regression analysis, simple population and utilization projections, queuing and inventory theory, and network analysis.

Analytic or optimizing models include mathematical programming (linear and dynamic) and Markovian analysis. Allocation models are discussed for decisions dealing with tuberculosis, allocating personnel, moving patients, and two environmental health examples.

B. The Nature and Context of Choice

Health sector analysts face analogous problems regardless of the resources available or the organizational level utilizing these resources.

The major task is arriving at decisions about choice - choices of what can be done as well as how to do it. The analyst's role is to assist those within governments and organizations in reflecting on the consequences of these decisions in a constantly changing environment.

A critical common concept of quantitative techniques for health planning is that of economic or opportunity cost. This is the cost consequence of a decision or choice - that is, the benefits of foregone alternatives. The analytical techniques are designed to specify alternative courses of action and to compare their consequences. Some approaches include optimization criteria, while others are limited to developing a framework for comparison, while the evaluation of preferred alternatives is done externally to the model by "decision makers" or the "political process".

One common problem is coping with uncertainty. Uncertainty is knowing that one doesn't know what must be known about the risks involved in alternative decisions. The purpose of this catalogue is to describe available analytic and statistical tools and methods which can offer informed information to improve the decision making process. The analyst's role includes reducing uncertainty, identifying risks, and estimating the implications of uncertainties that remain. The application of rational calculations, systematic modeling and operations analysis is only just beginning to be used in coping with uncertainty in national health planning.

Information about the consequences and effects of past and current programs and policies is usually poorly known. Finding this information is difficult, time consuming, and thus costly. The range of availability is from "information overload" - a mire of data, unformated and fragmented - to complete

ignorance. Obtaining new information is a second way of trying to cope with uncertainty. Building in expectations of uncertainty ("business cycles are normal", "nothing is sure but death and taxes") and spreading the risks (insurance) are two additional ways to cope with uncertainty. Thus, the range of avoiding uncertainty is from ignoring the issues that lead to it to translating the situation into a risk situation. A risk situation is differentiated from an uncertain situation when one can estimate the probabilities involved. Risk choices are based on the probability-based expectation that things will go one way rather than another.[1]

The nature of the choice decision limits the successful application of analytic and statistical techniques. Strategic decisions used in national policy guidance generally have wide-spread incommensurable ramifications. Objectives are often hard to specify, let alone, quantify. Most techniques - generally included under the general term, "systems analysis" - are limited to the extent of trying to classify the uncertainties in the factors on which the action can be based. Assignment and maximization of values of these factors are also sought. Health sector analysts here attempt to understand, for example, relationships of resources devoted to health to resources devoted to general social and economic improvements. Model building aids in this classification. Most models assume rational behavior of men and events. There is generally a gap in scientific knowledge; the analyst can offer bold conjecture, undertake substantive research or abandon the problem. His time, skills and financial constraints often decide which course will be taken. Obviously, reducing the

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[1] D. Michael, "On the Social Psychology of Organizational Resistances to Long-Range Social Planning", I.E.E.E. Transactions, Vol. 2, No. 5, November 1972.

uncertainty between values and objectives can't be solved by "techniques" alone. Because of the limitations due to uncertainty and socio-political constraints, systems analysis will always fail to include the problem (under study) within an "analytic formulation".

Managerial-Operational decisions, on the other hand, are generally narrower in scope and have a narrower range of consequences than strategic decisions. The issues are generally sharper. The narrower the scope of an operation, the greater is the likelihood that all of the consequences will be commensurable, sometimes in terms of money. More techniques are available and are generally included under the generic term "operations or operational research". Reinke[1] defines operations research as any formalized quantitative analysis whose purpose is to improve efficiency where "efficiency" is defined. Most applications are at middle or low levels within an organization. The clarity of objectives, the relative simplicity of relationships, and the availability of technical knowledge and statistical methods are possible reasons for its success. Decisions at these levels frequently concern matters that have short time horizons - often all consequences are practically immediate. Operations research is best adapted to dealing with routine, semi-technical, quantitative problems. It is easier to ascertain the objectives of a specialized clinic than a comprehensive national health strategic plan.

C. The Planning Process

All of the methods and tools to be discussed fall within a technology of planning. The process, ideally, flows from problem identification to analysis to objective setting to implementation to evaluation. Analysis includes

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[1] F. Grundy and W. Reinke, "Health Practice Resources and Formalized Managerial Methods", Public Health Papers #518, World Health Organization, Geneva, 1973.

the forecasting of relevant and desirable futures based on "what is"; and an appraisal of alternatives plans by tracing pertinent benefit and cost consequences within the direct operating environment (for example, the health sector), and outside the direct operating environment (for example, the national economy).

From analyses flows objective setting. Objectives are process guides - street signs rather than rigid end points. There are generally two types of objectives one may have (Reinke) - those that retain things of value (input minimization) and those that obtain things of value (output maximization). Concurrent high output and low input is impossibly ambiguous. From objective setting flows implementation or the laying out of sequenced chains of actions that define the plan. From implementation flows evaluation with allowance for feedback. A similar description of the planning process consists of three linked functions -- "planning", "management", and "control". Thus in the planning phase, one faces choices of objectives, choices of alternatives, and choices of criteria to select preferred alternatives. Within "management" there are choices of obtaining resources, and searches for obtaining and improving mehtods of productive efficiency, task definition, skills and motivation improvement, and organizational structural changes necessary to implement programs and policies. The "control" function includes the monitoring and evaluation necessary as feedback to the "planning" phase.

Thus, the process within the analysis phase is generally one of diagnosis - assessing the relative significance of problems, their functional relationships, and searching for and appraising alternative means to mitigate the problems while recognizing the constraints and limitations of obtaining and utilizing resources within the political-economic-cultural framework.

If successful, the planning process will reduce uncertainty about the likely effect of possible outcomes. Techniques of research involve statistical analysis and forecasting, epidemiological and social surveys, and to a limited extent, field experiments and controlled trials. Results are often synthesized in a model, almost always descriptive and partial. The processes are essentially geared to searching for choices for the productive use of resources in implementing policies and programs. If successful, the uncertainty of the linkage of the societies' values and objectives is reduced. The uncertainty of the effect of one decision on another is reduced. Techniques of choice include cost/benefit and related analyses, attitude surveys, and program budgeting. Organization management tools, for the implementation phase, include work study analyses, network analyses, and cost analyses.

Many systematic analyses fail because of the following reasons offered by Reinke: the analyses are of poor quality, they were not geared properly to the needs of the decision maker; decision makers have preference for "intuitive reasoning"; programs could be justified that don't need support; poor cooperation of analysis and operational departments; and lack of feedback to the analytic team. In addition, analysts frequently have failed to take into account the interrelationships between planning and implementation.[1]

The criteria for success would therefore seem to be in methods and techniques which (1) are simple to understand, described in practicable terms; (2) interact with each other (the budget as a tool, along with simulation studies of the "what-if...?" nature, and allocation techniques); (3) are didactic, and (4) are of reasonable cost.

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[1]Walter Williams, Social Policy Research and Analysis, Robert Levine, Public Planning, and D. Ewing, The Human Side of Planning.

As a general rule, the planner uses the best technique for which he has data, subject to his skills and budget. For example, a timeseries analysis enables the description and prediction of the future value of any one variable, if the process can be regarded as progressing in time. However, if more information is available about the nature of the process, multiple regression techniques may employ several disparate variables influencing the process. This may produce more accurate description and prescription. If these are the only two methods considered, the cost "tradeoffs" are between information availability, elegance, and analytic capability as well as the amount of error one can live with. Obviously, the greater amount of information available expands the range of utilization of several techniques. The more techniques used, the more certainty is attained, assuming the reliability and validity of the information.

From an economic standpoint, "elegance" can often be appropriately pursued. Any technique is appropriate whenever its use results in changes in system improvement by a larger dollar amount than it costs. For example, if forecasting bed demand at $50,000/bed, substantial sums are justified to improve the accuracy of the forecast.

Four areas of settings are described in which to apply these health sector techniques -- national, regional, single facility and single program.

The second section of the manual covers the arena of national health policy formulation replete with its seemingly overwhelming number of approaches to improving resource allocation. Yet, basic commonsense is required to identify the critical information needed by the planner. Program budgeting

techniques aid in problem identification, crude cost estimations of existing services, and professional education relating to the utility of "alternatives specification" as well as thinking in terms of relevant outcome measures. The fixed budget approach is relevant in developing nation settings even where only crude cost estimations are possible. As the costing of resources utilized within and between the health sector and other national programs also competing for scarce resources improves, the rationale for health programming becomes more apparent.

Cost-effectiveness techniques are often allied with the theory and practice of program budgeting. In health-sector planning, the common problem involves the formulation and specification of output measures and their relationship to inputs -- what we get in payoff for what we do with our resources. Clearly, the techniques are simple, the areas of potential application are great, and those with sufficient skills (mainly a question of orientation) are growing in numbers. Universities can play a major role in performing cost-effectiveness analyses for host countries, as well as for funding institutions and governmental agencies.

Section III is concerned with the analysis of regional health systems. Here, the traditional methods of "single-facility" planning are amplified to include not just the evaluation of existing facilities and estimating future bed needs but the questions of branching of services, such as clinics, the sharing of services, the location of hospitals and services, and the allocation of resources between these hospitals and services. The techniques used are derived from simple to advanced statistical analysis, basic cost analysis, spatial techniques derived from geography theory, and economic analysis as the scope of the problem goes from simple description to regional optimization and simulation studies.

Simple statistics are utilized in evaluating existing facilities. Determinations of services, admissions, length-of-stay information involve the use of the statistical measures of central tendency and dispersion. The forecasting of future bed needs can involve more advanced statistical analysis such as regression and time-series analysis. The analysis of branching and sharing services involves cost analysis including the basic economic criterion of economies of scale. Cost analysis consists of identifying discrete resource cost elements (often in unit terms) and then valueing them in monetary units. Total costs or expenditures are the product of unit costs times the quantity used. The location of hospitals and services can employ gravity models derived from simple physics and geographic theory. Valueing travel costs involves economic assumptions of the value of the time consumed in traveling. Cost-effectiveness analysis is also employed in regional planning in offering preferences for choices of services and facilities relative to location and populations served.

Section III is also concerned with the planning for and management of single facilities and agencies. Here the operations research tools come into use. Their applicability is again dependent on data availability and facilitative skills. While the use of operations-research is increasing, its value and impact has been limited. Erudite models that have little meaning are given low priority by health administrators and are seldom implemented. What is called operations-research is often degenerated to mathematical modeling exercises. The problems under attack have not been well formulated, the objective functions are often naively constructed, and effectiveness measures, sub-optimal. Quantitative variables are considered prime while behavioral

variables are neglected. Politically and socially infeasible alternatives are considered in the feasible set.

Forecasting techniques are used within this arena with most applications involving demand analysis. Variations in cost (resource use) and efficiency problems are also studied. Again, large quantities of data are required to acquire a reasonable sample size at reasonable cost.

The final area is concerned with single program management. The analyst has an array of management tools such as network analysis techniques (PERT, CPM), and evaluation techniques to determine the efficacy of program accomplishment. As individual programs are generally administratively linked, (or funding from a common source) successful future cost-effectiveness analyses depend on concise structuring of individual program inputs, costs, and basic output measures -- the major task of each individual program manager.

In summary, the successful analyses matches the purpose of the study with the best information feasibly obtainable. Elegance of myriads of computer output and esoteric statistical tests, and the gathering of data into expensive information systems is costly and generally avoidable.

II. PLANNING THE ANALYSIS OF HEALTH SECTOR PROBLEMS

A. Cost-effective and Cost-benefit Analysis

The concepts of cost-effectiveness and cost-benefit analysis are surveyed in three discussions by Grosse[1], Uemura[2], and Davis[3]. The latter two studies are prefaced by a discussion of structuring the analyses of specific disease oriented health sector problems.

The Grosse paper describes concepts of economic analysis employed in cost-benefit or cost-effectiveness analysis. Descriptions of two studies conducted at the U.S. Department of Health, Education and Welfare illustrate problems of estimating health program costs and benefits for use in improved budget making and legislative proposals. A third example considers "program budgeting" involving a current national (Indonesia) health program. An attempt is made to link resources to program objectives and accomplishments. Programs are categorized in three groups - designated priority health problems, medical care delivery programs, and support programs, with principal outputs offered for the first two, and costs for all three (over five years). As the total costs exceed estimated total budgets, several mixes of programs, of approximate equal

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[1] R. Grosse, Economics, Health Programs & Program Budgets, Seminar on Modern Management Approach in Health Administration, World Health Organization, Cairo, Oct., 1973.

[2] K. Uemura et al., Epidemiological Model of Cholera - Its Uses in the Planning of Control Programmes and in Cost-benefit Analysis, W.H.O, Interregional Training Course on Cholera Control, Malaysia, Oct., 1971.

[3] J. Davis et al., Malaria Control Program of Indonesia, U.S.A.I.D. Indonesia, July, 1972.

and lower value are offered.

Two disease-oriented analyses are discussed after a summary description of the logical process of disease control planning.

Different approaches to identifying and valueing benefits are offered in the cholera and malaria examples. A computer simulation model of cholera is utilized to choose alternative preventive and therapeutic strategies based on valueing reductions in hospital resource needs. A limited cost-benefit analysis is presented. The approach is applicable in endemic (pervasive) and epidemic (explosive) situations relying on the accumulation of historical data in a variety of settings. Sometimes, arbitrary averages have to be utilized with reliance on expert groups and individuals for information.

The process traces the natural processes of cholera based on past history. Next, the analysis estimates the effectiveness of preventative (vacines and/or sanitation) and curative measures in terms of population coverage and duration. Costs are developed for alternative strategies, and criteria for benefits are chosen. The structuring of the model is then complete and simulations can be performed testing the assumptions and their sensitivities.

The malaria control example more broadly defines possible benefits accrueing to a spraying control program in various sections of Indonesia. The benefits are valued in economic terms of avoidance of furture prevention, treatment, or rehabilitation from disease, and the decreased effects upon labor productivity of illness or premature death.

EXAMPLE 1

ECONOMICS, HEALTH PROGRAMS AND PROGRAM BUDGETS

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School of Public Health
The University of Michigan

Seminar on Modern Management Approach in Health Administration
World Health Organization - Regional Office for the Eastern Mediterranean
Cairo, U.A.R. - 4 October 1973

Perhaps the single most important concept of economics is that of cost. The meaning of cost, in a general sense, is that of sacrifice. Webster's Second International defines cost as "...whatever, as labor, self-denial, suffering, etc., is requisite to secure benefit."

In economic analysis, as employed in cost-benefit or cost-effectiveness studies, costs are benefits lost. They are the result of a decision to forego benefits that could otherwise be obtained. What we decide to do has as its costs those goods things we cannot achieve because of the decision to apply our resources in a particular way.[1] The interesting moral question is not to distinguish between good and evil, but rather to choose among different goods.

A decision to invest more of society's resources in health programs means that less will be invested in education, housing, transportation, national security, space exploration, or private consumption.

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[1]For good discussions of economic cost, see James M. Buchanan, Cost and Choice (Chicago: Markham, 1969); R. H. Coase, "The Nature of Costs," in Studies in Cost Analysis, David Solomons, ed. (Homewood, Ill.: Richard D. Irwin, 1968), pp. 118-133; and Robert E. Bickner, "Concepts of Economic Cost," in Gene H. Fisher, Cost Considerations in Systems Analysis (New York: American Elsevier, 1971), pp. 24-62.

The costs of the addition to health programs are the foregone benefits from the best additions to these others. Whether the cost is worthwhile depends on our values and on our ability to estimate and evaluate the benefits from the various alternatives.

In deciding how best to use resources in the field of health, the cost of an investment in research or hospital construction may be the benefits foregone in extending access to current health services. The cost of saving lives by expanding a tuberculosis control program is the lives that might be saved by expanding a cervical cancer program, if both cannot be done because the available resources are limited.

Ivan Illich has put this concept forcefully in regard to modernization:

"Each car which Brazil puts on the road denies fifty people good transportation by bus. Each merchandized refrigerator reduces the chance of building a community freezer. Every dollar spent in Latin America on doctors and hospitals costs a hundred lives... Had each dollar been spent on providing safe drinking water, a hundred lives could have been saved."[2]

If, then, the costs of a decision are those things we most prize - human life, reduction of suffering, enhancement of the quality of life,

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[2]Ivan D. Illich, *Celebration of Awareness* (New York: Doubleday, 1970), p. 163.

protection of the dependent-then consideration of such costs should be a serious element in such decisions.

The cost of saving a human life is not to be measured in dollars, but rather in terms of alternative lives to be saved or other social values sacrificed. A dramatic battle over the costs and benefits of alternative allocations of health resources took place in China in the past few years. A decision to shift physicians, nurses, and sanitarians to rural areas had great consequences in benefits lost to urban centers and to health professionals.[3]

If the concept of economic cost is such a desirable one to apply, is it difficult in practice to do so? Of course it is. One difficulty is that the benefits we compare are measurable only in very different dimensions. Health programs may have as ultimate benefits the reduction of premature death, reduction of disabling conditions, reduction in suffering, ability to function better socially and at given tasks. Resources expended on arthritis control may reduce pain and disablement, but will have little effect on mortality rates. Other programs, such as the artificial kidney or heart transplants, may have their primary effect in postponing death.

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[3]Descriptions of events and issues are in various issues of *Current Scene-Developments in Mainland China:* "Mao's Revolution in Public Health," May 1, 1968; "The Mao-Liu Controversy over Rural Public Health," June 15, 1969; "Public Health Developments - Continued Focus on Farms," December 15, 1969.

When we consider measuring health program costs in their effects on programs foregone in education or housing, the dimensions of benefit are even more difficult to compare.

The inability to measure benefits in commensurable units does not mean that costs (foregone benefits) cannot be estimated and compared. It does mean, however, that judgments and political processes must be used to make the choices. Cost analysis makes these decisions better informed, so that we know more about how social values may be best realized.

In the search for commensurability, attempts have been made to reduce benefits to a common denominator, usually dollars. But agreement on dollar values is unlikely.

The problem of incommensurability is only one in a long list of measurement difficulties. We lack knowledge of the outputs or benefits of past and existing programs and projects, let alone those of future programs which may be foregone. But if we recognize the necessity for cost (and therefore benefit) information, then we may put a higher value on evaluation and analysis of programs. The development of production functions to give us greater insight into relations among resources, techniques, and outputs is a high priority item for better decision-making.[4]

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[4]The relation of analysis and political decisions is well discussed in Charles L. Schultze, *The Politics and Economics of Public Spending* (Washington: Brookings Institution, 1968), pp. 55-76.

To illustrate some of the problems of estimating costs and benefits of health programs, as well as their use in aiding budget decisions and legislative proposals, two studies done at the U.S. Department of Health, Education and Welfare in the late 1960's are summarized.

Disease Control Programs

One of the first analytical studies at the Department of Health, Education, and Welfare was on disease control programs then under way. Considerable work had been done during earlier years in estimating the economic costs of particular diseases. Among the best known of these are Rashi Fein's *Economics of Mental Illness*, Burton Weisbrod's *Economics of Public Health* (in which he estimated the costs of cancer, tuberculosis, and poliomyelitis), Herbert Klarman's paper on syphilis control programs, and Dorothy Rice's studies covering the international classification of diseases. A generation earlier, Dublin and Lotka's classic study explored the impacts of disease and disability and their relation to changes in earning power. The economic implications of disability were, of course, a matter of central interest in the area of workmen's compensation insurance. It was not surprising, then, that when systematic quantitative analysis of government programs and policies began to spread from defense to civilian applications, one of the first analytical studies was a study of disease-control programs.

HEW supports, or could support, a number of categorical disease control programs whose objectives are, or would be, to save lives or to

prevent disability by controlling specific diseases. The study was therefore an attempt to answer the question: If additional money were to be allocated to disease control programs, which programs would show the highest payoff in terms of lives saved and disability prevented per dollar spent? The study defined *disease* liberally. Motor vehicle accidents were included, together with tuberculosis, syphilis, cancer, and arthritis.

These programs are not research activities but those in which a technology exists, and the problem is whether to put the same, more, or fewer federal funds behind these control programs to support activities in hospitals, states and communities. The question addressed is where to allocate the resources available for this purpose.

TABLE 1—CANCER CONTROL PROGRAM
1966–1972

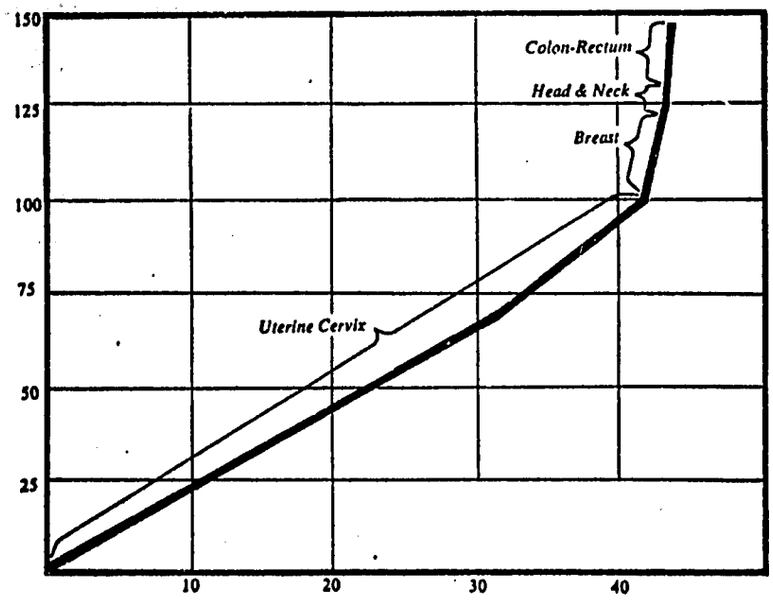
	Uterine Cervix	Breast	Head and Neck	Colon-Rectum
Grant funds total (in thousands of dollars)	$97,750	$17,750	$13,250	$13,300
Number of examinations (in thousands)	9,363	2,280	609	662
Cost per examination	$10.44	$7.79	$21.76	$20.10
Examinations researched per case found	87.5	167.3	620.2	496.0
Total cases found	107,045	13,628	982	1,334
Cost per case found	$913	$1,302	$13,493	$9,970
Total deaths averted	44,084	2,936	303	288
Cost per death averted	$2,217	$6,046	$43,729	$46,181

SOURCE: *The Analysis and Evaluation of Public Expenditures: The PPB System*, U. S. Congress, Joint Economic Committee, Subcommittee on Economy in Government, 1969.

Table 1 illustrates the approach to one set of diseases, cancer. HEW looked at cancer of the uterine cervix, breast, head and neck, and colon-rectum. Estimates were made of cost per examination and the probable

number of examinations that would be required for each case found. From this was derived the number of cases that would be found for a given expenditure level, and estimates of the cost per case found. An estimate was made of the number of deaths that could be averted by the treatment following the detection of the cancer, and then the cost per death averted was calculated; this ranged from about $2,200 in the case of cervical cancer up to $40,000 to $45,000 in the case of head-and-neck and colon-rectum cancer.

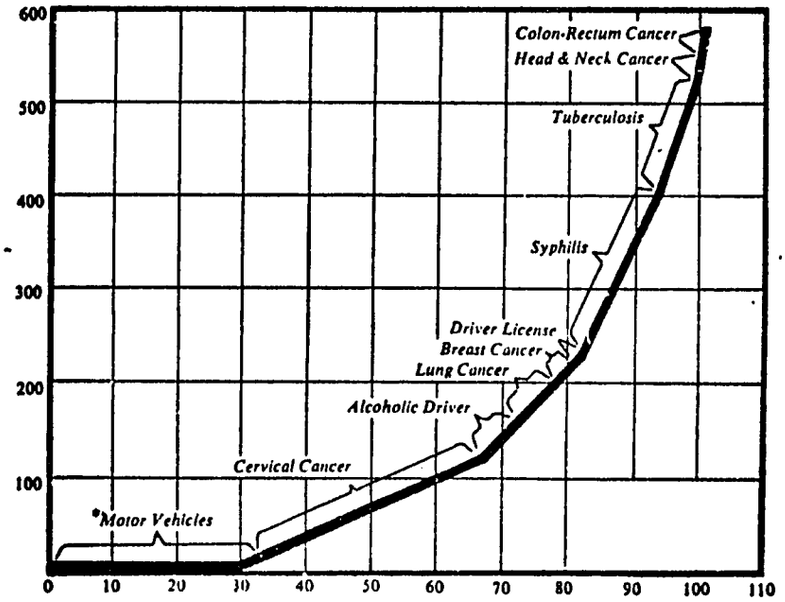
DEATHS AVERTED PER DOLLAR EXPENDED FOR VARIOUS HEALTH/SAFETY MEASURES
FIGURE 1—CANCER PROGRAMS



On the vertical axis of figure 1 are plotted the program costs; these include the cost of the treatment in addition to the federal detection program.

On the horizontal axis, estimates of deaths averted are ordered by the increase in cost per death averted in each program. Segments of the curve identified for each disease cover the extent of the program which it was estimated could be mounted in the years 1968-1972 before running into sharply increasing costs. In concept, the cervical cancer curve is cut off where costs become higher than the breast cancer program, and so on. From this analysis one might say that if there is available only $50 million, cervical cancer should get all the funds. If we have $115 million, then breast cancer control programs look quite competitive. Head and neck and colon-rectum cancer detection as subjects of major control programs did not look attractive when viewed in this context. The analysts recommended that these programs concentrate on research and development.

FIGURE 2—CANCER PROGRAMS COMPARED TO OTHER PROGRAMS



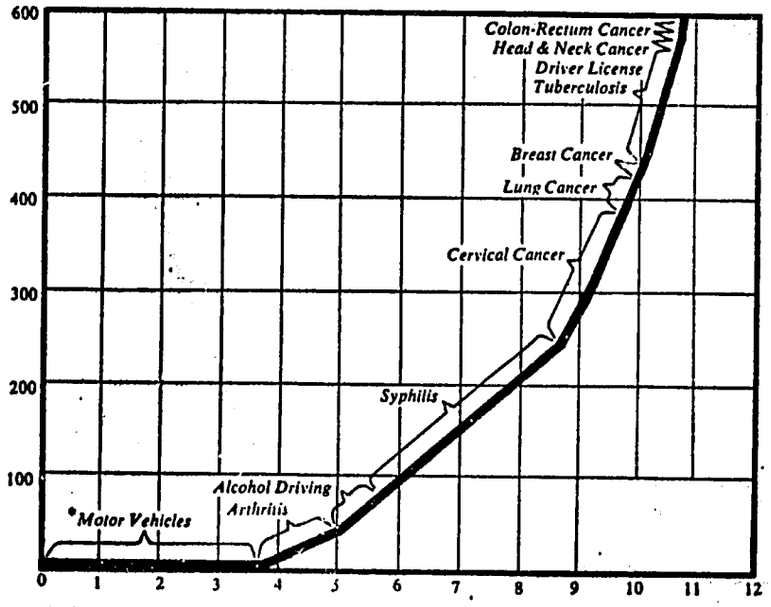
Horizontal: Deaths Averted—in thousands Vertical: Cost in millions of dollars
SOURCE: See Table 1. * Includes programs on use of seat belts, defensive driving, and reduction in pedestrian injuries.

The same kind of analysis was performed for each of the other, non-cancer programs studied (figure 2). There seemed to be a very high

potential payoff for certain educational programs in motor vehicle injury prevention: trying to persuade people to use seatbelts, not to walk in front of a car, and so on. And then as we move up this curve, again ordered by cost of averting death, we begin adding the others.

This particular criterion, deaths averted, was not completely satisfactory. The number of fatalities attributed to arthritis was negligible, and so is not shown. Secondly, there was the question, did it matter who died? Did it matter whether it was a thirty-year-old mother or a forty-year-old father of a family or a seventy-five-year-old grandfather?

FIGURE 3—DOLLAR SAVING IN CANCER PROGRAMS COMPARED TO OTHER TREATMENT PROGRAMS



Horizontal: Savings in billions of dollars
Vertical: Program costs in millions of dollars
SOURCE: See Table 1.
* Includes programs on use of seat belts, defensive driving, and reduction in pedestrian injuries.

On Figure 3, dollar-saving totaling the avoided medical treatments and a crude estimate of the average (discounted) lifetime earnings saved are plotted as a

variable in place of deaths averted. There are two changes in results: Cervical cancer and syphilis control programs change places in priority order, and we are able to introduce the arthritis program.

These studies were not greated with universal acclaim. Criticisms focused on a number of problems. First, with almost no exception the conclusions were based on average relationships. That is, the total benefits were divided by the total costs.

There was little evidence of what the actual impact of increasing or decreasing programs by small amounts might be. If we actually believed the average ratios to be valid at the margin, ought we not to put all our funds into the program with the highest benefit-cost or deaths-averted-per-dollar ratios?

Let me illustrate with a hypothetical example of how such marginal information might be used to determine the preferred mix of disease control programs. Assume that we can determine, as in tables 2 and 3, the number of

TREATMENT COSTS COMPARED

TABLE 2

Expenditure	Lives Saved
Disease A	
$ 500,000	360
1,000,000	465
Disease B	
$ 500,000	200
1,000,000	270

TABLE 3

Expenditure	Lives Saved
$1,000,000 on Disease A	465
$1,000,000 on Disease B	270
$1,000,000 { $500,000 on Disease A .. 360; $500,000 on Disease B .. 200 }	560

lives saved by different expenditures on disease A and disease B.

If we knew only the effect of spending $1 million, we might opt for a program where all our money went toward controlling disease A, by which we could save 465 lives instead of the 270 saved if we spent it all on disease B. Similarly, if we knew only the effects of programs using a half million dollars, we would probably prefer A, as we would save 360 rather than only 200 lives.

But if we knew the results for expenditures of both a half million dollars and $1 million in each program, we would quickly see that spending half our money in each program was better than putting it all in one, assuming we have $1 million available.

FOR HYPOTHETICAL DISEASES

TABLE 4

Expenditures	Lives Saved
Disease A	
$100,000	100
$200,000	180
$300,000	250
$400,000	310
$500,000	360
$600,000	400
$700,000	430
$800,000	450
$900,000	460
$1,000,000	465
Disease B	
$100,000	50
$200,000	95
$300,000	135
$400,000	170
$500,000	200
$600,000	225
$700,000	240
$800,000	255
$900,000	265
$1,000,000	270

TABLE 5

Expenditure		Lives Saved
$1,000,000	$600,000 on Disease A..400 $400,000 on Disease B..170	570

But suppose we had still more discrete data, as in table 4, which gives us the effect of each hundred thousand dollars spent on each control program. We could then spend the million dollars even more effectively, as in table 5.

The lack of marginal data resulted from both a lack of such data for most programs and a lack of economic sophistication on the part of the Public Health Service analysts who performed the studies. Despite the theoretical shortcomings, the results were useful when applied with some common sense.

Practical obstacles of existing commitments made it almost impossible to recommend reductions in any program. So the decisions dealt with the allocation of modest increments.

In the case of oral and colon-rectum cancer, the average cost per death averted seemed so high that the department recommended emphasis on research and development rather than on a control program to demonstrate and extend current technology.

In cervical cancer, investigation indicated a sizable number of hospitals in low socio-economic areas without detection programs which would be willing to establish these if supported by federal funds. The unit cost of increasing the number of hospitals seemed to be the same as that of those already in the program. Shifting the approach to reach out for additional women in the community would increase costs per examination but not so much as to change the relative position of this program. At most, it raised costs to about those of the breast cancer control program.

Despite the seemingly high potential payoff of some of the motor vehicle programs, there was considerable uncertainty about the success. As a consequence, recommendations were for small programs with a large emphasis on evaluation for use in future decisions. The same philosophy was applied to the arthritis program.

Programs were classified into categories by relative pay-off (deaths averted; savings) and certainty of result.

FIGURE 4—PROGRAMS CLASSIFIED BY MAGNITUDE AND CERTAINTY OF RESULT

		PAY-OFF: HIGH	PAY-OFF: LOW
CERTAINTY	HIGH	Cervical Cancer Syphilis	Colon-rectum Cancer Head and Neck Cancer
	LOW	Motor Vehicle Education Arthritis	Heart Transplant

Thus, a matrix of four possibilities might be drawn, as in figure 4. Some of the programs falling within these possibilities are inserted for illustration.

In programs for which the pay-off looked very good, and with relative confidence in the calculations, recommendations for substantial increases in funding were made. Where the pay-off looked high but was rated with considerable uncertainty, as in educational programs to stimulate use of

restraining devices in automobiles, modest funding was suggested with large evaluation components to buy more information. Where results looked relatively poor, it was recommended that no additions to program be made, and that investment might better be placed in additional research to develop improved screening techniques, epidemiological knowledge, or therapy.

The analyses and recommendations were fed into the decision-making process, which also considers existing commitments, the political situation, feasible changes in the rates of spending, the ability to get people moving on programs, and so on.

What resulted, then, was a setting of priorities for additional funding, based on the analytical results, judgment about their reliability, and practical considerations.

A second type of criticism of the analysis described above was concerned with the criteria, especially the calculation of benefits. They were considered inadequate in that they paid attention to economic productivity alone, and omitted other considerations. In particular, they were thought to discriminate against the old who might be past employment years, and women whose earnings were relatively low. It was also feared that the logic, if vigorously pursued, would penalize not only health programs for the aged such as the newly launched Medicare, but also programs aimed at assisting the poor, whose relative earning power is low by definition.

In actual practice in the programs studied, these concerns were only hypothetical. The programs for cervical and breast cancer, limited, of course, to women, seemed to be good. As for the poor, most of the

programs considered, especially cervical cancer, syphilis, and tuberculosis, were directed primarily at them, and projects were usually located to serve low-income residents.

Another type of objection was raised not against the technique of analysis, but against its being done at all. Choices among diseases to be controlled and concern with costs of saving lives can be viewed as contrary to physicians' attitudes in the care of an individual patient. Yet, such decisions are made analysis or no. Prior decisions on allocations to various health problems rested upon a combination of perception of the magnitude of the problem and the political strength organized to obtain funding, as in the National Tuberculosis Association.

The disease control cost-benefit analyses suggest that additional considerations are very relevant. Given scarce resources-and if resources are not scarce, there is no allocation problem-one ought to estimate the costs of achieving improvement in health. If we can save more lives by applying resources to a small problem-in numbers affected-rather than a large one, we ought to consider doing so.

Maternal and Child Health Programs

In regard to maternal and child-care programs, the stated goal was to make needed maternal and child health services available and accessible to all, in particular to all expectant mothers and children in health-depressed areas. Health-depressed areas could be characterized as areas with excessive infant mortality rates. There is no universal index of good or bad health among children. Two measurable areas were selected: mortality, and the

prevalence of chronic handicapping conditions. Over a dozen possible programs aimed at reducing these were examined.

TABLE 6—YEARLY EFFECTS PER $10,000,000 EXPENDED IN HEALTH-DEPRESSED AREAS

	COMPREHENSIVE PROGRAMS		CASE FINDING OF TREATMENT 0,1,3,5,7,9 years of age
	to age 18	to age 5	
Maternal deaths prevented	1.6	3	
Premature births prevented	100–250	200–485	
Infant deaths prevented	40–60	85–120	
Mental retardation prevented	5–7	7–14	
Handicaps prevented or corrected by age 18:			
Vision problems: All	350	195	3,470
Amblyopia	60	119	1,140
Hearing loss: All	90	70	7,290
Binaural	6	5	60
Other physical handicaps	200	63	1,470

SOURCE: See Table 1.

On table 6, three selected programs addressed to the problem of coverage of maternal and child health are illustrated, two of them comprehensive programs of care to expectant mothers and children. This table shows the annual effects of spending the same amount of money, $10 million a year, in different ways. The analysts examined comprehensive care programs covering up to age eighteen and up to age five, with estimates based on the best assumptions derived from the literature and advisers on the probabilities of prevention of maternal deaths, premature deaths, infant deaths, and mental retardation, and handicapping conditions prevented or corrected by age eighteen. They also looked at a program of early case-finding and assured treatment which focused on children at birth (aged four days) and again every other year until they were nine. Expending the same amounts, the money yields different results depending on where it is put. With respect to reduction of infant mortality, several other programs had higher pay-offs than these. For example, a possible program

of intensive-care units for high-risk newborns was estimated to reduce annually 367 deaths if we "put all our eggs in one basket"; this would cost about $27 thousand per infant death prevented. The programs shown cost about four times that amount, but they do other good things, too.

The HEW analysts also looked at programs with a given amount of money aimed at reducing the number of children who would have decayed and unfilled teeth by age eighteen (see table 7).

TABLE 7—REDUCTION IN NUMBER OF CHILDREN WITH DECAYED TEETH PER $10 MILLION EXPENDED

TREATMENT	APPROXIMATE POPULATION COVERED (IN THOUSANDS)	REDUCED NUMBER OF CHILDREN (IN THOUSANDS)
Fluoridation alone	14,085	294
Comprehensive dental care with fluoridation	729	44
Comprehensive dental care without fluoridation	333	18

SOURCE: See Table 1.

Introducing fluoridation programs in communities which do not possess them, will, for the same amount of money ($10 million), give us close to 300,000 fewer children in this condition, compared to the 44,000 or 18,000 fewer in the other programs noted. Fluoridation looks like a very attractive program. It is so attractive that it could be inferred that a program as cheap as this is not being inhibited by lack of financial support by the federal government; there are other factors at work.

One other program, additional funds on family planning, looked like a very good way to reduce not only the number of infant deaths but also the rate of infant mortality in high-risk communities.

Despite the information difficulties, several conclusions emerged clearly from the study. Two of these conclusions resulted in new legislation being requested from Congress. First, it seemed clear that a program of early case-findings and treatment of handicapping conditions would have considerable pay-off. It was also clear that if the large number of children who do not now have access to good medical care were to be provided with pediatric services, an acute shortage of doctors would be precipitated. Ways have to be found to use medical manpower more efficiently. The Social Security Amendments of 1967 include provision for programs of early case-finding and treatment of children with handicapping conditions.

These condensed discussions of some of HEW's applications of cost-benefit analysis to disease-control and child health programs illustrate both the usefulness and limitations of such analyses for decision-making. Issues are sharpened, and quantitative estimates are developed to reduce the decision-maker's uncertainty about costs and effects. Nevertheless, the multiplicity of dimensions of output and their basic incommensurabilities, both with costs and with the outputs of other claimants for public expenditure, still require the use of value judgments and political consensus.

The two studies described are concerned with reasonably narrow health objectives - control of specific diseases and maternal and child health. While the bundle of concepts known as "program budgeting" includes program analyses, the problems of determining allocations to the many programs and objectives of a Ministry of Health or of a whole society are not so conveniently handled. "Program budgeting" is a term used to describe efforts to develop insight and

information relating resources to program objectives and accomplishments. We need to know the resource requirements of each program, the accomplishments of each, and the relative social values of the program accomplishments.

There are numerous difficulties in determining these: Accomplishments may be multiple for any one program, of different dimensions from program to program, may be the result of more than one program, and may occur at a much later time than the application of resources. Accomplishments may be unknown and unidentified or difficult to predict. Accomplishments of changes in programs may be unknown or highly uncertain. Costs of programs, of program elements, and of changes in programs, may be unknown or highly uncertain.

Given the unknowns and uncertainties, what can be done? The answer, of course, depends on the particular situation - political, economic, and social of each society, but some general guides may be helpful.

First, I suggest that we examine criteria for choice. Economic analysis suggest four that might be of use.

1. Maximize benefits less costs.
2. Minimize costs of achieving our goal.
3. Maximize the social values of resources utilized.
4. Evaluate incremental gains against incremental costs.

It is unlikely that for any broad mix of health programs that we could use either of the first two criteria. The first requires that benefits and costs be measured in the same dimensions, so they can be additive. Usually this is impossible, and attempts to convert outputs of health programs to monetary numeraire have found little agreement.

The second criteria - minimizing costs of achieving goals is difficult if our goals are in more than one dimension. Health program effects impact on different sub-sets of the population - by age, socio-economic status, region, and time, and are measureable in reductions of deaths, pain, disability, fertility, uncared for populations, etc.

I believe we should concentrate on the last two criteria. The third criteria would start with a given budget over a period of time. Assuming that we had reasonable estimates of the costs of each program, we could select various strategies for allocations among programs which would have one thing in common - identical costs for resources used. We could then compare the strategies and programs and select that mix of programs we felt to be preferable. In making this decision, those responsible for decisions could take into account any information, judgement, or intuition they believed available and relevant. The preferred strategy may utilize cost-effectiveness analyses, but cannot be arrived at by any mathematical or analytical formula. It would have to take into account political, cultural and administrative realities.

Such an approach to program budgeting could be done at any budgetary level. And we would have some basis for using our fourth criteria - comparing the differences in costs and results of preferred program mixes at various budget levels - to demonstrate what differences there would be if our health budgets were increased or decreased.

I have included as an annex to this paper an example of such an approach to a wide array of health programs from work in which I recently participated in Indonesia. You might note Table 7 on its last page which

arrays half a dozen strategies each costing 100 billion rupiahs during the period of the next five years.

These very general statements and limited examples do not address all of the techniques, problems, and limitations to the application of program-budgeting to management of resource allocation decisions in national health planning. It is my hope that they are illustrative of some of the major issues, and that further, more specific, discussions can lead us to a better understanding of some approaches to improved decision-making.

ANNEX

ALTERNATIVE STRATEGIES FOR A 5-YEAR PROGRAM BUDGET - INDONESIA

In this discussion the programs and their outputs and costs are reviewed, using the "maximum" programs designed by the Task Force on Health Planning as the basis. As the total of these programs appears to be more than can be expected in the new five year development budget some alternative approaches are illustrated which outline some of the choices that must be made.

Programs have been divided into three broad categories:

1. Those aimed directly at designated priority health problems:

   - high fertility
   - ignorance
   - communicable diseases
   - nutrition
   - environmental sanitation

2. Programs concerned with the delivery of medical care:

   - Health centers, maternal and child health centers, polyclinics
   - General and special hospitals
   - Programs for mental, dental and eye health.

3. Support programs, such as food and drug control, training and education, laboratories, planning, research, etc.

Table 1 summarizes information on principal outputs and five year costs (investment and operating; central, provincial and kabupaten; donors) for the priority programs.

TABLE 1

Priority Programs	Output Indicators	Costs (Billions of Rps.)
Family Planning	6,000,000 acceptors	57
Health Education		6
Malaria Control		
Treatment	40,000,000 people	2
Spraying	15,000,000 houses	7
Smallpox control		
Vaccinations and Revaccinations	5,000,000 children each	2
Cholera and Gastro-enteritis		
Prevention of dehydration	720,000 patients	1
Rehydration	110,000 patients	1
TB		
BCG vaccinations	12,000,000 per year	1
Case finding and treatment	200,000 cases	2
Other CDC (yaws, DPT, polio, VD, leprosy, et al.)		3
Environmental sanitation		
Piped water	4,800,000 rural residents	9
Wells	20,000,000 rural residents	5
Latrines	2,375,000 rural residents	2
Nutrition		
Vitamin A	7,500,000 children	1
Supplementary feeding	130,000 children	
	TOTAL	99

The total costs of the priority programs is almost 100 billion rupiahs for the five years, but a substantial portion of this is estimated to be financed by donor agencies from overseas assisting countries. The total required to be financed by the Republic of Indonesia is then about 44 billions.

TABLE 2

Priority Programs	Rp. Billions		
	Total	Donors	R.I.
Family Planning	57	47	10
Health Education	6	-	6
Comm. Disease Control	19	1	18
Environmental Sanitation	16	7	9
Nutrition	1	-	1
TOTAL	99	55	44

The second broad category of programs, those for medical care make up the largest cost category of the three, 220 billion rupiahs for the five year period. Table 3 shows the operating costs and the investment costs of these programs; Table 4 shows the costs and services in terms of outpatient visits, inpatient days, etc.

TABLE 3

Medical Care Programs	Rp. Billions		
	Investment	Operating	Total
Health Centers, Maternal and Child Health Centers, Polyclinics	21	75	96
Health Type - D	14	53	67
Health Type - C	6	14	20
Health Type - B	7	8	15
Health Type - A	1	2	3
Health Type - E and Eye	2	4	6
Mental Health	2	7	9
Dental Health	1	3	4
TOTAL	54	166	220

TABLE 4

Medical Care Programs	Millions of Visits	Operating Costs (Bill. Rp.)
Health Centers		
MCH	37.5	11.2
Polyclinics @30 visits/day/center	735.8	52.2
MCH	12.9	6.7
Polyclinics @10 visits/day/center	171.3	12.9
	- - -	
	Millions of Inpatient Days	
Hospital		
D - rehabilitated	13.2	15.0
D - not rehabilitated	27.7	31.3
C - rehabilitated	9.9	14.0
B - rehabilitated	6.6	7.7
A - rehabilitated	1.3	1.9
E and Eye		3.9
Mental	12.8	6.9
	- - -	
Dental Health	5.9 million children treated in school; 40% reduction in disease	1.8
	20 million patients/ year treated	.8
	TOTAL	166.3

Support programs are shown in Table 5, which compares the estimates made for each program with the amounts expended during the first five year plan.

TABLE 5

Support Programs	Costs (Bill. Rp.) FIVE YEAR ECONOMIC PLAN I	II
Food and drug administration	.5	3.4
Epidemiological survey	.2	.6
Quarantine	.3	.6
Laboratories, Pusat and Daerah	.5	3.3
Upgrading and training	.6	.9
Institutional education	2.7	7.9
Research	.6	2.0
Planning	.3	.6
Management	.4	2.3
Physical facilities (doctors' housing)	.6	4.9
Overseas activities	.3	.6
Production	.5	.9
Libraries	.1	2.8
TOTAL	7.6	30.8

The requirements on the Republic of Indonesia are summarized in Table 6 by major program category and between central and regional budgets.

TABLE 6

	Billions of Rupiahs		
	Central	Regional	Total
Priority Programs	41	3	44
Medical Care Programs	68	145	213
Support Programs	30	1	31
TOTAL	139	149	288

With respect to regional financial responsibilities, almost everything is in medical care programs. Three billions in priority programs are the operating costs of rural environmental sanitation programs. The one billion in support programs are for the regional laboratories. The rest of the almost 150 billions is in operations of hospitals, health centers, and clinics. The levels and allocations of these regional expenditures are related not only to provincial and national policy decisions, but also to investment actions taken by the Central government Department of Health. Investment in hospital rehabilitation may result in substantial increases in hospital utilization and its costs, as may investment in MCH or Health Centers result in increasing operational costs for these facilities.

With respect to central government development budget during the next 5 years; it seems likely that the 130 billion rupiahs is considerably more than be obtained. Various estimates of what can be expected range from about 100 to 115 billion rupiahs, representing a required reduction of about 25 to 40 billion rupiahs for the five years.

I fear there is no automatic scientific black box which will give us the correct answer as to what changes and reductions to make. The decisions will flow from judgements about the relative values of programs from a technical medical sense, politics, social problems, and judgements of conformance to national objectives such as improved distribution of services to the masses of our rural population.

It should be feasible, however, to develop a number of possible strategies or policies of allocation all costing the same amount, say the "maximum" budget less about 40 billions, to start with a pessimistic prediction of the next five year plan allocations to health. Decision makers and advisors, both provincial and national could compare pairs of these hypothesized allocations and assert that one is preferred to the other (or that they are of equal value, in which case either would be acceptable). After this has been done to all interesting and possible strategies, we determine which is the most preferrable one.

I have outlined some of the dimensions of possible alternatives, and will set these before you for the purposes of initiating these discussions. I have used the assumption that the maximum levels in the Health Planning Task Force's position papers are to be the objects of comparison, and have more or less accepted them as internally already optimized.

Table 7, at the end of the paper summarizes the specific budgetary changes for each of the strategies considered. If we designate the "maximum" budget as Program I, and look for ways to reduce the five year expenditure levels by 40 billion rupiahs, then Program II might:

- Eliminate the construction of buildings in the Health Centers. program, but procure equipment.
- Reduce hospital investment to only a demonstration and evaluation program, designed to yield information on the actual relationships between hospital physical rehabilitation of improvements in utilization. These relationships have been assumed by the hospital program, but seem highly uncertain.
- Support programs would be reduced to half of the projected levels, which would be about twice the first five year plan level.
- Priority programs would be supported at the maximum levels projected. CDC, nutrition, family planning, and environmental sanitation. With the possible exception of health education, we are relatively certain of their results, they seem highly effective relative to their costs, and large masses of the population are covered. Medical care investment would be restricted to health centers.

Program III would take a very different approach:

- Focus central government development funds on building a hospital referral system and on the "priority programs".
- Eliminate all investment in health centers.
- Eliminate investment in rural hospitals.

- Reduce communical disease control by two billions (largest priority program)
- Cut support programs in half.

Program IV, with a still different strategy, would focus on mass primary medical care in the health centers and rural hospitals, and upon the priority programs. In this case the opportunity cost is sacrificing all referral hospital investment, and cutting support programs even further.

- Focus central covernment development funds on:

  health centers
  Rural hospitals (D)
  Priority programs

- Cut all new investment in A,B,C,E, and mental hospitals.
- Cut support programs by 2/3.

Program V would generally support the hospital construction program, but at the cost of health center investment and sharp reductions in priority programs and support:

- Cut health education by 1/3
- Cut CDC by 1/3
- Cut environmental sanitation by 1/3
- Eliminate health centers capital investment
- Cut support by 2/3
- Focus central budget on support of hospital program construction

Program VI keeps support programs at a considerably higher level than the other alternatives, on the assumption this is a major central ministry responsibility, cuts into hospital investment sharply, and

somewhat into PusKesMas investment and priority programs. The relatively larger cut in Health Education is on the assumption that this program of training educators and preparing materials for media is not really as significant to educating the public as the direct contact work of the health center personnel.

- Cut health education by 1/3
- Cut CDC by 1/6
- Cut health centers investment in construction partially
- Cut investment sharply in all hospital programs
- Cut support by 1/3

Program VII and other alternatives I leave to your fertile imaginations.

TABLE 7

Central Government
1975-1979

Program mix (Bill. Rps.)

PROGRAMS	I (max.)	II	III	IV	V	VI	VII	VIII
Family Planning	9.5							
Health Education	6.5			-2.0	-2.0	-2.0		
Communicable Disease Control	18.1		-2.0	-1.1	-6.0	-3.8		
Environmental Sanitation	6.4				-2.0			
Nutrition	1.3							
Health Centers	17.4	-6.0	-10.0		-10.0	-2.7		
Polyclinics	3.1							
Maternal & Child Health	2.2							
Hospitals - D	13.4	-10.0	-13.0			-7.5		
Hospitals - C	3.1	-2.0		-3.1		-2.0		
Hospitals - B	7.6	-7.0		-7.6		-7.0		
Hospitals - A	3.4			-1.8		-1.5		
Hospitals - E & Eye	3.6			-1.5		-1.5		
Mental Health	9.2			-2.0		-2.0		
Dental Health	2.8							
Support Programs	30.8	-15.0	-15.0	-20.3	-20.0	-10.0		
	140.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0

B. Structuring the Analysis of Specific Disease Oriented Programs[1]

The analysis begins with epidemiologic considerations of the problem identifying, crudely, the biological - functional states an individual possesses and the probability of moving to another state (states are precurser, infection, disease, and consequence) in the absence of public health intervention. Standard health indices give modest clues to estimating the proportion of population in these states and the flows between them. Some researchers have attempted to quantify the transitional flows utilizing Markovian analyses.[2] A fuller discussion is found in section III-C-II of this paper.

Next, public health strategies are conceived. A strategy is a series of possible actions (preventive, promotive, or therapeutic) to efficiently modify the risks of moving to a worse state. Thus, epidemologic effectiveness represents the influence of a specific technique on the community at large (expressed, perhaps, in terms of new cases prevented), in contrast to clinical efficacy, applying to individuals (measured by controlled clinical trials.)

Applying the technology is constrained, obviously, by the availability of resources. In implementing services, human, material, and financial resources are used and they are constrained.

Costing methods aid in revealing the total expenditure needed to perform an activity in terms of the total resource costs including manpower estimates by function (time required, estimated cost/unit time), total bed-days required, and a very rough work load (population at risk) - possibly estimates of urban versus rural symptomatics.

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[1]. This section is a summary adapted from M. Feldstein et. al, "Resource Allocation Model for Public Health Planning", WHO supplement to Vol. 48 of the Bulletin of the World Health Organization. (1973). See also Section III-C-I of this paper.

[2]. T. Dahl, "Operations Research on Health Care in Chile: An Experiment," International J. of Health Services, Vol 1 #3, (1971), p. 271.

Given we have (1) a grasp on the epidemiology of the problem, (2) alternative ways we can tackle the problem, and (3) a knowledge of what we have and will have (in the near term) in resources to tackle the problem, assessing potential benefits of alternative strategies is a crucial factor in health-sector resource allocation. Measurement of the benefits (outcomes) ranges from controlled trials, essentially clinical, to obtain direct health benefits to individuals to epidemiological simulation, expressed in future cases prevented, where the community fares better-off than the sum of the individuals treated. Obviously, effectiveness varies and estimating the marginal effectiveness of control strategies in different settings is most difficult.

Valueing the benefits to health is often considered as a "human capital" investment within the overall economic development process. Public health programs affect the availability of labor, productivity of labor, accumulation and productive use of capital, and population growth. Population growth, in turn affects the economic dependency ratio and the national per capita income. This investment is a slow process with lags generations long making association difficult. The role of health services in improving human capital is confounded by the role of independent and "synergistic with health" factors such as better housing , education, nutrition, water supply, etc. Thus, there are multiple inputs to be utilized to improve health. Likewise health service investments produce outputs related to an improved rate-of-return on educational investments and general manpower development in that poor health is wasteful-- more people must be trained.

In addition to the role of ill health on labor, its role on capital is similarly assessed. Poor health resulting in low national income results in low savings resulting in low investments and capital growth possibilities.

Less clearly understood is the impact of ill health on population growth. Some treat illness as the classic "Malthusian Check" as excess morbidity and mortality within the ages of reproduction reduces further births. Alternative theories postulate ill health resulting in a higher population rate. If per capita income increases with better health, family size decreases and vice versa - if lower health reduces income, family size increases. Allied to the theories is the concept of "desired family size" or the number of surviving births (sons). Low survival probability increases parents' uncertainty about their children's survivability. Thus, valueing the effect on national income by instituting a health program is complicated. The common approach involves valueing gains in productive worktime through reductions in disability, absenteeism, and loss of capacity through impairment and death. Reduced bed-days, while implying a corresponding gain in productive work days, is often hampered by legal, social or insurance restrictions interfering with immediate work resumption.Reductions in premature death results in an increase in productive work years; however, using ave.life expectancy to value the gain is hampered by the exposure of an individual to death from disease of another cause. Also,impaired workers can be shifted to other jobs and productive work-time does not have to be totally lost.

Social benefits also accrue from improved health. The CENDES method uses life expectancy as the criterion for health planning decisions. This implies no "weight" for reduction in impairment and to productivity gains. Others have considered the discounted present sum of "Years of healthly living" as the social benefit.

EXAMPLE 2
APPLYING THE CHOLERA MODEL

First, the natural infection course of the disease is simulated. It is next interfered with by combinations of preventative and curative measures any of which decrease new cases. Generally, sanitation improvements reduce the force of infection, immunization reduces the number of susceptibles for a short period, and chemoprophylaxis, the number of new infectives. The model simulates the effects of the interplay of these measures to show the effectiveness of preventative measures (Figures 1-4). This cost-benefit analysis examines the prevention and treatment costs compared with treatment costs with no prevention measures taken. The program producing the greatest reduction in incidence given a fixed budget (or the program achieving a set target at least cost) is preferred.

To add realism, endemicity and epidemics are simulated. During endemics, the disease spreads through the increase in infection, peaks, and then declines as the number of susceptibles diminishes, first gradually, then rapidly (the dynamics of any endemic curve). Oscillations around the descrete cycle is due to variations in climate and population movements. The epidemic curve sharply rises with the introduction of infection followed by a less rapid decline often the force of infection has again dropped to zero. A contaminated water or immigration of cases and/or carriers or both might be the trigger. Chain reactions can start in other areas due to migration (for example the 1973 Italian outbreak). Thus rapid chlorination does not end the epidemic as contacts keep the outbreak from abruptly ending. Figures 1-4 display the dynamics and alternative patterns of cholera incidence.

Conducting the Simulations

Preventive measures -- endemic area

Vaccines at 70% effectiveness are given 30 days prior to the seasonal rise to 75% of the population resulted in a 17% incidence decrease. For U.S. $750,000 spent, 2040 cases were prevented in a 10 year period or $368/prevented case. Thus against a background of high stable endemicity, there are small benefits in terms of cases prevented and economic benefit.

In comparison, prevention of one case through sanitation costs about $29 with the total investment over a period of years less than any other preventative measure. While improved sanitation has a long-lasting effect, it cannot be immediately implemented.

Chemoprophylaxis while very inexpensive is not very effective. The simulated cost/ case prevented is $77.

Combinations of programs show large variability. Sanitation plus vaccination costs $83; chemoprophylaxis plus vaccination cost $163; and sanitation plus chemoprophylaxis cost $28.

Cost-effectiveness and cost-benefit analysis

Judging the simulations by "reduced incidence" only is unacceptable. Relative costs that are feasible and benefits other than reduced incidence should be taken into account. Table 1 values costs and benefits. Choice of strategy depends on resources available. If $200,000 is available sanitation can be applied. However, the relative cost/prevented case has also to be considered (col, 11). Also as relatively expensive measures may accrue additional benefits (sanitation will prevent other enteric and diarrhoeal as well as promote tourism), "one-disease" oriented

cost-benefit analyses should be made from a wider point of view. Benefits can be calculated on the basis of savings on treatment of prevented cases net the cost of preventive measures. Examining col 12 of Table 1 , one would choose sanitation either alone or combined with chemoprophylaxis, since these measures are economically the most beneficial and require the least investment. Chemoprophylaxis is the cheapest measure requiring the least investment, but the return is low (see columns 2 and 3). Thus sanitation is the strategy of choice. If "saved lives" were accounted for, further financial benefits would accrue.

In that all "net benefits" are negative, one logically could apt for the first alternative, doing nothing. However, three alternatives are close enough to zero, and, if additional benefits were identified and valued, economic justification for proceeding with a cholera program would exist.

Fig. 1. CHOLERA DYNAMICS - FLOW CHART

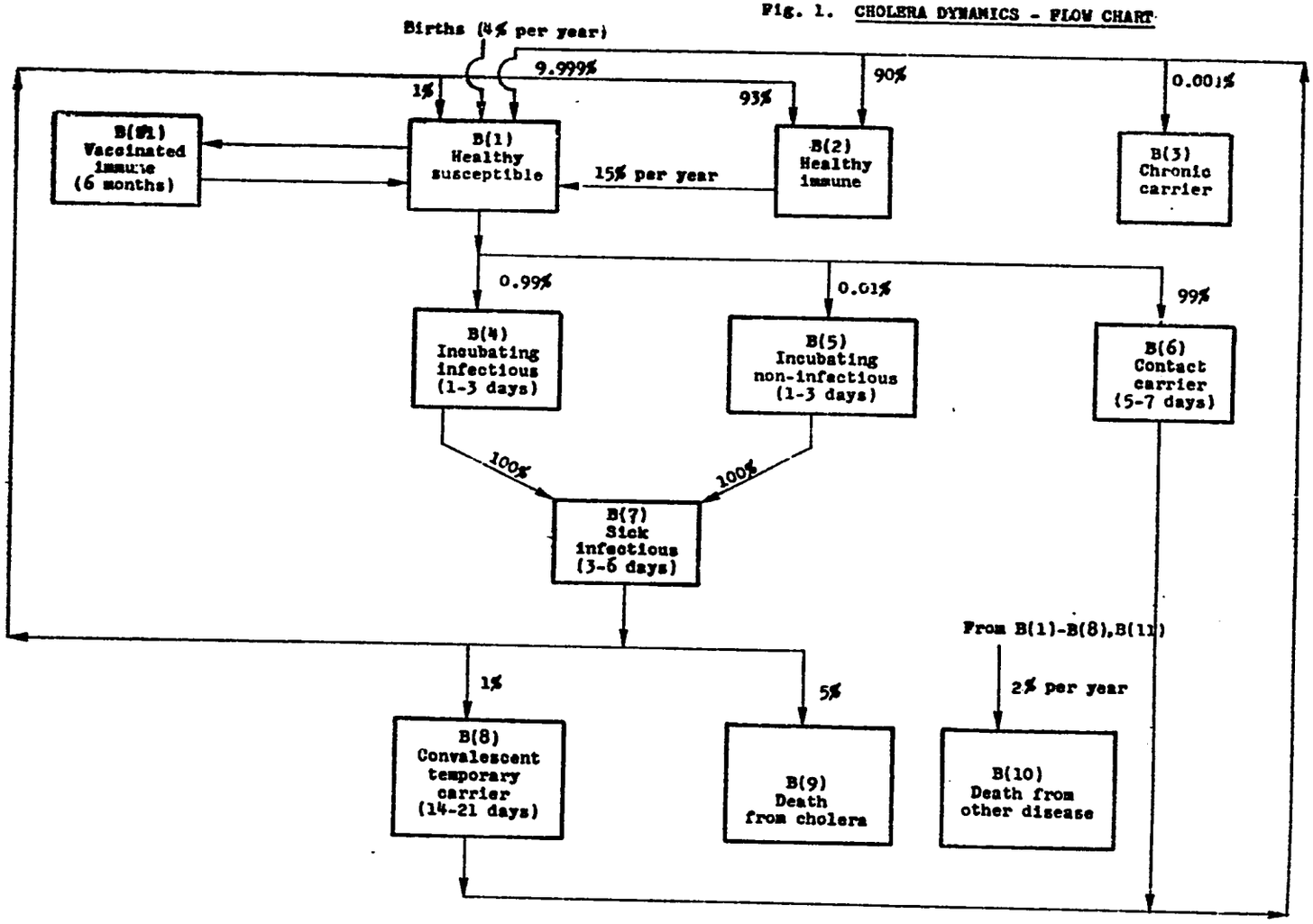

FIG. 2. ENDEMIC PATTERN OF CHOLERA WITH SEASONAL INCREASE OF INCIDENCE

(without application of any preventive measure)

Population: 1 000 000; Force of infection = 2.0 during high season
= 1.0 during low season

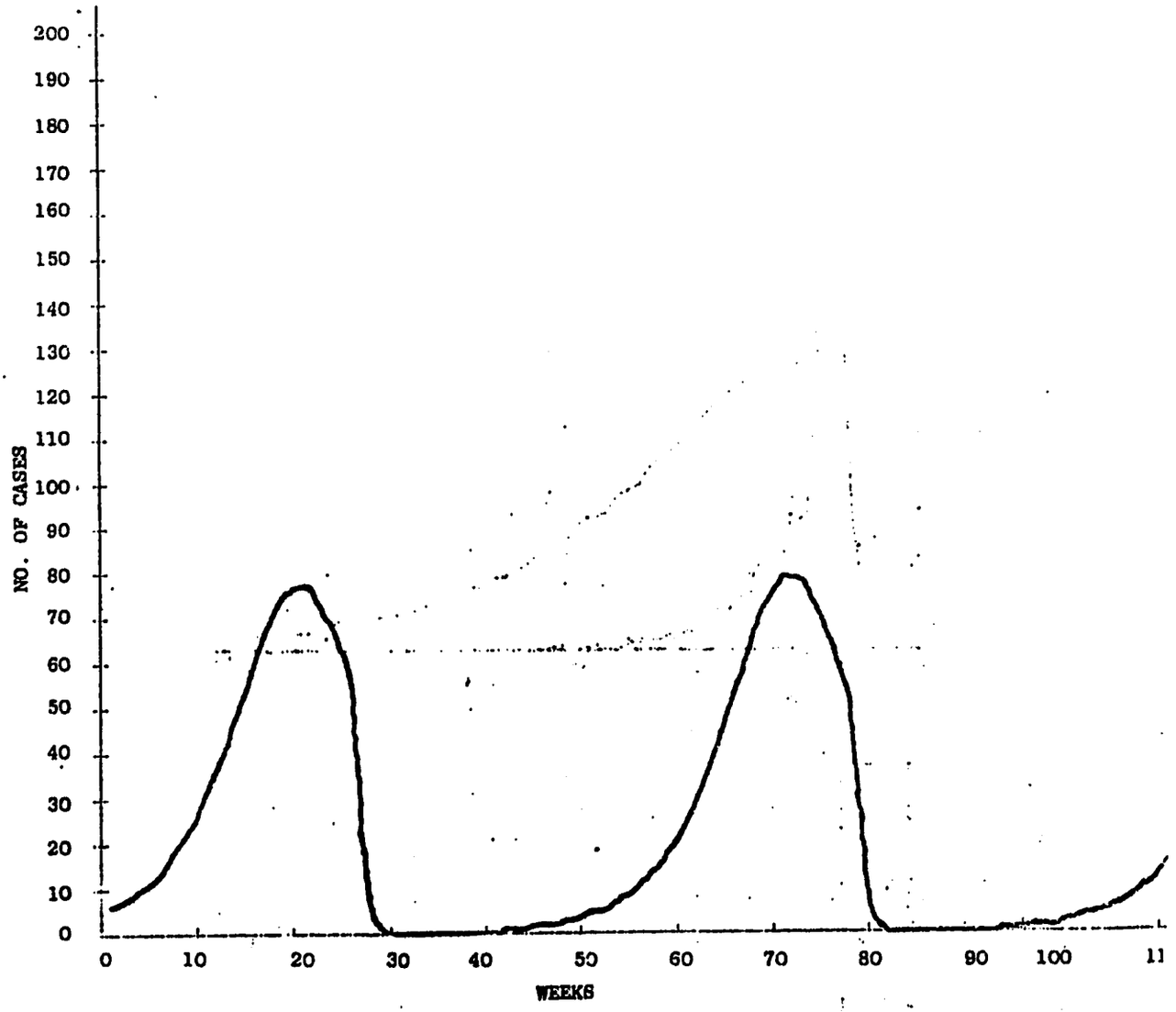

FIG. 3. EXPLOSIVE WATER-BORNE EPIDEMIC PATTERN OF CHOLERA IN ENDEMIC SITUATION

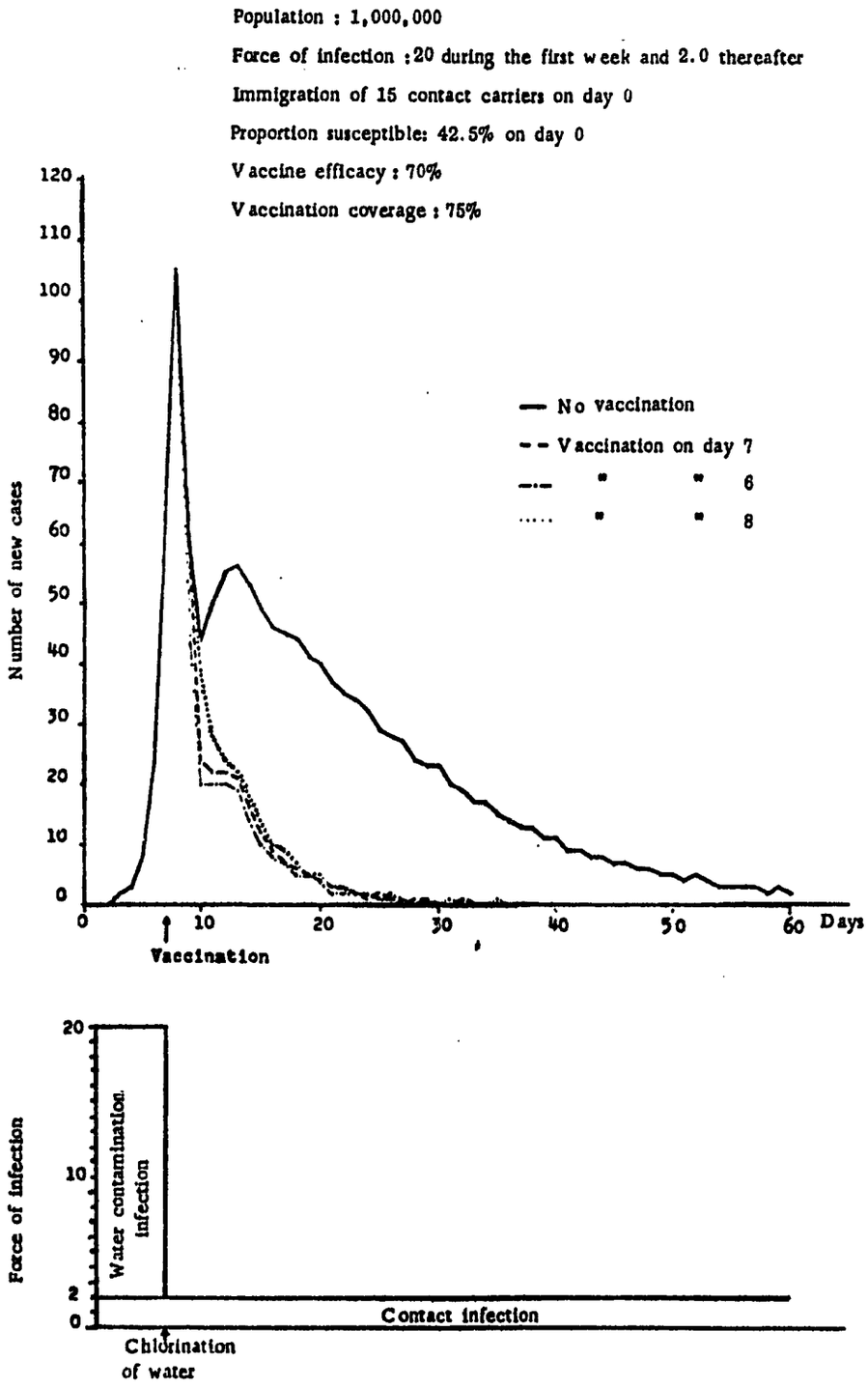

FIG. 4. EXPLOSIVE WATER-BORNE EPIDEMIC PATTERN OF CHOLERA IN NON-ENDEMIC SITUATION

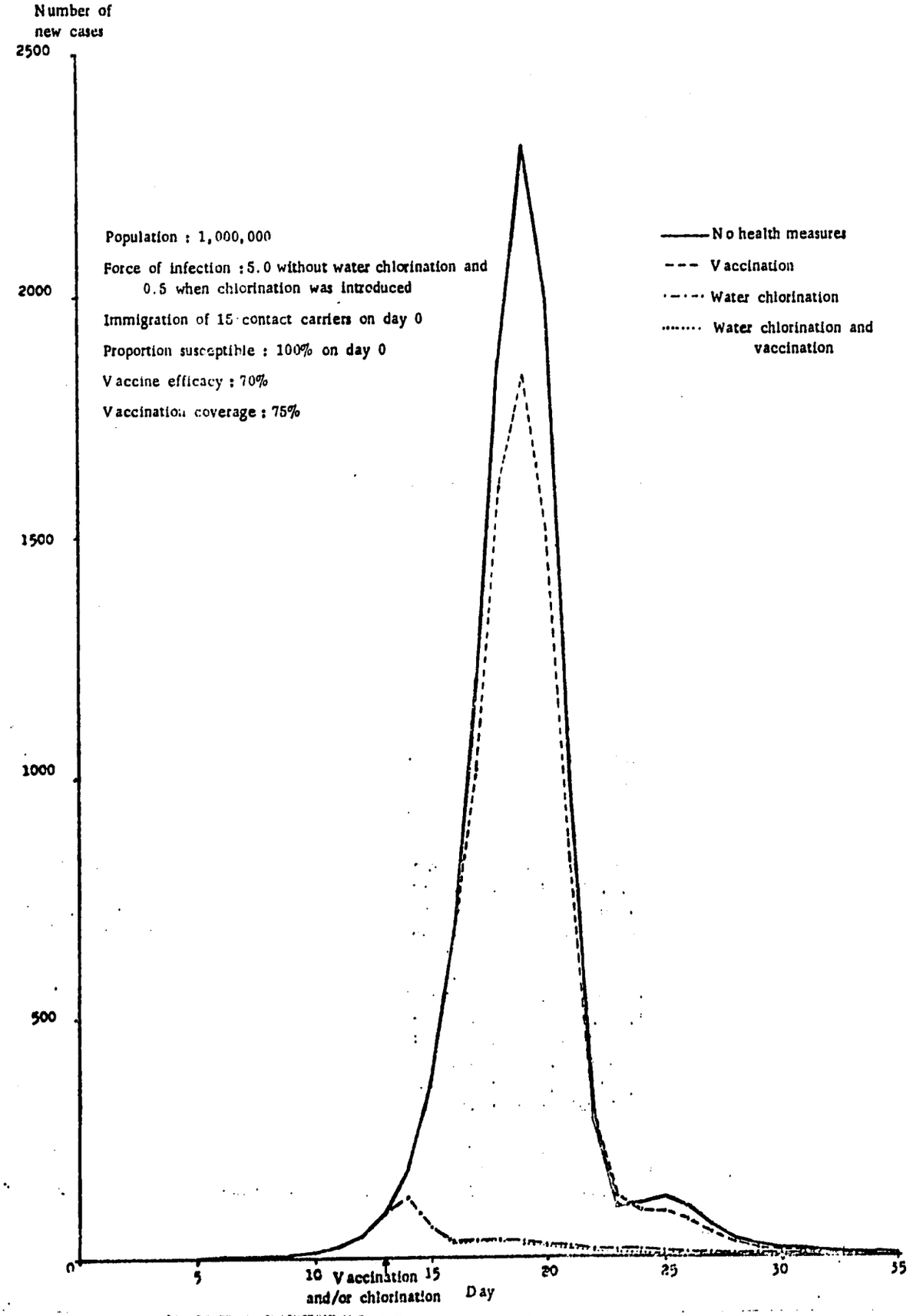

TABLE 1. THE TOTAL NUMBER OF CASES AND COSTS OF TREATMENT AND CONTROL MEASURES OVER 10 YEARS

Control measure	(1) No. of cases	(2) No. of cases prevented	(3) % of cases prevented	Cost per million population in $							(11) Cost per one prevented case of cholera (9)/(2)	(12) Benefit (+) or loss (-) resulting from preventive measure(s) (5)-(9)
				(4) Hospital treatment	(5) Hospital treatment saved	Preventive measures				(10) Total expenditures (4)+(9)		
						(6) Vaccination	(7) Sanitation	(8) Chemoprophylaxis	(9) Total cost of prevention			
1. None	11984	0	0	323 568	0	0	0	0	0	323 568	0	0
2a. Vaccination (regular)	9944	2040	17	268 488	55 080	750 000	0	0	750 000	1 018 488	368	-694 920
2b. Vaccination (ad hoc)	6658	5326	44	179 766	143 802	825 000	0	0	825 000	1 004 766	155	-681 198
3. Sanitation	4970	7014	59	134 190	189 378	0	200 000	0	200 000	334 190	29	-10 622
4. Chemoprophylaxis	11818	166	1	319 086	4 482	0	0	12 822	12 822	331 908	77	-8 340
5. Vaccination (ad hoc) & sanitation	572	11412	95	15 444	308 124	750 000	200 000	0	950 000	965 444	83	-641 876
6. Vaccination (ad hoc) & chemoprophylaxis	6397	5587	47	172 719	150 849	825 000	0	83 891	908 891	1 081 610	163	-758 042
7. Sanitation & chemoprophylaxis	4725	7259	61	127 575	195 993	0	200 000	5 974	205 974	333 549	28	-9 981

Example 3

COST-BENEFIT ANALYSIS OF MALARIA CONTROL IN INDONESIA

Introduction

This attempt to analyze and compare the costs and benefits of the proposed Malaria Control Program (MCP) will largely restrict itself to the analysis of the tentative proposal made by CDC to USAID and its associated costs. No attempt will be made to evaluate the previous Malaria Eradication Program (MEP) in terms of its relative costs and benefits since such an exercise would have no practical policy implications at the present time.

The analysis will examine the two alternatives of the proposed intensified control activity and the alternative presented by the Review Team for the islands of Java and Bali.

The analysis will treat separately the proposed control programs for Java and Bali and the Outer Islands. This division is due to the greater effect upon malaria and the subsequent greater economic benefits to be expected from the activities in the Outer Islands.

In the event that the analysis indicates that the costs of the proposed program exceed the benefits, other alternatives will be explored to see if some intermediate level of malaria control activity can be justified economically on the basis of its effect on agricultural sector productivity.

Method of Analysis

Cost-benefit analysis is simply a planning process by which costs of a proposed program are compared to the probable benefits to be derived from the program. In applying this process to health sector programs as in other investments in human capital, certain problems occur both in the quantification of costs and of benefits. In the case of malaria control, a sufficiently ample and documented experience exists from which fairly accurate cost estimates can be drawn. Other portions of this report will evaluate the appropriateness of the specific budget plan of the Indonesian Ministry of Health. The cost estimates used in this analysis will incorporate any modification resulting from the budget evaluation. A general review of cost-benefit analysis or its application to health sector programs will not be given in this paper. Instead, readers are referred to references cited at the end of this section.

In malaria control programs, as in many other health programs, the conceptual area of benefits is quite broad and includes benefits of several diverse types. The analysis presented in this report will limit itself to the economic benefits to be derived from malaria control, i.e., those benefits whose quantification can allow the government and assistance

agencies to compare the returns from investment in malaria control to investments in other projects. This limitation of the analysis to these variables which impact directly on national economic development should not be interpreted as a claim that no other personal, political or social parameters are involved in malaria control. Instead, it is an attempt to outline the opportunity costs of decisions made on these criteria in terms of their impact on national income. The evaluation of the social and humanitarian benefits is left to those qualified to make them, the national government.

Limiting the analysis to the economic aspects also can be sufficient from the point of view of the public health professional. Sufficient experience exists in presently developed countries to clearly show that the major portion of improvements in health of populations were the result of a rising standard of living rather than the result of specific health interventions. Thus, one of the tasks of the health planner and health economist become the analysis and presentation of health sector projects which may enhance general economic development.

The economic benefits to be derived from malaria control are several. The two main categories of benefits are the avoidance of future costs of prevention, treatment or rehabilitation from disease and the decreased effects upon labor force productivity of illness or premature death.

The future costs avoided by an intensified malaria control program include (1) costs of treatment and hospitalization of malaria cases; (2) costs of excess caloric requirements of individuals suffering from febrile diseases; and (3) costs of control of malaria if eradication can be achieved or control at a lower level can be maintained more cheaply than at the previous level of control.

The increase in agricultural sector productivity may be of two types. The first and most common is the increase in productivity due to making available a larger portion of the labor force by reducing debility from malaria. In other terms, the intermediate good of health is valued in terms of its effect on a final good, productivity.

The appropriate evaluation of the increased labor supply is obviously the marginal wage paid to labor. A second particular case is when new areas of a country may be opened to agricultural exploitation as a result of malaria control. In this case, all the benefits which accrue to the investment of labor in these areas are attributable to the malaria control program.

The cost-benefit ratio will be calculated by the equation:

$$\sum_{t=1}^{T} \frac{(Pt)(Bt)}{(1+i)^t} \left(\sum_{t=1}^{T} \frac{0}{(1+i)^t} + K \right)^{-1}$$

where B_t = benefits received in year t
O = operating maintenance and routine replacement incurred in year t
K = fixed or initial investment
i = discount rate
t = life of project
P_t = operational probability of accomplishing predicted benefits in year t.

Certain economically quantifiable benefits or disbenefits are beyond the scope of this cost benefit analysis due to lack of time and resources to take them fully into account and carry out the more rigorous analysis required when the general equiliberium conditions are modified. These variables are (1) employment engendered by an expanded control program; (2) effects on distribution of wealth by distributing in-kind health services; and (3) effects of population increase secondary to malaria control on growth of national income. Estimates will be presented concerning the probable magnitude of these variables so that the Mission can consider them and compare their implications with the economic implications presented in this paper.

Synopsis of the Current Malaria Situation and the Proposed Control Program

At the time of cessation of malaria eradication activities in 1965, annual malaria incidence on Java and Bali had fallen from its past WWII level of 300 cases per thousand to approximately .25 cases per thousand. Since 1965 malaria incidence increased at an expected exponential rate to a level approximately 20 times its 1965 low by 1969. At that time, limited control measures were undertaken which may have halted what otherwise might have been a further marked increase in cases. The limited control measures introduced have achieved control at an approximate level of 5.3 cases per thousand.

This level of disease has been maintained for the past 3-1/4 years at an approximate annual cost of 1,441,000,000 rupiah (79% of development budget + 95% of routine budget of MCP supports activities in Java and Bali). (Note: All budgets or expenditures projections in the remainder of this paper will include both the development and routine budgets. What effect natural and other factors contributed to the relative stability of disease incidence is not known.)

Table 1.

Expected Malaria Cases in 6 Years of the Expanded Malaria Control Program

Year	Expected Cases
1972	400,000
1973	272,000
1974	184,000
1975	124,000
1976	84,000
1977	60,000
1978	40,000
All subsequent years	40,000

The proposed program will involve an additional expenditure of Rp. 10,382,000,000 over 6 years for Java and Bali. The predicted result of the expanded control program will be a control level for malaria in the range .5 - .6 annual cases per thousand. (See Table 1 for intermediate malaria levels.) This level can be maintained by an annual expenditure of Rp. 963,000,000 annually. This estimate is derived from data which shows for East Java that with the diminished incidence one could expect malaria to be confined to 1/3 its previous area. This may well be a substantial understatement of the required maintenance cost due to the probability of large numbers of imported cases from the outer islands. In fact, the maintenance cost at the new control level conceivably could exceed the cost of the present control level.

An important aspect to keep in mind during the remainder of this discussion is that malaria control is characterized by rapidly decreasing returns for expenditures. This is demonstrated in that by an expenditure of 158 million dollars U.S. from 1952 to 1965 malaria incidence was reduced from 300 cases per thousand to .25 cases per thousand. Now, to reduce malaria from 5.3 cases per thousand to .5 cases per thousand will require an expenditure of about 22 million dollars U.S.

Both the present malaria situation and proposed program in the Outer Islands are considerably different from those of Java and Bali. The disease has reverted to its original mesoendemic state and annually effects some 15% of the population of the Outer Islands. Although little information exists concerning mortality from malaria, the disease probably is directly or indirectly incriminated in a small portion of deaths in the Outer Islands. Malaria appears to have almost no effect on mortality or fertility in Java or Bali.

The annual cost would be Rp. 1,620,000,000 for the Outer Island program.

Transmigration projects, estimates and regional development projects are to be granted first priority. The results of this activity are not as predictable (due to lack of previous experience to extrapolate from) as in

Java and Bali, but a conservative estimate would be that malaria incidence would be reduced to 50 cases per thousand annually and maintained at that level. There is sufficient uncertainty concerning the estimates of incidence of malaria and probable effectiveness of DDT; however, that some research into these parameters is indicated prior to undertaking a large scale program.

Estimation of the Magnitude of the Benefit Parameters of Malaria Control in Indonesia

For those patients who are treated by the active surveillance workers or who obtain antimalarial drugs from private or commercial sources, the cost of treatment of approximatley Rp. 50.

Patients who receive treatment from outpatient clinics or polyclinics for malaria incur personal or governmental costs of approximately Rp. 300.

Those patients who require hospitalization usually remain for 7 days for an average cost of Rp. 10,500.

Individuals who suffer from any febrile disease have excess caloric requirement. In malaria, the excess caloric intake required daily is 400 kilo calories or 100 grams of carbohydrates for an average of 10 days in cases of treated malaria. The value at current prices of 1 kg. of rice is Rp. 40.

The value of time lost from agricultural endeavor is very difficult to quantify in a society with significant unemployment or underemployment as in Java and Bali (stated to approach 30% of available labor supply). Two values are suggested: (1) An average opportunity cost of Rp. 50 per day is assigned to marginal labor since some studies have indicated that work for food programs can attract labor for goods with this value and public works projects can attract workers for this value; and (2) Assign a 0 marginal wage to additional labor for most of the year, but to assign a value of Rp. 70 as the marginal wage during rice harvesting season.

The average implied wage in the agricultural sector in Indonesia as a whole is approximately Rp. 80/day, but the marginal wage would be expected to be lower and further depressed in Java and Bali due to the oversupply of labor on these two islands. If a value other than 0 is appropriate, using an annual marginal wage of Rp. 50 or a seasonal fluctuation from 0 to Rp. 70 would yield similar results since malaria is at its peak incidence during rice harvest season.

The value of future labor lost due to premature death will be valued at the discounted marginal per capita value added in the agricultural sector (Rp. 15,000 annually). The liability of adding an additional

person to an already oversupply of labor will be presented in terms of its impact on rate of population increase. It would seem, however, that there would be few conceptual problems involved with assigning a positive value (magnitude somewhere between 0 and Rp. 50 per day) for loss of productivity due to premature mortality in adults since these individuals no longer make significant demands on social overhead investments.

In the case of infants, it may well be the case that the required social overhead investments outweigh the loss of productivity implied in premature death. For the purposes of this analysis, however, the benefits assigned to this parameter are so small in comparison to the other parameters that even assigning a modest negative value would not change the B/C ratios to less than or greater than unity.

It will be assumed for the sake of simplicity that the average wage in the agricultural sector does not vary with age or sex between the ages or 15 and 65.

There appear to be no areas in the Outer Islands which are not exploited due to uncontrolled malaria. Even in areas where malaria prevalence is quite high, colonies are transmigrated and it is quite uncommon to hear an example mentioned of a colony which failed due to health reasons. Therefore, again the marginal value of labor will be utilized as the value for additional days productivity added to the labor force. Due to a smaller supply of labor in the Outer Islands, the value of additional labor is higher than on Java and Bali and is at least Rp. 130 per day. This is a conservative estimate based on wages paid to temporary employees on estates and in some instances in Lampung a wage of 300-400 rupiah a day is required to obtain labor for public works projects.

While no accurate data exists concerning mortality from malaria in Indonesia, certain estimates of number of deaths due to malaria were generated on the basis of Ceylon data and its analysis in Malaria Eradication and Population Growth by Peter Newman. The equation used for infant malaria mortality was equal to .3453 x malaria prevalence = deaths from malaria per 1,000 population in age group 0-1 = 165 deaths for Java and Bali.

For adults the generating function was .0239x malaria prevalence = deaths from malaria per 1,000 population in age group 10-45 = 136 deaths.

A rather conservative discount rate of 18% is chosen. The market interest rate on long-term loans is somewhat above this figure but this is the rate at which consumers appear to be willing to forego present consumption for future consumption (1 year time deposit rate). The argument might be made that the social discount rate should be lower if the rate of capital investment is suboptional. Unfortunately, the author has not had sufficient time or exposure to the Indonesian economy to make a judgment on this aspect.

In discounting future benefits due to the avoidance of premature mortality, the discount rate is modified by the assumption of a 5% annual increase in labor productivity. This modification yields a net effective discount rate of 12.4%.

Table 2.

Calculation of Benefits from Expanded Malaria Control Program in Java and Bali (in thousand rupiah)

Program year	a Avoided Malaria cases see Table 1	b Value of Avoided labor loss 1)	c Value of Avoided calorie loss 2)	d Value of Avoided treatment costs 3)	e Value of Avoided clinic costs 4)
1973	128,000	65,600	5,120	6,420	3,100
1974	216,000	116,900	8,640	10,860	5,340
1975	276,000	156,000	11,040	13,860	6,820
1976	316,000	188,800	12,640	16,500	7,810
1977	340,000	211,200	13,600	17,100	8,400
1978	360,000	234,400	14,400	18,120	8,900
All subsequent years		1,876,000	115,200	144,840	71,300
TOTAL		2,848,900	180,640	227,700	111,750

	f Value of Avoided hospitalization costs 5)	g Value of Avoided mortality in adults 6)	h Value of Avoided mortality in children7)	i Value of Avoided absenteeism from school8)	j Decreased future control costs 9)
1973	8,000	19,200	5,200	15,400	
1974	13,100	32,800	8,800	26,000	
1975	16,600	42,400	11,600	34,200	
1976	19,200	48,000	13,200	38,900	
1977	20,600	52,400	14,000	41,300	
1978	21,800	55,200	14,800	43,700	
All subsequent years	174,000	441,600	119,600	353,000	3,850,000
TOTAL	273,300	691,600	187,200	552,500	

1) Value of Avoided labor loss =

$\sum_{t=1}^{T}$ Total number of cases avoided t x .50 (portion of population of working age) x Rp. 50 (Avg. marginal wage) x 20.5 (Avg. number of days disability) x $(1+i)^{-t}$
(See Table 3 for values)

2) Value of Avoided calorie loss =

$\sum_{t=1}^{T}$ Total number of cases avoided in year t x 5 (length of febrile treated malaria) x Rp. 40 (value of excess calorie consumption per day) x $(1+i)^{-t}$

3) Value of avoided treatment costs =

$\sum_{t=1}^{T}$ Total number of cases avoided in year t x .67 (that portion of patients being treated outside clinic facilities) x Rp. 50 (cost of course of treatment) x $(1+i)^{-t}$

4) Value of Avoided clinic costs =

$\sum_{t=1}^{T}$ Total number of cases avoided in year t x .33 (portion of malaria cases treated in clinics) x Rp. 300 (cost per clinic visit) x $(1 + i)^{-t}$

5) Value of avoided hospitalization costs =

$\sum_{t=1}^{T}$ Total number of cases avoided in year t x .006 (estimates of portion of cases treated in hospital) x 7 days (average course of treatment for malaria) x Rp. 1,500/day x $(1+i)^{-t}$

6) Value of Avoided mortality in adults =

$\sum_{t=1}^{T}$ Death avoided in year t $x^{65}_{j=35}$ survivorship to year j (see table 1) Rp. 15,000 (marginal wage in agriculture sector x $[i + i]^{-t}$ x $(1+i)^{-[j-35]}$)

7) Value of Avoided mortality in children =

$\sum_{t=1}^{T}$ Deaths avoided in year t $x^{30}_{j=0}$ survivorship to year j x Rp. 25,000 (average wage in agriculture sector) x $(1+i)^{-t}$ x $(1+i)^{-j}$

8) Value of Avoided absenteeism from school =

$\sum_{t=1}^{T}$ Cases avoided of malaria in year t x .374 (% malaria cases in age 5-15) x .55% population age $5\text{-}15^{45}_{j=10}$ attending school x survivorship to year j x Rp. 2,500 (additional annual wage imputed to completing 1 year of elementary school) x $(1+i)^{-t}$ x $(1+i)^{-(j-10)}$ x .10 (portion of school year missed due to absenteeism for case of malaria)

9) Decreased future control costs =

$$\sum_{t=1}^{T} \text{Original control costs} - \text{future control costs in year } t \times (1+i)^{t}$$

Table 3.

Net Effective Discount Rate
Discount Rate (12.4%)[x]

Year		Year	
1	.889	15	.173
2	.790	16	.154
3	.704	17	.137
4	.627	18	.122
5	.557	19	.109
6	.493	20	.097
7	.441	21	.085
8	.392	22	.076
9	.348	23	.068
10	.311	24	.060
11	.276	25	.054
12	.246	26	.048
13	.219	27	.043
14	.195	28	.039

Table 4 Life Table

Percent Survival for Five Year Cohorts at Given Age

	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65
15	.836	.936	.976										
16	.820	.918	.957										
17	.815	.912	.952										
18	.810	.907	.946	.995									
19	.805	.901	.940	.990									
20	.800	.896	.934	.984									
21	.789	.883	.921	.967									
22	.775	.867	.906	.950									
23	.760	.851	.888	.933	.982								
24	.745	.834	.870	.916	.963								
25	.732	.819	.854	.898	.944								
26	.724	.811	.845	.889	.935								
27	.716	.802	.836	.880	.925								
28	.707	.791	.825	.868	.914	.987							
29	.699	.783	.816	.858	.903	.976							
30	.690	.772	.806	.848	.892	.964							
31		.764	.796	.838	.881	.952							
32		.755	.787	.828	.870	.941							
33		.747	.779	.817	.859	.929	.988						
34		.739	.771	.807	.849	.917	.975						
35		.732	.763	.796	.838	.905	.961						
36			.751	.785	.826	.892	.948						
37			.739	.773	.813	.878	.934						
38			.727	.760	.800	.864	.918	.984					
39			.715	.747	.786	.849	.904	.966					
40			.703	.734	.771	.834	.887	.950					
41				.720	.767	.818	.870	.932					
42				.707	.743	.803	.854	.913					
43				.694	.729	.788	.838	.897	.981				
44				.680	.716	.773	.822	.881	.963				
45				.667	.702	.758	.806	.864	.944				
46					.685	.740	.786	.843	.922				
47					.668	.722	.766	.821	.898				
48					.650	.703	.747	.800	.875	.974			
49					.634	.685	.728	.779	.853	.950			
50					.617	.667	.708	.759	.830	.924			
51						.648	.689	.738	.807	.899			
52						.628	.668	.715	.782	.871			
53						.608	.646	.692	.757	.843	.968		
54						.588	.625	.669	.732	.815	.937		
55						.568	.605	.648	.709	.790	.907		
56							.581	.622	.680	.757	.870		
57							.556	.595	.651	.725	.832		
58							.531	.568	.622	.693	.795	.956	
59							.506	.542	.593	.660	.758	.911	
60							.481	.516	.564	.628	.721	.867	
61								.487	.532	.593	.681	.818	
62								.458	.502	.559	.641	.770	
63								.430	.470	.523	.601	.723	.939
64								.402	.438	.489	.561	.674	.877
65								.377	.408	.454	.521	.627	.814

Results of the Analysis

From Table 2 it can be derived that the cost-benefit ratio for the proposed expanded malaria control program in Java and Bali is B/C = $\frac{8,924 \text{ million}}{10,238 \text{ million}} = .87$

Two alternatives should be discussed. The first being the potential benefits of a malaria eradication program (if such an activity were technically or organizationally feasible). For purposes of the example we will state that the program would progress to maintenance phase in six years. The potential benefits would then be 1.11 x benefits, listed under columbs b to i of Table 2 +

$$\sum_{+=1} \text{30 percent control program costs} \times (1+i)^{-+}$$

or approximately (assuming maintenance costs = 0) 16,614,000,000. It seems unlikely that an eradication program could be designed within this budgetary constraint or that the maintenance costs could approach 0.

A second alternative is suggested by East Java which indicates that a few areas have the majority of cases. Therefore, using smaller amounts of DDT but focusing directly on those areas with highest incidence could be expected to lower the malaria case load substantially.

Specifically, the amount of DDT presently being utilized could spray for two cycles annually those villages in which 75-80% of the malaria cases occur, while some 2-1/2 times that amount would be required to spray villages in which 100% of reported cases occur.

It is, however, the feeling of the Review Team that the tentative proposal of the MCP to USAID significantly overstates the resource requirements if, in applicable areas, dosage rates are reduced to 1 gram per square metre. The following differences in DDT requirements for Java and Bali are noted:

Tons DDT

Year	MCP Requirement estimate	Team requirement estimate
1973	2,500	3,375
1974	2,500	2,250
1975	3,000	2,250
1976	4,000	2,250
1977	4,500	2,250
1978	5,500	2,250
TOTAL	22,000	14,625

It is also considered that the continued control following 1978 would require a level of activity approximately that of the present control effort.

For these more modest resource requirements, additional resources of approximately Rp. 4,850 million (above the average 1969-1971) would be needed over the six years of expanded operation. The same benefits would accrue as shown in Table 2 with the exception of reduced future control costs (annual future control costs are assumed to equal the 1969-1971 average).

The resultant cost benefit ratio would be $B/C = \frac{5,526 \text{ million}}{4,580 \text{ million}}$ or 1.14.

It must be pointed out that this ratio varies sensitively with the level of future activity required to maintain the new level of control. If the requirements for maintenance at this new level are greater than the level of activity required for the present level of control, then the alternative is no longer an economically feasible one.

It must be pointed out that this more modest program could almost be accomplished within the present resource allocations to the MCP. Following the initial years the costs of the program would be about Rp. 2,350,000,000 vs. an allocation for 1972/73 or about Rp. 1,900,000,000. Thus it is to be expected that significant amounts of external assistance would be required only for the initial year of more extensive spraying activity. The projected cost of the first year's activity would be about Rp. 2,850,000,000.

This analysis in no way should be taken to question the wisdom of the existing level of activity of the malaria control program since the benefits to be derived from preventing malaria from increasing tenfold or 100-fold obviously outweigh the cost of the program.

The situation is markedly different in the Outer Islands.

Since malaria incidence is so great and only a portion of the effected households are to be sprayed, it is safe to assume that malaria will decrease as a linear function of intensity of spraying activities (versus the exponential decay functions used in the case of Java and Bali). Further, it is assumed that the same level of spraying activities must be maintained indefinitely to maintain a given level of control. With these two assumptions one can then calculate the cost-benefit ratio for any year of the proposed program and it will be the same for any other year.

For illustration purposes, the example chosen is that of 6 years after the initiation of the program when the full level of activities is realized.

Certain values of the variables are changed other than the explicit change in cases avoided. They are (1) the marginal wage is taken to be Rp. 130/day and (2) the deaths caused by malaria in adults are calculated

as in Table 4 to avoid overstating this parameter. However, this aspect will be reexamined later when the population implication of malaria control are presented. The analysis yields a B/C = $\frac{2,061}{1,620}$ = 1.27.

Since an attempt was made to adopt minimal estimates for the benefits it would require a substantial change in the estimated cost or an actual incidence of malaria or effectiveness of the program much below that presented to change the B/C ratio to less than 1.

The program presented would require an annual input of 2,500 - 3,000 tons of DDT.

Thus, the cost-benefit criterion would favor the expansion of the program in the Outer Islands over an expanded program in Java and Bali.

In other sections of this report, convincing reasons are presented for a cautious expansion of the malaria control program in the Outer Islands. It is hoped that this demonstration of the greater economic attractiveness of investment in malaria control in the Outer Islands will stimulate the research required to more adequately identify the vectors and analyze the bionomics of malaria in these regions. The shift of program emphasis from eradication to control makes possible the implementation of programs where the major problems exist, where unit costs for a case prevented would be less and there the value of additional labor is greatest, i.e., in the Outer Islands. To state it differently, this simply means that the artificial criteria of "technical feasibility of eradication" have become meaningless. Therefore, the government now has the flexibility to expand its programs to areas where the cost per case of malaria prevented, conservatively estimated, will be only 30-40% of that of Java and Bali. The only prerequisites to this expansion should be the carrying out of the above mentioned research using either national or external resources.

A reasonable estimate of the cost of the research would be Rp. 200,000,000. If the research validated the assumptions made in the economic analysis, the B/C ratio including the cost of research would still be in the range of 1.25, superior to that to be expected from investments in the malaria control program in Java and Bali.

Effects of the Proposed Malaria Control Program on Non-Economic Efficiency Parameters

As stated in the introduction, no attempt has been made to impose cost-benefit criterion as the sole determinant of program decisions. Three other parameters which require consideration are: (1) employment generation, (2) redistribution of wealth, and (3) effect on population growth rates.

The employment generation variable of the program is fairly easily estimated. The majority of new employment will be of spraymen to spray the additional houses. The output per sprayman is fairly accurately known to be about 7.5 houses/day. Additional support personnel for equipment repair, transportation and supervision add 33% to the number of employees required. Therefore, the additional employment generated in Java and Bali would total 5,700 man years annually. The proposed program in the Outer Islands would total 3,200 man years annually. The new employment generated would in general require no special skills except for literacy for most of the workers.

The redistribution of wealth aspects of the proposed program are also fairly obvious. Since malaria control is a problem of rural areas and in Java and Bali many of the vectors are closely related to rice culture, the program represents a redistribution of wealth from those populations who make the largest contribution to government revenues to rural populations. The extent of this transfer is exactly the benefits derived by these populations as listed in Tables 2 and 5 or Rp. 135,000,000 annually in Java and Bali and Rp. 2,476,000,000 for the Outer Islands.

The proposed program will have minimal effects on rate of population increase in Java and Bali. This is due both to the relatively low incidence of the disease and the infrequency of recurrent infections which appears to be one of the main determinants of mortality. As previously stated under Table 2, the number of deaths averted by the program would be 311 or .0050/1,000. The increased crude birth rate (CBB) would be .0268 x malaria prevalence which equals .0031/1,000 (generated by coefficients for Ceylon in

The combination of these two factors is equal to an increased crude rate of natural increase (CRNI) of .0008%, a negligible amount.

In the Outer Islands, the situation is quite different due to the increased prevalence of malaria and the effect on mortality of recurrent malaria infections. The CBR increase would be .268/1,000. The crude death rate decreases would be .3285 x malaria prevalence = 3.285/1,000. The combination of these two factors would be an increase in the crude rate of natural increase of .35% (corresponding in a 14% increase over the present level of CRNI).

Obviously, the extrapolation of technical coefficients between Ceylon and Indonesia can create sizable errors. The validity of the specific coefficients used has been questioned in the Ceylon situation by other researchers. They are used as a last resort in the absence of any other alternative estimates. The results they yield should be interpreted as only first order approximations of the effect to be expected on population by an expanded malaria control program.

Table 5.
Calculation of Benefits from Malaria Control
in the Outer Islands
(effected population 10 million)

Program Year	a Avoided Malaria Cases	b Value of Avoided labor loss	c Value of Avoided caloric loss	d Value of Avoided treatment cost
1978	1,000,000	1,330,000,000	40,000,000	33,500,000

e Value of Avoided clinic costs	f Value of Avoided hospitalization costs	g Value of Avoided mortality in adults	h Value of Avoided mortality in children
99,000,000	65,500,000	354,000	94,700,000

i Value of Avoided absenteeism from school
110,000,000

Summary

From the analysis presented, it appears that the proposed program for Java and Bali would (1) yield returns less than the cost involved; (2) exert a negligible effect on population growth; (3) result in job creation of 5,700 new jobs for a period of 6 years; and (4) involve an urban to rural, wealthy to non-wealthy redistribution of wealth of about Rp. 150,000,000 annually.

The alternative proposal for Java and Bali generated by the Team's requirements assessment would have the same effects on population growth, job creation and distribution of wealth. It would, however, be expected to yield benefits in excess of the costs of the program if the program can be implemented within a budget of 15,000,000,000 rupiah and maintenance costs would not exceed the present control costs.

The hypothetical program presented for the Outer Islands would (1) yield returns greater than the cost involved; (2) result in a significant increase in population growth among the population effected by the program; (3) result in job creation of 3,200 new jobs for the indefinite future; and (4) involve an urban to rural, wealthy to non-wealthy redistribution of wealth of about Rp. 2,500,000,000 annually. The benefits to be realized from malaria control in the Outer Islands make imperative appropriate research to outline the epidemiological and technical parameters involved and to recommend alternative control measures and their costs. Unfortunately, it has not proven possible to generate other alternative control levels and their associated costs. If access could be gained to records of the MCP 1952-1959 or to malariometric surveys taken during the early years of MEP it might be possible to construct a mathematical function which would generate other alternatives. This information would prove useful to planners in the Indonesian Government.

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III. THE USE OF MODELS AND MODELING

A. Survey of the Range of Use

Models are used to describe, explain, predict and prescribe. Prediction provides a basis for deduction that can be compared with observations while prescription suggests what should be done to achieve or approach a stated objective. The "tradeoff" with the use of models is between simplification and reality. Generally, it is easier, more feasible, less costly, and less time consuming to obtain information from models than from experimentation with the reality that the model represents. A model, then is useful when it is simple to understand, has explanatory and preditive power, and permits one to draw valid inferences regarding the behavior of the system.

Models can be classified by their degree of abstraction. A physical model such as a toy airplane cannot predict anything but is easy to build. A graphic model can be schematic -- a flow chart, a PERT chart, a computer program, an organizational chart. Even disease incidence tables, epidemiological curves, and population pyramids are models. As epidemiological knowledge improves, so do causal models as shown in example 1.

A mathematical model can represent a system or reality by employing mathematical symbols and relationships. Analytic mathematical models can have single period, or stage, decisions processes (linear, integer, and quadratic programming) or sequential decision processes whose parameters do change from period to period (dynamic programming).

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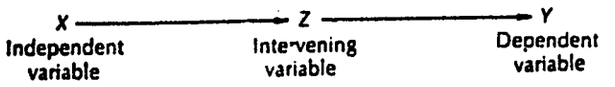
[1] M. Susser, Causal Thinking in the Health Sciences, Oxford: London, p. 16, 1973.

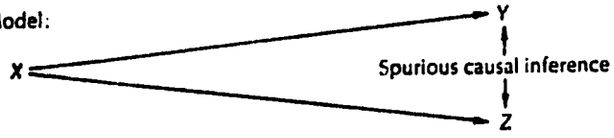
EXAMPLE 1

Factors: Winter (X), Icy water (Z), Phlegm and hoarseness (Y)

Hippocratic Model:



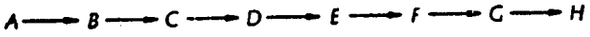
Current Model:



EXAMPLE 2

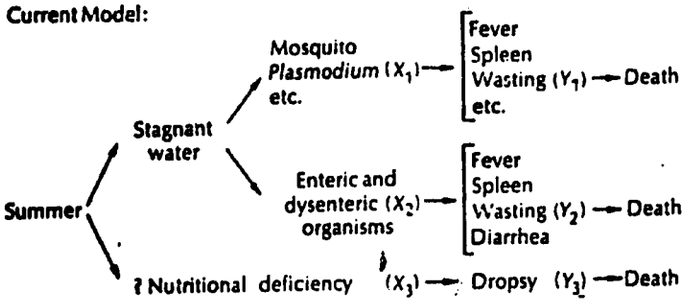
Factors: Summer (A), Stagnant water (B), Spleen (C), Wasting (D), Diarrhea (E), Fever (F), Dropsy (G), Death (H)

Hippocratic Model:



Linked chain of events in sequence

Current Model:



Optimal solutions to models within the health sector and other public policy problems are often not the optimal solutions to the actual problems themselves. The inability to define objectives is probably the reason. Because of political, technological, and economic uncertainties, one should not expect the results from any quantitative study to be implemented or transferred to another area without modification, no matter how impressive the results may appear. This is true, moreover, if the results happen to appear on the printout of a computer! The quality (effectiveness) of any quantitative study should not be evaluated in terms of immediate and direct implementation. Rather its value lies in whether or not the information derived was useful in the decision-making process.

Community health care "systems-analysis" models are being developed. Charts 1 and 2[1] show the structuring of such attempts. Notice the combinations and interrelations of four models.

Dorfman[2] considers three stages in model development-description creative hypothesizing, and quantification. Description usually involves algebraic symbols related by equations or inequalities which translate a real world situation into a set of abstract and simplified symbols. Creative hypothesizing adds motivational, behavioral, and technical assumptions generally introduced as constraints. Quantification is the assignment of numerical values to the parameters of the model.

Dorfman divides all optimization models into two parts: (1) a part describing the structure of an operation or a system and the relations

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[1] Milly, G., et al., "A computer Simulation Model for Evaluation of the Health Care Delivery System," Geomet, Inc., Rockville, Md. (1970), p. 29.

[2] R. Dorfman, Operations Research, American Economic Review, June 1961.

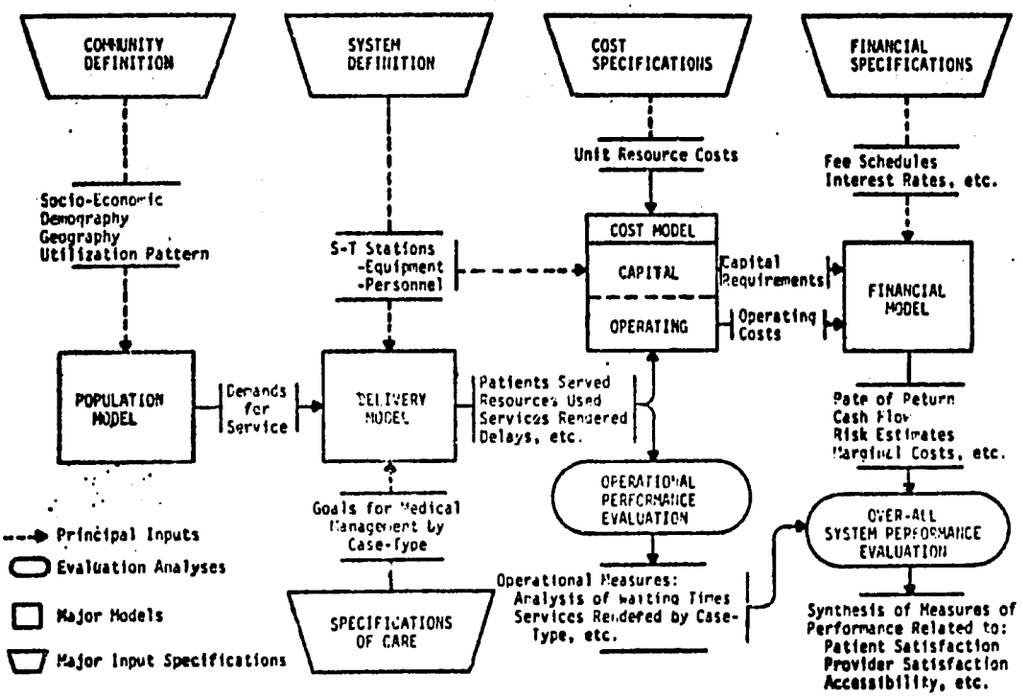

Chart 1 Major features of systems analysis model.

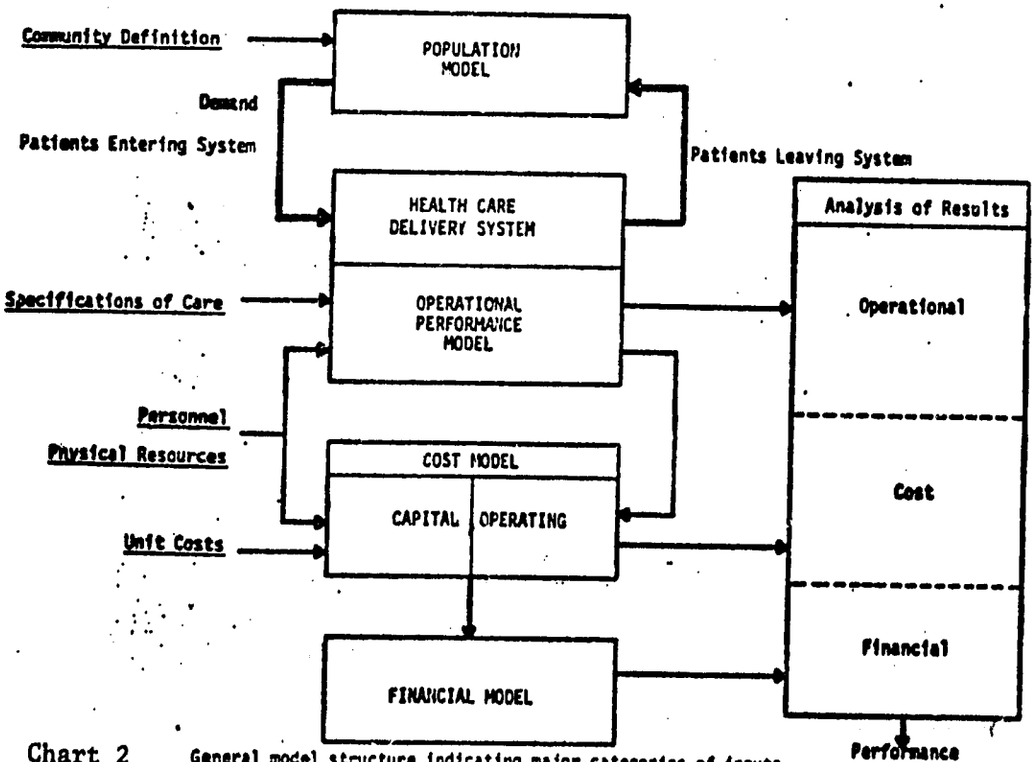

Chart 2 General model structure indicating major categories of inputs and outputs. Major inputs are underlined.

among the variables, and (2) a part that evaluates the consequences of any choice of variables in terms of cost, profit, or some other measure of desirability. The first part are constraints and the second is the objective or criterion function. Most operations-research studies search for the values of variables that maximize or minimize the value of the objective function while satisfying the constraints.

The problem is often one of combining various objectives into a single objective function to be maximized. The problems include (a) comparing consequences that occur at different times, (b) the uncertainty of the consequences in the future, and (c) the incommensurabilities of the consequences of a decision. For (a), discounting procedures offer relative values to costs, revenues, etc., at different dates, for (b) the result of a decision is not a predictable value but a probability distribution of values. Therefore, the comparison of the desirability of consequences presumes that we are able to compare the desirability of probability distributions.

Reinke[1] classifies models as to the behavior of the parameters. Deterministic models have parameters that are constant or vary predictably. Stochastic models depend partly on chance or when the model takes account of variability such as queueing. Static models have parameters independent of each other and vary in a way not altered by time. Dynamic models take changing circumstances into account and the way in which decisions will affect or be affected by these circumstances.

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[1] W. Reinke, Health Practice Research and Formalized Managerial Methods, WHO--Public Health Papers #51, 1973, p. 33.

III. B. Descriptive Models

I. Forecasting Models and Techniques

Forecasting is widely used in health sector modeling and has grown in importance, complexity and accuracy with the advent of the computer. This does not preclude successful forecasting by manual tabulations. While a large number of comparative statistics are being collected in the health field relatively little is being done with analysis. Forecasting aids in evaluating the input or effect of activities, programs, and strategies by expressing functional (causal) relationships among relevant factors. Detection of future change (turning points) in response to related planned activity is the primary concern of forecasting. Because health planning is concerned with making future allocative decisions or present decisions whose effects extend into the future, forecasting is often a prerequisite for the application of other methodologies.

Forecasting techniques are qualitative and quantitative, the former based on human judgment through experts' opinions on information about special events when data is scarce(for example, Dephi Technique methods); the latter is based on applying statistical techniques on historical data to predict future events.

Three groups of quantitative techniques are discussed: time series analysis -- forecasts based on time trends, single-equation, and simultaneous equation regression models. The latter two are forecasts based on functional relationships. As a forecast is basically a guess -- it does not guarantee an exact prediction -- it is associated with some error. The three techniques grow in sophistication in treating

this error, as well as in cost and data and skill requirements. The more accurate the forecast needed, the more complex the process. The more obscure the data, the greater will be the cost of obtaining it. The tradeoff is between the cost of improved accuracy and the value of the additional accuracy.

III. B. I. A. Time Series Analysis

The analysis seeks to discover trends or long term movements and patterns of seasonal or periodic effects around the trends from historical data and to forecast or extend this trend into the future. Random (unsystematic components) are also taken into account. Most epidemiologic forecasting of disease considers two separate forecasts -- one of the disease incidence (numerator) and one of the population at risk (denominator). Most health facility forecasts consider admissions and/or services rendered. As a continuation of historical patterns is assumed, the influence of outside factors is not taken into account. The first step in the analysis of a new time series is the determination of the nature of underlying process. The procedure for doing this is very analogous to the "cracking" of petroleum, in that both resolve a mixture into one or more "pure" components plus a residuum (residual error; "gunk"). Graphing the data series reveals the overall structure, statistical analysis aids in determining overall causes of the trend and fluctuations.

Forecasts based on an average are commonly used in health facility planning. Only if processes are stationary can past behavior be the best estimate of the future. For non-stationary trends or even deterministic (no chance variations) trends, the use of the average can give poor results.

Examples of stationary (A and B), non-stationary (C) and deterministic (D) processes are shown in Figure 1.[1] Here processes A and B are the only ones applicable for forecasting as their past behavior is the best estimate of the future.

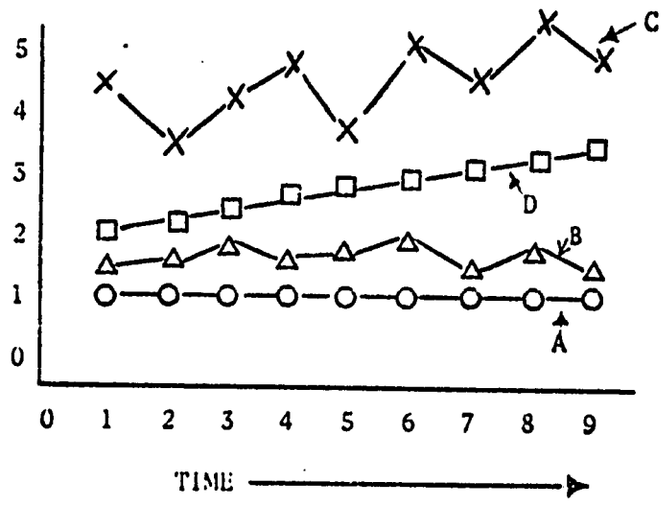

Figure 1

TYPES OF PROCESSES

Jelinik attempted to predict hospital admissions using historical data forecast one month in advance[2]. Figure 2 shows the large discrepancy that may occur if the process is non-stationary.

Since observed stochastic (random) processes are often time dependent, two more sophisticated methods of prediction are useful ---the moving-average forecast and the exponential smoothing forecast.

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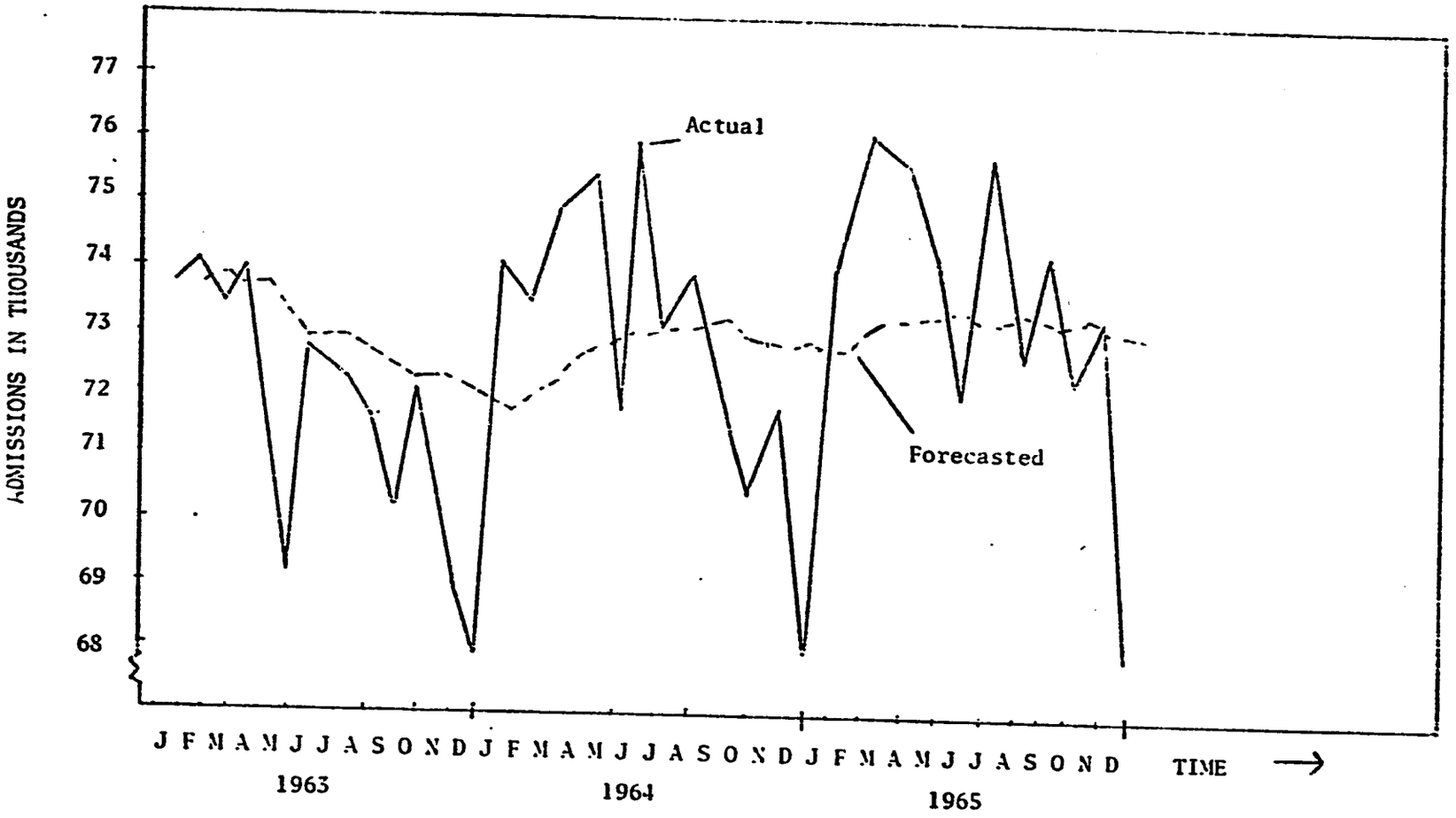
[1]R.C. Jelinek, Operations Research in the Planning and Control of Health Services, Ann Arbor, Michigan, 1968.

[2]Ibid.

FIGURE 2

FORECAST BASED ON AN AVERAGE OF PAST DATA



The moving average technique uses only data from a specified number of immediately preceding periods rather than all available past data points. The forecast is the sum of the data points for the desired number of past periods divided by the number of data points included in the sum. A new forecast is computed for each period by dropping the data points for the most distant time period and adding the data points for the most recent period. Figure 3 shows forecasted admissions using a three month moving ave. and shows the ability of this approach in following the cycles of actual admissions. The computations can be carried out by hand.

The exponential smoothing technique considers all past data but places more emphasis on the more recent data points than on prior data. An advantage of this approach is that it requires minimum storage of historical information. Like the moving-average, the approach has the power of following the cycles of actual admissions as shown in Figure 4. Further corrections for trends and seasons can greatly improve the quality of the forecast (Figure 5).

If hospital demand is successfully forecasted, the preparation of the hospital (clinic) budget is facilitated. Yet annual budgets are inflexible with staffing and other costs adjusted to the budget and not the the actual fluctuating demand. Thus if forecasting is improved, a more flexible budget system is possible.

It is possible to forecast production measures such as patient-days, surgical procedures, or number of treatments. These statistics, in turn, are indicators of manpower needs within the hospital or clinic.

The exponential smoothing method, discussed above, is a good forecasting candidate in this situation as (1) the forecast is short-range,

FIGURE 3

FORECAST BASED ON A MOVING AVERAGE
(3 MONTH MOVING AVERAGE)

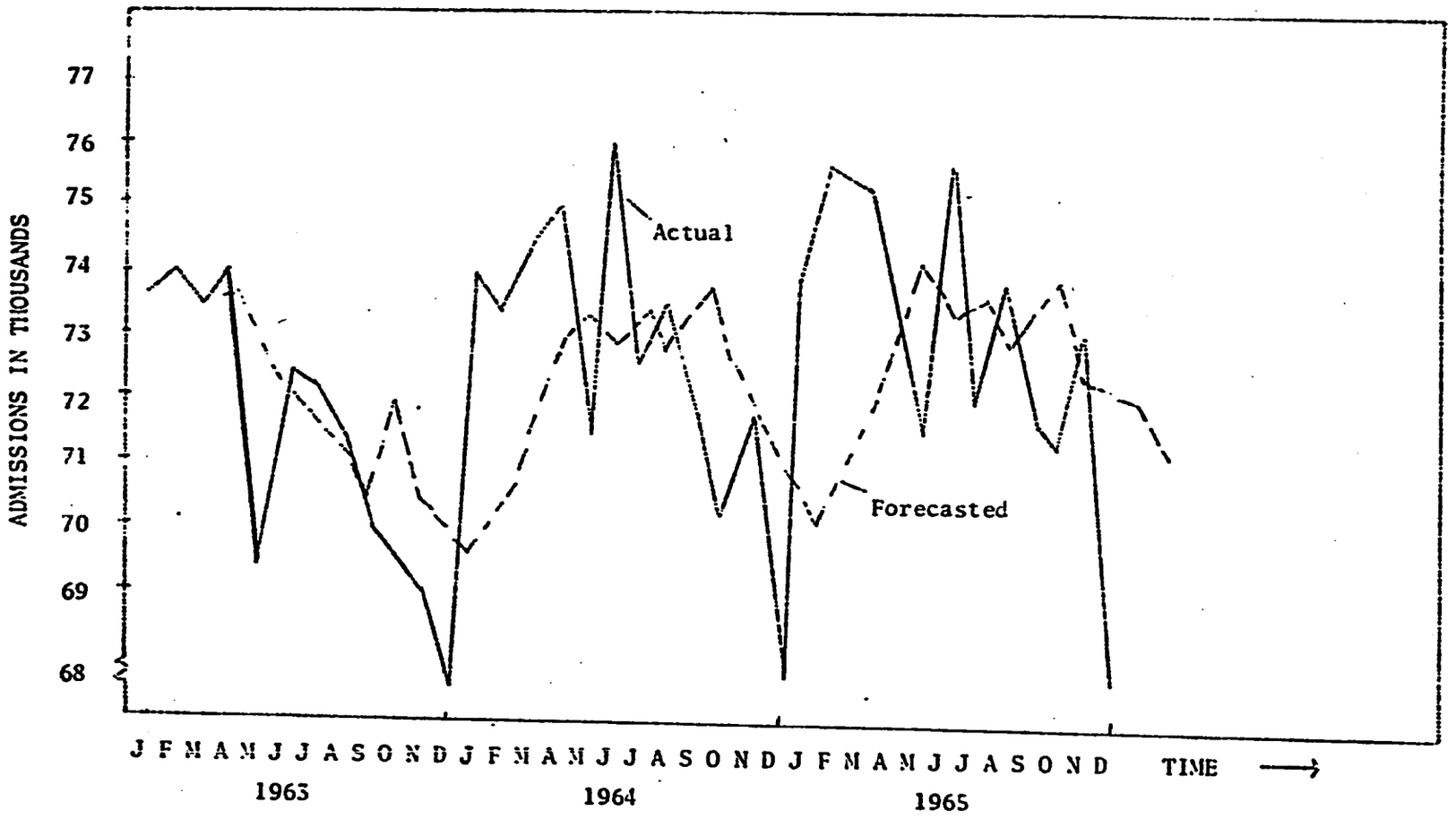


FIGURE 4

FORECAST BASED ON EXPONENTIAL SMOOTHING
(WITH WEIGHTING FACTOR OF 0.8)

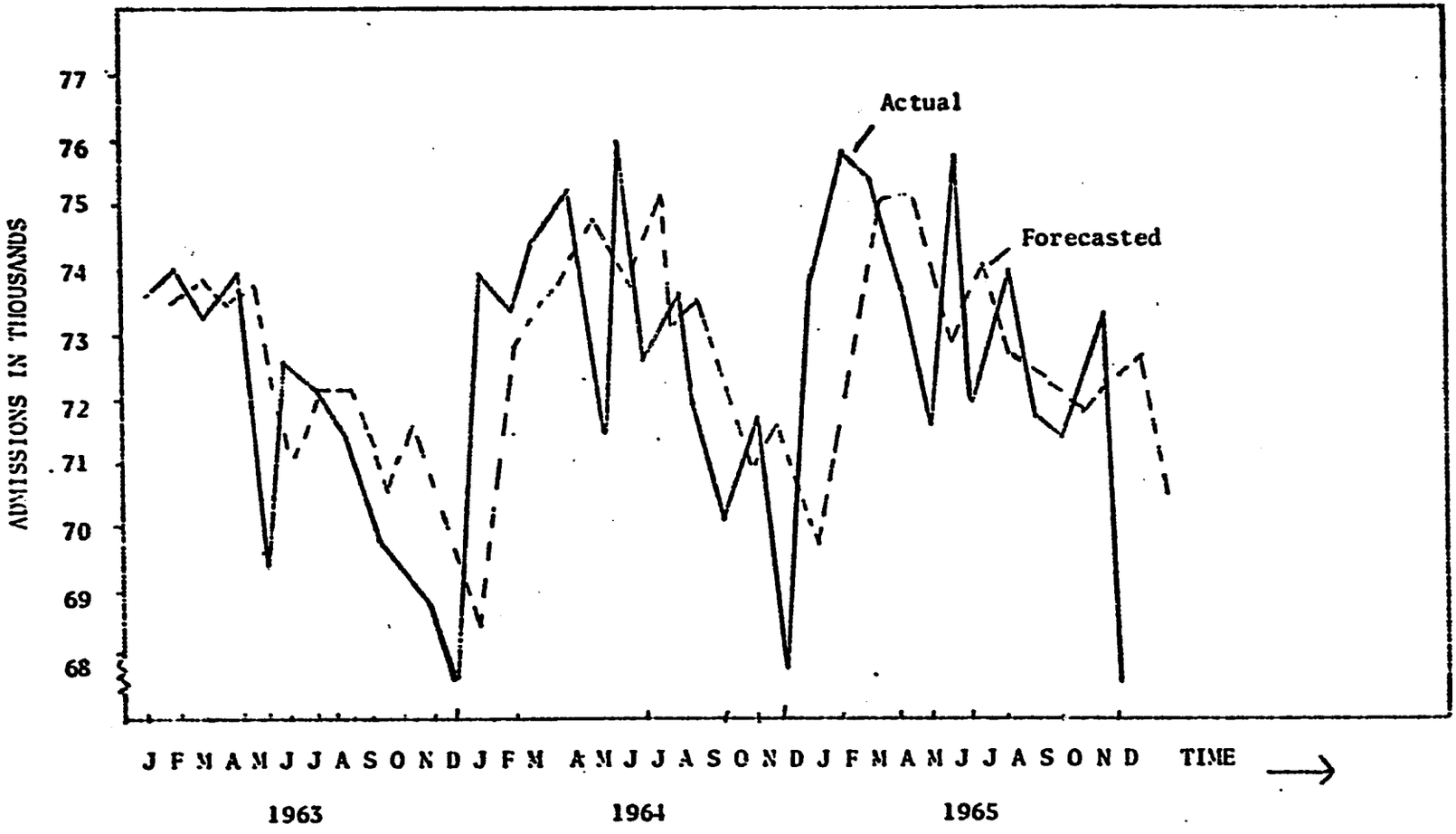
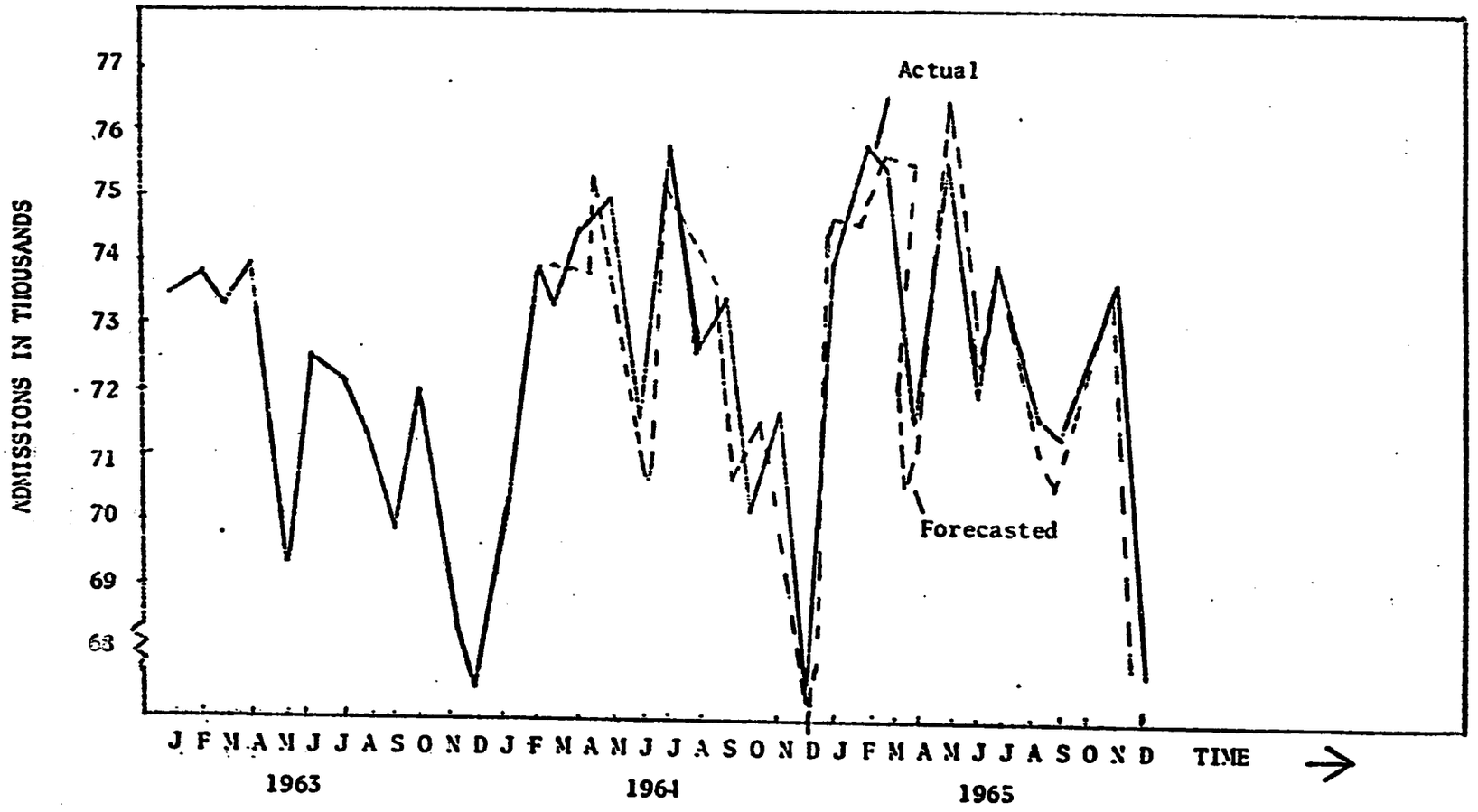


FIGURE 5

FORECAST BASED ON EXPONENTIAL SMOOTHING WITH A SEASONAL AND TREND CORRECTION



(recent changes can be taken into account), (3) not much data needs to be stored, and (4) the computations are simple. Other techniques are the seasonally adjusted simple regression trend analyses technique, which is common for budget preparation. Multi-variate regression analysis and other techniques are too complex and costly -- it is difficult and expensive to identify and quantify the set of independent variables.

The improvements brought about by a more accurate estimate of resource needs based on forecasted demand varies with the volume of work produced (and, thus, saved) If a 1% variation reduction in surgery is equivalent to reduction of 20 patients/month, and if man-hours required of patient-day is 5, 100 hours/month are saved. However, a 1% improvement in X-ray outpatient testing might result in improving accuracy by 18 procedures/month or 18 hours of human resources at one hour/procedure.

III. B. I. B. Single Equation Regression and Multivariate Models

Generally, relationships exist between the variables we wish to forecast or explain. The variable we wish to predict is referred to the dependent variable -- it depends on related variables acting singly or in combination. These later variables are referred to as independent variables. "Time" is generally implied as an independent variable in forecasting. Figure 6 projects patient days over a fifteen year period. Assumptions based on a linear versus nonlinear relationship vastly affects the projection (48,000 vs. 58,500).[1]

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[1] J. Griffith, "Quantitative Techniques for Hospital Planning and Control", Toronto,1972, p. 25.

Independent variables may represent a feature of the system or environment the future level of which is known, or they may represent some feature of the system which is an advanced indicator of a change in the dependent variable.

Thus, demand for health services (dep. variable), for example, is a function of the following non-exhaustive list of independent variables: the price of the service, the income of the patient, and his perception of the quality of care he expects to receive. The functional form for this relationship is a model with one dependent and three independent variables:

$$Y = f(X_1, X_2, X_3)$$

The most widely used form of this model is in a linear (straight-line) form represented as $Y = a_0 + a_1X_1 + a_2X_2 + \ldots = a_nX_n$.

Here, the model expresses the quantitative effect of a <u>change</u> in one of the independent variables, X_i on the dependent variable, Y. Regression coefficients (the numbers preceding each independent variable, the "a's") are the factors by which changes in each of the independent variables are to be multiplied to yield <u>estimates</u> of corresponding changes in the dependent variable.

For developing countries, the following independent variables are good candidates for estimated demand for services using a multiple reg. model.

(1) Age of population and its distribution

(2) availability of facilities

(3) education and income levels

(4) urban-rural mix

As is the case in simple regression, the goal of the analysis is a function or mathematical statement related the dependent variable (ex-demand for services) to a given set of independent variables. The aim is to study the ability of the independent variables to reduce the variation of the dependent variable. The success of the analysis is the reduction in variance of the dependent variable.

Large quantities of data are usually required -- a constraint albeit the "quality of data" dilemma. Census data or previous published studies (secondary data) are preferable to collecting raw (primary data) due to the excessive costs involved. The accuracy of the input measurements, obviously affects the accuracy of output. Variables which are only crudely estimated themselves should be avoided as should estimates collected from a variety of sources taking different estimating approaches. Independent variables highly correlated with themselves must be avoided (% of population greater than 65 and social security support).

Other techniques can handle non-linear relationships as well or interrelations between independent variables.

III. B. I. C. Simultaneous-Equation Regression Model

In many real world problems, more than one relationship is observed. For example, hospital demand is influenced by price and at the same time, demand, influences price. The presence of a two-way conversation makes a simultaneous-equation model necessary. These models have the ability to describe more complex and mutually influencing relationships by introducing as many equations as are necessary to represent the relationship. "Econometric models" are based on series of simultaneous equations.[1,2.]

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[1] M. Feldstein, "Economic Analysis for Health Service Efficiency", Amsterdam, 1967.

[2] Paul Feldstein, "An Econometric Model of the Medical Care Sector", Ann Arbor, 1973.

Table 1[1] offers criteria of choosing forecasting techniques.

TABLE 1

	Techniques		
Criteria	*Time-series analysis*	*Single-equation regression model*	*Simultaneous-equation regression model*
Consideration on external conditions	No	Yes	Yes
Turning-point detection	Yes (limited to seasonal or cyclic change)	Yes (limited)	Yes
Consistent prediction or related events	No	No	Yes
Dynamics of the flow system	No	Yes (limited)	Yes
Accuracy			
Short term (0–3 months)	Fair to Excellent	Good to Very Good	Good to Very Good
Medium term (3 months–2 years)	Poor to Good	Good to Very Good	Very Good to Excellent
Long term (2 years and up)	Very Poor	Poor	Good

[1] M. Aiso, Forecasting Techniques, I.B.M. Systems Journal #2, p. 189, 1973.

III. B. I. D. Applications: Three Examples of Predicting Facility Needs

Applications of health facility forecasting are descibed by three studies. The Feldstein-German study utilizes multivariate regression analysis with cross sectional information on factors relating to hospital utilization. Combinations of independent variables are subjected to regression. Thus, a one per cent increase in a selected variable, other things equal, produces estimated changes in utilization based on a derived regression equation. The range of error, in projection, utilizing this approach is discussed.

The second example is a summary of a study conducted by the Greater Detroit Area Hospital Council to predict bed needs in that large region(over one hundred hospitals). The analysis relies heavily on 1970 decennial census data as well as patient origin estimates. Developing countries would require signigicant investments in time and resources to gain such information. However, estimates, age stratified if possible, can be useful. Of interest is the fact that in many regions within developed countries, the supply of existing beds is often greater than "needed" in the near future.

The third example is a summary of a training course seminar on regional health planning. It summarizes the statistical requirements used in surveying a region's need for health facilities, as well as offers rough indicators of factors affecting utilization. The concepts are simple and direct application to developing countries is possible.

EXAMPLE 1

THE FELDSTEIN-GERMAN STUDY[1] PREDICTING HOSPITAL UTILIZATIONS

Bed supply studies can utilize several forecasting models. The level of hospital utilization is the factor to be explained (dependent variable) and the many factors explaining possible variation in utilization are the independent variables. Differing models explain what is "going on in the real world." Models that merely extrapolate past utilization (first example) do not offer causal explanation of <u>why</u> there is utilization. Thus, if we hypothesize that hospital utilization is explained by, for example, the available bed supply, we have a "causal" theory. Various "demand" theories are also causal models - the explanation is in terms of several underlying factors, a combination of population characteristics plus past experience. A simple linear relationship using, for example, 3 variables can be formulated and described as $U = a + b_1 I + b_2 M + e$, where

U = number of patients per day/1000 population

I = proportion of the population with insurance

M = proportion of the population aged 55 and over

a = a constant term referring to the utilization level if both I and M are equal to zero

"b's" = regression coefficients which represent the change in utilization with respect to a unit change in each independent variable holding constant the other independent variables.

"e" = error term composed of all other factors affecting utilization in terms of the difference between the actual and predicted estimates of utilization

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1. P. Feldstein and J. German, "Predicting Hospital Utilization: An Evaluation of Three Approaches", Inquiry, 2(1), 13-36, (1965).

If, as a result of computations, "a" = 400PD/1000 (400 patients days/ 1000 population), "B_i" =3PD/1000 for each % point of the population insured and "b_2" equals 10PD/1000 for each % point of population over 55 years, the equation would read U=400+3I+10M. To predict utilization (U), estimates for I and M must be inserted (50% of the population is insured and 20% is over 55 years, for example,) U=500+3(50)+10(220)+150+200=750 patients days/ 1000 population.

Trend models are constructed similarly. If we assume utilization in a given year is a function of utilization in the previous two years, the equation would be: $U_{year3}=a+b_iU_{year2}+b_2U_{year\ 1}$

Some variation always exists between the estimated results from analysis and actual results. Statistical measures such as the "standard error of estimates, and the "standard error of the net regression coeficient", and the coefficient of multiple correlation are usually employed.

An expanded Socio-economic model demonstrates the demand approach to utilization and might be expressed as: Patient days=a+b(income)+c(insurance)+d (%of pop.> 55)+e(5urban)+f(room rate)+g (non-white) (EQ.1).

Here patient days are linearly related to several factors. The relationships of coefficients to predict error in patient days is tabulated below in table 2. Here, a "T" value ± 1.68 implies a significant effect. Thus, income and insurance affect utilization, while room rate and % non-white has less effect.

Table X Factor coefficients and their significance

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

If the combined influence of all the factors of concern is taken into account, multiple regression analysis then shows that the standard error of P is 125 in the present case. Thus the number of patient-days per 1000 population predicted for a state from Equation 1 could be in error by as much as: ±(1.68)(125)=210patient-days per 1000 population.[2]

Summary

1. Using past trends to predict the future assumes that the underlying forces act in a consistent fashion. Changes in these factors can be incorporated to predict changes, and the utility of the approach is sound if no abrupt changes occur. It is also the easiest approach. Incorporating influential socio-economical factors into the analysis offers the ability to incorporate changes which may occur. The planner is forced to decide which variables are the most important, and must gather data on each factor. Thus the approach is more difficult and costly.

EXAMPLE 2

APPLYING BED-PLANNING IN THE REGIONAL SETTING

The logical step after model development is its use in predicting utilization. Predictive ability declines as equations developed over a given period are used further in the future.

Metropolitan U.S. facility planning councils devote much attention to predicting bed utilization.

Table 3 shows a 1980 projection of bed supply within several "study areas" of Southeastern Michigan[1]. The formulae used to calculate the projections are described.

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[1] Interim Report on Acute Care Bed Data, 1973, Greater Detroit Area Hospital Council..

TABLE 3
Greater Detroit Area Hospital Council, Incorporated

INTERIM REPORT ON ACUTE CARE BED DATA
FOR SOUTHEASTERN MICHIGAN, 1980 PROJECTIONS

June 1973

Study Area	1980 Projected Need for Acute Beds	Beds Serving Area's Residents			Surplus or Deficit for 1980 Needs	Net Other Beds Proposed as of May 1973	Study Area
		Existing	Under Constr. or Approved by GDAHC-CHPC	TOTAL Projected for 1980			
ALL	13,842	19,730	1,615	21,345	+2,503	503	ALL
Area 1	4,313	5,604	160	5,764	+1,451	109	Area 1
Areas 2 & 5	4,900	4,737	398	5,135	+ 235	260	Areas 2 & 5
Areas 3 & 4	3,618	3,173	562	3,735	+ 117	88	Areas 3 & 4
Area 6	271	222	2	224	- 47	--	Area 6
Area 7	443	430	25	455	+ 12	--	Area 7
Area 8	535	485	15	500	- 35	1	Area 8
Area 9	339	303	4	307	- 32	--	Area 9
Area 10	2,014	2,120	126	2,246	+ 232	14	Area 10
Area 11	2,409	2,656	323	2,979	+ 570	31	Area 11

Beginning with the year 1972, data on the number of inpatient days used by the residents of specific geographic areas is obtained from the Patient Origin and Hospital Use Study, an ongoing survey conducted by GDAHC.

Origin of patients. Data on the distribution of individual hospital's patients by their place of residence is also obtained from the Patient Origin and Hospital Use Study.

Population. The latest population estimates are taken from the figures released by the Population and Housing Committee of the Southeastern Michigan Council of Governments (SEMCOG) unless current figures from the U.S. decennial census are available, in which case census figures are used. Similarly all population projections are obtained from SEMCOG.

Bed complements. The number of acute care beds in the hospitals is determined based on the number of licensed beds, in some cases adjusted using the bed complements reported to GDAHC. Rehabilitation, tuberculosis, psychiatric, and long term beds are excluded from those figures. Beds known to be closed temporarily (e.g., for remodeling) are included in the inventory.

THE FORMULA AND INVENTORY

1. Bed Need Formula

The acute care bed need formula consists of two steps. First, the regional bed need is calculated to obtain the number of acute care beds needed to serve the entire region served by GDAHC. The second step involves the reapportioning of these needed beds among all Study Areas.

Regional bed need. The regional bed need for the year 197X is obtained as follows: the average number of inpatient days per person per year for the region (taken for the most recent five years for which data are available) is multiplied by the projected population for the region for 197X, to obtain the total inpatient days per year projected for the region for 197X. This quantity is then divided by 365 (to reduce it to a per day figure) and by .88 (the expected overall occupancy rate for the region's hospitals), thus obtaining the number of acute care beds needed based on an 88% occupancy level.

In formula form, this gives:

$$\text{Regional Bed Need} = \frac{\left(\begin{array}{c}\text{5 yr. average}\\ \text{Patient Days}\\ \text{Per Person}\end{array}\right)\left(\begin{array}{c}\text{Projected}\\ \text{Regional}\\ \text{Population}\end{array}\right)}{(365)\ (.88)}$$

-continued-

Study Area bed need. The regional bed need is initially reapportioned among Study Areas based on projected population figures; the result is then multiplied by an index derived from utilization rates.

The number of beds needed to serve the population of a Study Area is obtained as follows: the regional bed need figure for the year 197X is multiplied by the ratio of the Study Area's projected population for 197X and the region's projected population for 197X. The result is a Study Area bed need figure directly proportional to the Study Area's projected population.

That figure is then multiplied by a utilization index, which is defined as the ratio of the utilization of hospital care by the Study Area's population for the latest available year--expressed in terms of inpatient days per thousand population--and the utilization of hospital care by the region's population, also for the latest available year. (The resulting figures for individual Study Areas add up to less than the original regional bed need, and the difference--in the order of 5% of the total--must be reapportioned proportionately among the Study Areas).

Finally, the quantity obtained is multiplied by .9, thus decreasing it by 10%, the adjustment factor for appropriateness of utilization of acute care facilities.

In formula form, this gives:

$$\text{Study Area Bed Need} = \left[(\text{Reg. Bed Need}) \times \frac{(\text{197X Study Area Pop.})}{(\text{197X Reg. Population})}\right] \cdot \frac{(\text{S. A. Pt. Days/1000 Pop.})}{(\text{Reg. Pt. Days/1000 Pop.})} \quad (.9)$$

2. Acute Care Bed Inventory

The inventory of acute care beds involves the determination of the total acute care beds available to each Study Area's population, in each of three catagories: existing beds, beds under construction, and additional beds approved by GDAHC and CHPC.

The existing and projected beds of every hospital in the region are thus reapportioned among Study Areas according to the proportion of patient days of care provided by the hospital to residents of each Study Area, as determined from the Patient Origin and Hospital Use Study. (Since no utilization data are

-continued-

available for new hospitals yet to be built, reasonable approximations are made in such cases, using where feasible known patterns of use of facilities in the area).

3. Deficits and Surpluses

By comparing the number of beds available to serve the Study Area's population by 197X (rather than the beds located in that Study Area) with the estimate of beds needed to serve that population by 197X, future surpluses or deficits are identified.

EXAMPLE 3

THE COMMUNITY SURVEY IN HEALTH FACILITIES PLANNING

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Prepared for
the
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on
Operational Analysis
in the
Management of Health Services

June 1967

The Community Health Facilities Survey

Objective of the community health facilities survey.

1. Hospitals and other health care facilities should be planned in response to present and future community needs and in relation to community resources.

2. The basic objective of the survey is to assist the community in developing a coordinated system of hospitals and other health care facilities which will provide a broad range of services for all members of the community in an economic and effective manner.

Specific purposes of the community health facilities survey.

1. To assist the community in determining the present and future need for hospitals and other health care facilities.

2. To recommend a plan of action for meeting this need.

3. To recommend an information system and planning procedures which will enable the community to measure its need for health care services on a continuing basis and to plan its health care facilities in response to this need.

4. To stimulate a better understanding of the nature of the health care delivery system, and the interrelationships among the various elements in this system, and the advantages of coordinating these elements.

Most communities face several or all of the following problems relating to their health care facilities.

1. Population growth

2. Changing demands for health care services

3. Increasing costs of care

4. Too many beds of some types and/or too few of others

5. Unnecessary duplication of facilities and services

6. Gaps in facilities and services

7. Obsolescence and delayed response to advance in medical science

8. Over-use of some services and/or under-use of others

9. Poorly coordinated use of facilities and services

10. Shortage of personnel.

The community health facilities survey is one approach to studying these problems in an objective and scientific manner and developing a plan of action to solve them. The survey should provide answers to the following questions and many others which are critical to rational health care facility planning.

1. What facilities and services does the community have?

2. What condition are they in?

3. Are they properly located?

4. Are there too many beds? Too few?

5. Are there gaps in services that result in high-cost hospitalization when long-term units, outpatient services, home care, etc. might be more appropriate?

6. Are there unnecessary duplications in services or facilities?

7. How is the community using - or misusing - its facilities?

8. Does the community have a balanced, integrated, health care system that offers the best possible care at a reasonable cost?

Factors existant in many communities which lead to irrational decisions regarding the construction or expansion of health care facilities.

1. Imagined need for additional services

2. Community pride

3. Competition among hospitals

4. Competition and/or discrimination among physicians

5. New or expanded facilities viewed as a means of recruiting physicians and/or other professional personnel

6. Misdirected benevolence

7. Empire building

8. Overemphasis on more attractive or newer services

9. Simultaneous perception of needs by several institutions

10. Additional beds needed to sell fund raising drive

11. Lack of understanding of changes in health care.

The organization requesting the community health facilities survey must agree to the following conditions before the survey will be undertaken.

1. The survey will consider the needs of the entire community for all types of health care services - prevention, diagnosis, therapy, and rehabilitation.

   a. It will not be limited to any one segment of the community.

   b. It will not be limited to any one type of service.

2. The survey will consider all types of health care facilities - ambulatory care facilities, acute and long-term hospitals, extended care facilities, nursing homes, rehabilitation facilities, and home care programs.

   a. It will not focus on any one element of the health care delivery system, since the elements are interrelated, the actions of one affect the others, and coordination between the elements is essential to good patient care.

   b. A survey will usually not be undertaken for one hospital in a multi-hospital community.

3. The survey team will communicate with various health care professionals, and organizations - physicians, public and private health care agencies, public and private welfare agencies, and others - and representatives of community leadership, consumers, insurers, etc.

   a. Good planning considers the viewpoints of all participants in the community health care system.

   b. Too often the views of one participant are imposed on the others, resulting in poor cooperation.

What are the advantages of seeking the assistance of an organization outside of the community?

1. Outside organization is likely to be objective and unbiased.

2. Outside organization may see new approaches to the solution of problems.

3. Outside organization may have talents and resources not available in the community.

4. Outside organization may bring new research findings and techniques to the community planning process.

Disadvantages of assistance by an outside organization.

1. Recommendations may not be implemented because of a lack of community involvement and commitment to the survey.

2. Outside organization may lack sensitivity to the community power structure, community problems, and community resources.

3. Outside organization may alienate itself if viewed as "telling" the community how to allocate its health care resources.

4. Community may depend too much on outside organization and not develop its capability to carry on its own planning in the future.

Methodology of the community health facilities survey.

1. Project the future need for health care services in the community. (Surveys are generally limited to services provided in or by health care institutions.)

2. Determine the type, size, scope and arrangement of facilities required to meet these needs.

3. Inventory the existing facilities to determine the degree to which they meet these requirements.

4. Identify the gaps between existing and needed facilities.

5. Explore alternative methods of filling these gaps and make recommendations regarding the best plan of action.

Approaches to projecting the need for health care facilities.

1. Medical

   a. Determine the amount of illness and injury in the community (morbidity and mortality by specific diagnosis).

   b. Determine the quantity of the various components of patient care (outpatient visits, inpatient days of care, surgical procedures, obstetrical procedures, laboratory tests, X-ray examinations, and other diagnostic and therapeutic services) needed to properly diagnose and treat each diagnosis.

   c. Develop a means for assuring that patients use the predetermined quantity of each type of service appropriate for their diagnosis.

   d. Add up the amount of each type of service that will be used and translate this into facilities.

   e. This approach is still in the research stage and is not developed to the point that it can be used in planning at the present time.

2. Demand (two approaches)

   a. Project the past trend in the demand for services into the future and translate this into facilities.

      (1) This approach assumes that the factors which influence demand will continue to operate in the future as they have in the past.

      (2) Relatively accurate in the short run but less so for long range projections.

      (3) Simplest method, but does not lead to an understanding of the complex nature of demand.

   b. Identify the demographic, economic, medical and social factors that influence the demand for services and determine the extent and manner (positive or negative) that each factor (independent variable) affects the demand for services (dependent variable). Develop a demand model. Use the model to estimate future demand by plugging in estimates of each factor for some future point in time.

$$\text{Hospital Use} = f(a_1x_1 + a_2x_2 + \ldots + a_nx_n)$$

(1) This approach recognizes the factors which influence demand and does not assume that they will continue to operate in the future as they have in the past.

(2) This approach is still in the research stage and not developed to the point that it can be used in planning at the present time.

Approach used in the community health facilities survey.

1. Combination of the two demand approaches.

   a. The trend in the utilization of various health care services over the past five years is projected five to ten years into the future, modified by expectations about changes in the factors which influence demand and changes in the nature of the health care delivery system.

   b. In addition to changes in the factors which affect demand, other changes may be recommended based upon knowledge about ways in which the health care delivery system can be improved. These recommendations also modify the projection of the utilization of services if there is a good chance they will be implemented.

   c. Examples of recommendations

      (1) More emphasis should be placed on the use of alternatives to acute inpatient hospital care such as ambulatory care, extended care, self-care, nursing home care, and home care.

      (2) More emphasis should be placed on utilization review as a means of reducing unnecessary hospital use (i.e., use motivated by financial or social rather than medical reasons) and encouraging the prompt movement of patients to alternative facilities.

      (3) Affiliation and transfer agreements should be developed between hospitals and long-term care facilities to facilitate the prompt movement of patients to alternative facilities.

(4) Affiliation should be developed between community hospitals and large regional or university hospitals to facilitate the referral of patients requiring specialized services and other types of care which are not available (and often should not be available) in the community hospitals.

Specific steps in the community health facilities survey.

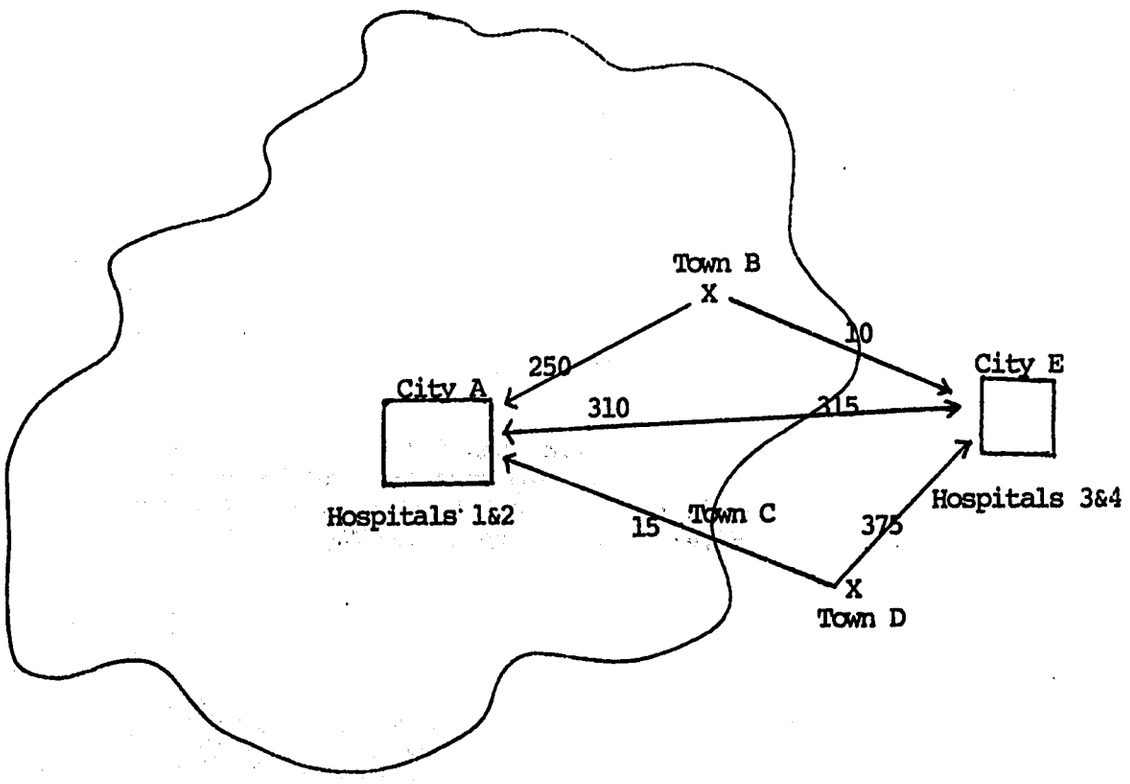
1. The area served by the hospital or hospitals in the community is determined. This is accomplished by:

   a. Collecting data on the place of residence of all patients admitted to the hospitals in the community during the most recent twelve month period.

   b. Collecting similar data for the same period from all hospitals surrounding the community.

   c. Circumscribing the geographic area within which the majority of people use the hospitals in the community under study whenever hospitalization is necessary.

Hospital Service Area



d. The hospital service area not only reflects the movement of patients, but it also reflects the patterns of practice of physicians, since they refer patients to hospitals for admission.

2. The past and present population of the hospital service area is determined using U.S. Bureau of the Census or other population information. The population is broken down by major age groups, since different age groups use different types of hospital services.

Age	Service
14 and under	Pediatric
14-44 (female)	Obstetric
14 and over	Medical and Surgical
65 and over	Long-term Care

3. The future population of the hospital service area is projected five to ten years into the future using the best available population estimates. Projections are made to specific years for which health care facility needs are to be determined. Again, the projected population is broken down by age group.

(Although population data should be broken down by age group, this is not done in the example presented in this section of the outline.)

Year	Service Area Population	
1960	18,000	
1961	18,200	
1962	18,400	5.6% increase
1963	18,600	
1964	18,800	
1965	19,000	
1970 (estimate)	20,060	5.6 % increase (estimate)
1975 (estimate)	21,190	5.6% increase (estimate)

The past and present utilization of hospital beds is determined from hospital records. Use is measured in admissions and days of care per year for each clinical service.

(Although utilization data should be broken down by clinical service, this is not done in the example presented in this section of the outline.)

Year	Admissions	Average Length of Stay	Days of Care
1960	2,000	8.2	16,400
1961	2,100	8.1	17,010
1962	2,200	8.0	17,600
1963	2,300	7.9	18,170
1964	2,400	7.8	18,720
1965	2,500	7.8	19,500

5. Past and present utilization rates are calculated using the population of the hospital service area and admissions and/or days of care.

$$\text{Admission Rate} = \frac{\text{Admissions}}{\text{Population}} \times 1{,}000 \text{ (Admissions/1,000 population)}$$

$$\text{Utilization Rate} - \frac{\text{Days of Care}}{\text{Population}} \times 1{,}000 \text{ (Days of Care/1,000 population)}$$

Year	Service Area Population	Days of Care	Utilization Rate
1960	18,000	16,400	911
1961	18,200	17,010	935
1962	18,400	17,600	957
1963	18,600	18,170	977
1964	18,800	18,720	996
1965	19,000	19,500	1,026

6. The utilization rate is projected five to ten years into the future based on the trend experienced during the past five years, modified by expectations about changes in the factors which influence the demand for hospital care. Projections are made to specific years for which health care facility needs are to be determined.

Year	Utilization Rate	
1960	911	
1961	935	
1962	957	13% increase
1963	977	
1964	996	
1965	1,026	
1970 (estimate)	1,160	13% increase (estimate)
1975 (estimate)	1,310	13% increase (estimate)

The factors which influence the demand for hospital care include:

Demographic	As this factor increases it tends to affect hospital use in the following manner
population	+
% of population in female 14-44 age group	+
% of population in 65 and over age group	+
% of population living in urban areas	+
% of population married	-
% of population with little education	-
% of population nonwhite	-
Economic	
% of population with high income	+
% of population covered by health insurance	+
Medical	
physician/population ratio	+
specialist/population ratio	+
hospital beds/population ratio	+
availability of alternatives to hospital care	-

Legislation	As this factor increases it tends to affect hospital use in the following manner
Medicare	+
Medicaid	+
Community Mental Health Centers Act	+

7. One problem which must be considered in making projections from the utilization rate experienced during the past five years is that utilization may be artificially low because hospital facilities are inadequate to meet the potential demand. In other words, the utilization rate would have been higher had more beds been available. In determining whether such a situation exists, the physicians in the community should be consulted and a number of indicators of bed shortage examined.

   a. high occupancy rates

   b. short average length of stay

   c. waiting list for admissions

   d. difficulty of admission for elective procedures

   e. beds set up in halls and day rooms

   f. cancellations of scheduled surgery

8. The projected utilization rate is applied to the projected population to determine the estimated number of days of hospital care that will be provided in the future. This is divided by 365 to determine the estimated average daily census. Since hospitals cannot operate at 100% occupancy the average daily census is divided by the planned occupancy rate to determine the number of beds needed.

Year	Projected Service Area Population		Projected Utilization Rate		Estimated Patient Days of Care
1970	20,060	x	$\frac{1,160}{1,000}$	=	23,270
1975	21,190	x	$\frac{1,310}{1,000}$	=	27,760
1970	$\frac{23,270}{365}$	=	64 average daily census		
1975	$\frac{26,260}{365}$	=	76 average daily census		

1970	$\frac{64}{80\%}$	=	80 beds needed
1975	$\frac{76}{80\%}$	=	95 beds needed

(As noted above, separate determinations should be made for the number of beds needed for each clinical service rather than for the hospital as a whole.)

9. Estimates are also made of the quantity of service that will be provided by the major diagnostic and therapeutic departments in the hospital. These estimates are based on the trends experienced during the past five years in the use of these services.

   a. Lab tests per admission (or per patient day)

   b. X-ray examinations per admission (or per patient day)

   c. Surgical procedures per surgical admission (or per patient day)

   d. PT treatments per medical-surgical admission (or per patient day)

   e. Prescriptions per admission (or per patient day)

10. The projections of the use of services are modified by expected changes in the pattern of services, changes in hospital policy, and advances in medical care. Consultation with the medical staff of the hospital is essential in developing projections of the use of diagnostic and therapeutic services. Many factors must be considered.

    a. The addition of new services

    b. The addition of specialists to the medical staff

    c. The actions of other hospitals

    d. New hospital policies

       (1) All patients must have a chest X-ray upon admission.

       (2) All patients must have certain laboratory tests as part of their admission workup.

       (3) Outpatients may have prescriptions filled in the hospital pharmacy.

11. The levels of inpatient, outpatient, diagnostic, and therapeutic services which the hospital will be required to provide in the future are translated into the facilities needed to accommodate these services. This translation is based on past experience, general standards developed in the hospital field, and the efficiency of hospital operations. General standards regarding the square feet of space, equipment, and other facilities needed in an average or typical patient room ,delivery room, operating room, laboratory, X-ray department, etc., also exist, although they must be tailored to the local situation.

    a. One bed in a patient room can accommodate one patient per day.

    b. One operating room can accommodate five to six surgical procedures per workday.

    c. One outpatient or emergency room examination and treatment station can accommodate 12 to 14 patient visits per workday.

12. After estimates have been made of the hospital facilities which will be required in the future, the hospital (space, beds, equipment, and other facilities) is evaluated to determine its adequacy to meet these future requirements. The adequacy of individual departments is evaluated in terms of the following questions:

    a. Can the future workload requirements be handled in the department?

    b. Can the work be done safely?

    c. Can the work be done reasonably efficiently?

    d. Can the work be done with due regard for the patients' dignity?

13. Recommendations are made regarding the amount and type of modernization, expansion, or new construction that will be required to provide hospital facilities adequate to meet future workload requirements. In developing such recommendations, community resources must be considered.

a. construction funds

b. operating funds

c. availability of physicians

d. availability of specialists

e. availability of paramedical personnel

f. availability of services in other hospitals

14. Essentially the same steps are undertaken regarding other health care facilities, nursing homes and home care programs. Future utilization is estimated, the adequacy of existing facilities to meet these levels of service is evaluated, and recommendations are made as to the modernization, expansion, or addition of facilities.

15. Emphasis is placed on areas of potential cooperation, coordination and consolidation of effort among health care facilities. Opportunities for the sharing or joint cooperation of services exist in many areas.

a. laundries

b. blood banks

c. purchasing

d. ambulance services

e. nursing schools

f. X-ray therapy

g. intern and residency training programs

h. rehabilitation

i. personnel

j. pharmacy

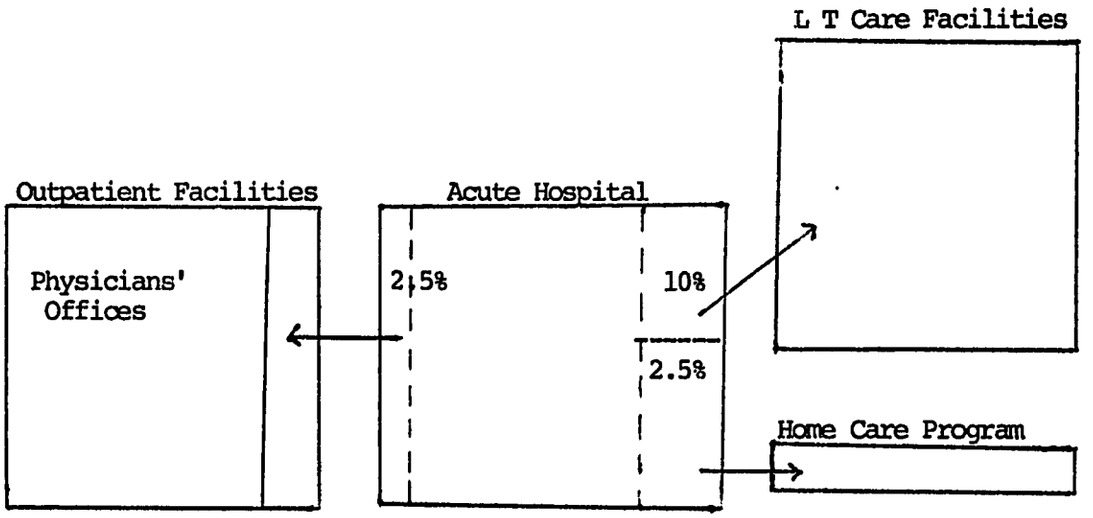
k. cardiac and neurosurgery

l. premature nurseries

m. laboratory services

16. Emphasis is placed on the entire community health care delivery system and on the savings in construction and operating funds and the improvements in patient care that can be achieved through the development of appropriate relationships among the elements in the system. For example, many studies have shown that a significant number of patients in acute hospitals do not need to be in the hospital but could be adequately cared for at home (assuming a home care program is available in the community), on an ambulatory basis (assuming outpatient facilities are available), or in rehabilitation facilities, extended care facilities, nursing homes, homes for the aged, or foster homes (again, assuming these facilities are available). Unnecessary acute hospital use is estimated to be as high as 10% to 20% of the days of care rendered. Since alternative facilities are less expensive to construct and operate and since they can meet appropriate levels of medical need, it is important that the community have an adequate supply of each type of facility and that the community health care system encourage the prompt movement of patients to the type of facility that best meets the patient's medical needs.

Community Health Care Delivery System



III. B. II. Queuing and Inventory Problems

A queue is any backlog of tasks waiting to be performed - a pile of unanswered letters on a desk to out-patients requiring examinations. Due to uncertainty and scarcity of resources, queues and bottlenecks are almost inevitable. Queuing problems utilize alternative measures to improve service provision, and such problems can also be described as involving "probablistic service"..

There are 9 basic characteristics describing any queuing problem:

1. There is a service facility.

2. There are customers requiring services.

3. There are servers providing service to the customers. Thus, a clinic is a facility with doctors and nurses treating patients. No problem would exist if there were enough doctors to immediately see every patient; however, the doctors would be idle for long periods. Thus, a balance is sought between waiting and service costs.

4. There is a customer arrival pattern, in terms of inter-arrival time of successive customers.

5. There is a service pattern, in terms of the distribution of service time, approximated by a probability distribution.

6. There is a queue discipline - the order in which customers receive service. Examples include a "first come-first serve" discipline or an appointment scheme.

7. There is a server arrangement - generally in a "parallel" or "series" fashion. Three possible queuing systems are shown in Figure 7.[1]

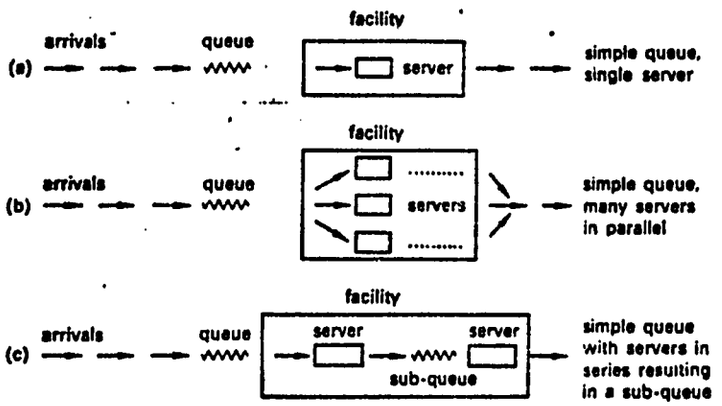


FIGURE 7 *Three queueing systems*

8. There are customer cost arising from the time queuing and in service, and the benefit derived.

9. There are the service cost of the facility and the servers both when idle and when in service.

In industrial contexts, explicit resource costs are obtainable. How customers cost (value) their idle time is difficult to calculate and is generally inferred by observation of those leaving the queue when it is considered to long or too slow.

Hospital queue costs are difficult to define. What is the cost of keeping a patient waiting? What is the cost of rejecting a patient? Is it desirable to put these costs in monetary terms?

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1. G. Luck et al., "Patients, Hospitals, and Operations Research", Tavistock, London, 1971, p. 97.

A flow diagram links the procedures for tackling a queuing problem.[1]

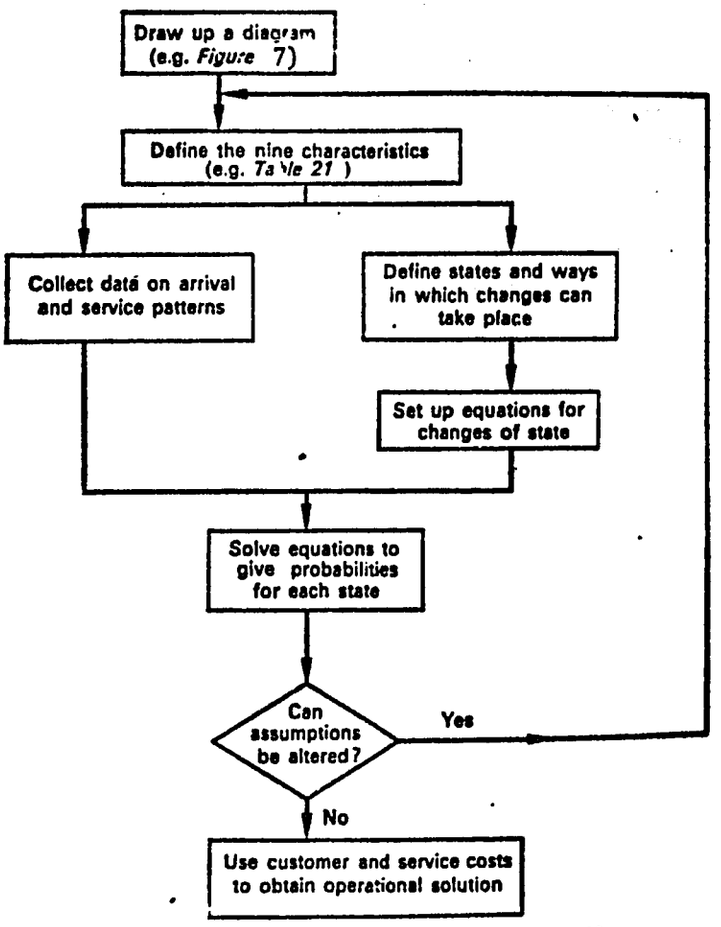

FIGURE 8 *Procedures for tackling a queueing problem*

A hospital can be looked upon as a system of queues linked together. In the past, out-patient clinics have been extensively studied by queuing methods in order to develop appointment systems; yet, important aspects of the inpatient system have not been extensively studied.

1. Luck, op. cit., p. 102.

Table 4 summarizes four hospital queuing problems.[1]

Four hospital queueing problems

	Inpatient waiting list	*Outpatient waiting list*	*Outpatient clinic waiting*	*Operating theatre lists*
Facility	Inpatient care	Outpatient clinic	Outpatient clinic	Operating theatres
Customer	Patient referred from outpatient dept	Patient referred by GP	Patient with appointment	Patient recommended for surgery
Server	Staffed and equipped bed	Doctor and consulting room	Doctor and consulting room	Surgeon
Arrival pattern	Weekly binomial probability distribution	Usually random	Unpunctuality around appointment times	Planned admission but patients do not always arrive
Service pattern	Length of stay skew probability distribution	Fixed number of appointments each week	Consultation time variable	Weekly timetable of theatre sessions
Queue discipline	Varied; usually three categories, urgent, soon, other	Usually first come first served; may be screened for urgency	Usually appointment order	Order of list made up by surgeon to his preference
Arrangement of servers	Parallel with traditional ward; series-parallel with progressive patient care	May be complex if consultant, junior, and clinical assistant	May be complex if consultant, junior, and clinical assistant	Single server; sometimes two theatres in parallel
Customer cost	Benefit: diagnosis, treatment, and care. Waiting cost: deterioration, inconvenience	Benefit: diagnosis, referral to treatment. Waiting cost: deterioration, anxiety, inconvenience	Benefit: diagnosis, referral to treatment. Waiting cost: time sitting in outpatient dept	Benefit: probable improvement in condition or prevention of deterioration. Waiting cost: deterioration, inconvenience
Service cost	Building, equipment, staff	Building, equipment, staff	Loss of time for doctor if patients unpunctual	Operating theatre, equipment, staff

Inpatient waiting lists enable the hospital to smooth out its work load and act as an allocative mechanism in choosing between hospitals. The list is an indicator for planning the expansion and contraction of resources. (Possible on a long-term basis.) Queue discipline determines the way patients are removed from the list for admission - generally in priority terms of "urgent", "soon", and "in turn". Planners need to know the average rate of additions to the list and to see how far these are in balance with the admissions to hospital.

1. G. Luck, op. cit., p. 107.

Queuing will not be eliminated as it is impossible to accurately predict (1) emergency admissions and (2) the way in which individual patients respond to treatment. Probability distributions approximate these assumptions made about arrivals and service times. Thus, in a non-appointment setting, one assumes that the probability of an arrival at a given moment is constant over time - an arrival at 10:15 A.M. is equally as likely as one at 10:15 P.M. This situation is approximated by a Poisson distribution. The only parameter needed to make the estimation is the average arrival rate. Service times are also assumed to constantly terminate "at the next moment". Thus, a patient after 20 minutes of service and one with 15 minutes are both assumed to terminate the next minute. Negative exponential distributions describe this situation. The only parameter needed to make the estimation of the service time variability is the average service time (arrival rate/service rate). This ratio can't exceed one, or the queue will grow indefinately as arrivals are faster than the ability to service them. Table 2 shows the beginning of the clogging phenonemon as the arrival rate (col. 1) approaches the service rate (col. 2).[1]

Steady-state operating characteristics of paediatric clinic

Mean interval between arrivals (min) (60/A)	Mean service time (min) (60/R)	Ratio of arrival rate to service rate (A/R)	Patient-oriented characteristics: Mean time (min)		Patient-oriented characteristics: Mean no. of patients in clinic		Staff-oriented characteristics
			Waiting	Total	Waiting	Total	Proportion of time doctor idle (%)
40.0	10	0.25	3	13	0.1	0.3	75
20.0	10	0.50	10	20	0.5	1.0	50
13.3	10	0.75	30	40	2.2	3.0	25
11.1	10	0.90	90	100	8.1	9.0	10
10.5	10	0.95	190	200	18.0	19.0	5
10.1	10	0.99	990	1000	98.0	99.0	1

1. Grundy and Reinke, op. cit., p. 164.

Reinke[1] offers three remedies - a) remove chance arrivals by instituting an appointment system, b) redesign the clinic to handle less than its capacity of 6 patients hr. (col. 2), c) add additional services, say an additional physician. Thus, the model is useful if it can foresee the need to consider these alternatives to avoid difficulties.

Inventory Problems. Queuing problems are related to inventory problems as both concern accumulations with additions to them and substractions from them. In queuing problems, additions are random and beyond direct influence while substractions are controlled through service. In inventory problems, additions are subject to at least partial control, through reordering, but substractions are often random beyond the control of the organization maintaining the inventory. The uncertainties affecting stability include changes in demand, scheduled services, and rates of innovations. Hundreds of inventory modes, classified generally by product, level, location and price makes this the most developed aspect of operations research. The problems are served analytically or by simulation utilizing queuing, linear programming and dynamic programming models.

Health applications include estimating service, net profit, and supply needs. Computer models can maintain perpetual inventory information, write purchase orders and print daily and monthly reports. Predicted use of hospital items is facilitated by exponential smoothing and regression analysis.

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[1] op. cit, p.64

A model of a community hospital's arrivals and discharges has been simulated by S. Heda into a game. The objective is to aid the admitting officer to plan a stable occupancy as well as instantly examine the consequences of various admission and discharge decisions. Seven days are simulated with each day divided into five parts. Emergency, medical, surgical, and obstetrical patients arrive into, and transfer between intensive and coronary care units, med-surgery wards, and OB/GYN floors as shown in the Flow Diagram. Arrival patterns and mean LOS (Length of Stay) are often based on historical information. One week's simulation is played with summary statistics offered on the last page.

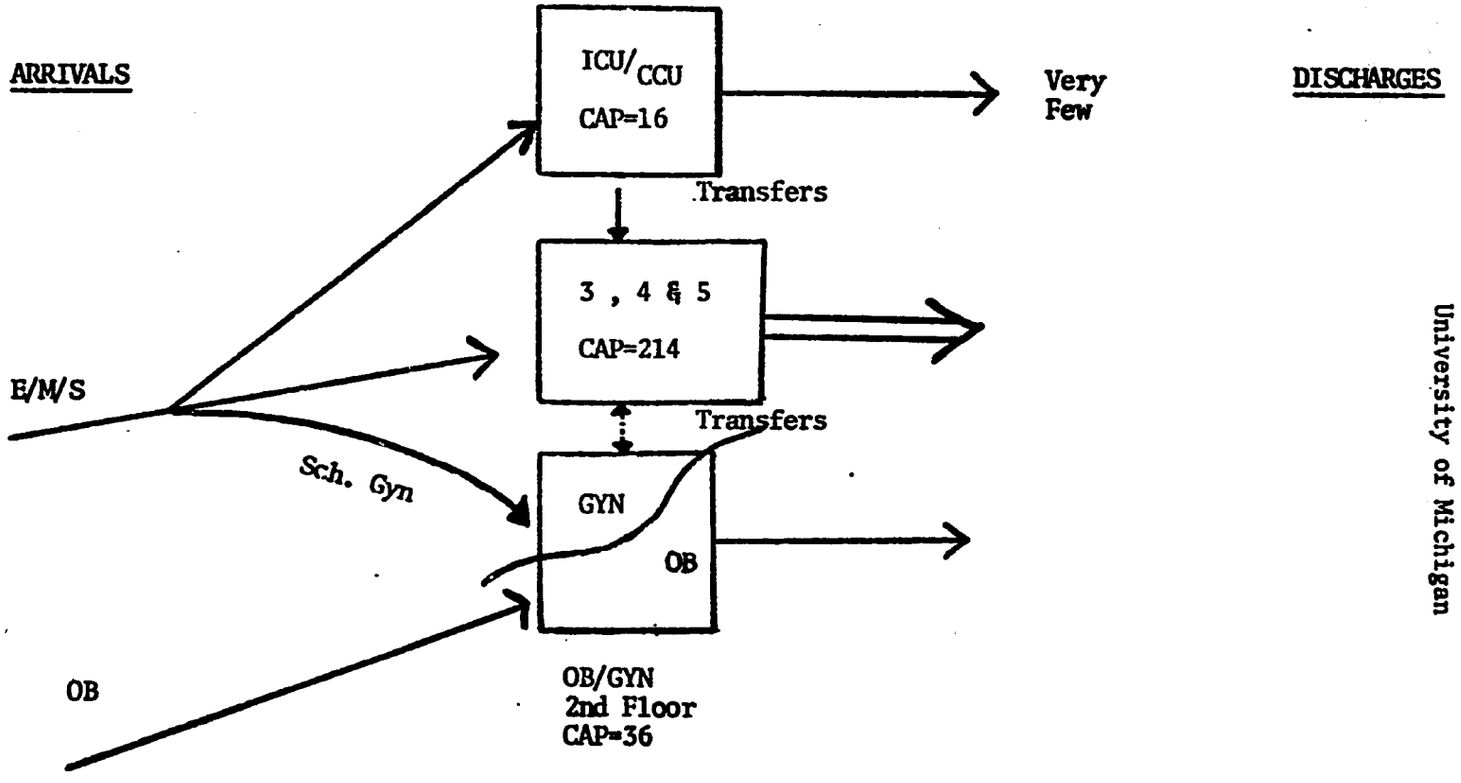
Thus, gaming is simulation with human intervention. The utility of the game as a pedagogical devise is that it tests changes in performances based on changes in circumstances and data under the user's control. Gaming is very expensive.

EXAMPLE 1

A SIMULATION-GAME FOR HOSPITAL DECISION MAKING

S. Heda
University of Michigan

FLOW DIAGRAM



SIMULATION MODEL

Time Schedule:

Time	3, 4, & 5	OB/GYN	ICU
Midnite	Census	Census	Census
	Emergency Arrivals	OB Arrivals Discharges	
7 a.m.	Emergency Arrivals		
9 a.m.	Emergency arrival Discharges (4/5) Transfers from ICU/CCU		Transfers out
11 a.m.	Emergency arrivals Discharges (1/5) Transfers from ICU Sched. Medical Arrival Cancellations		Transfers out
1 p.m.	Emergency arrival Transfers from ICU Call Ins. Scheduled Surgical Cancellations Gyn from 2nd Floor	Gyn Arrival OB Arrival Cancellations	ICU Arrival Transfers Out Overflow
Midnite	Census	Census	Census

ARRIVAL PATTERNS:

	M.	T.	W.	Th.	F.	S.	S.
Scheduled Medical	3	3	3	3	6	6	3
Scheduled Surgical	15	14	14	14	0	0	17

[Scheduled surgical includes gyn, which are poisson distributed with mean of 2/day]

Arrival to Queues:

Medical	Poisson with mean 7/day
Surgical	Poisson with mean 12/day

Emergency Arrivals: (All Poisson)

Midnite	- 7 a.m.	.7	Mean Arrival Rates
7 a.m.	- 9 a.m.	2.33	
9 a.m.	- 11 a.m.	.29	
11 a.m.	- 1 p.m.	.29	
1 p.m.	- Midnite	3.38	
	Total	7.0 / Day	

OB Arrivals:

Poisson with means of

Midnite	- 1 p.m.	2.5 / Day
1 p.m.	- midnite	2.5 / Day
	Total	5.0 / Day

ICU/CCU Admissions Poisson with mean 2/Day

OTHER DISTRIBUTIONS

1. Isolation beds mean = 2/day

2. Length of stay (means)

ICU/CCU	-	6/days
OB	-	3.8/days
GYN	-	3.5/days
MED	-	10.0/days
SURG	-	5.5/days
Emergency	-	11.5/days
ICU/Transfers	-	10.0/days

```
 THIS PROGRAM IS A SIMULATION GAME FOR UNDERSTANDING THE DECISION
MAKING PROCESS OF THE ADMITTING OFFICE IN A HOSPITAL.
THE OUTPUT IS SELF-EXPLANATORY. INPUT SHOULD BE RIGHT ADJUSTED UNDER XS

IF YOU HAVE ANY QUESTIONS, CONTACT :
          SHYAM HEDA
          BUREAU OF HOSPITAL ADMINISTRATION
          UNIVERSITY OF MICHIGAN
          TEL NO.: 764 1394

DO YOU WISH EXPECTATIONS OF THE DAY PRINTED?
TYPE YES OR NO
yes
DO YOU WISH 24 HRS DISCHARGE INFORMATION?
TYPE YES OR NO
yes

DELAY TIME : SURG =  23 DAYS
             MED =  13 DAYS

THE MEDICAL & SURGICAL ALLOWANCES IN THE PROGRAM ARE :
       MON TUE WED THU FRI SAT SUN
MED      3   3   3   3   6   6   3
SUR     15  14  14  14   0   0  17

DO YOU WISH TO CHANGE THESE ALLOWANCES?
TYPE YES OR NO
no

    MONDAY
MID-NITE CENSUS...
3,4&5 FLOORS                 208
2ND FLOOR                     13
ICU/CCU                       12

EMER ADM (12-7) :  1
EMER ADM (7-9)  :  4

 9 A.M. :
CENSUS = 213
PATS AWAITING TRANSFER FROM ICU :  1

EXPECTATIONS TO-DAY ...
DISCHARGES : 17 (MAX= 24,MIN= 11)
SCHED.MED :   3
SCHED.SUR :  15( INCL GYN EXP ADM = 2)
EMER.ARRIV :  5 (MAX=  8,MIN=  2)
ISOLATION BEDS :  3
EMPTY BEDS : -6 (MIN=-15,MAX=  4)
FOR AVAIL. BEDS = 211
(TRANSFERS NOT INCLUDED)
(NEG. NUMBER INDICATES OVERFLOW)

OB/GYN...
```

```
(TRANSFERS NOT INCLUDED)
(NEG. NUMBER INDICATES OVERFLOW)

OB/GYN...
EXP. DISCH. :  7 (MIN=  3, MAX= 11)
EXP. OB ADM = 5 AND GYN ADM = 2

HOW MANY TRANSFERS NOW ?
XX


DISCH. TOMORROW : 16

11 A.M. :
DISCH TILL 11AM : 21
EMER ADM(9-11) :   0
= CENSUS : 192
PATS AWAITING TRANSFER FROM ICU :  1
HOW MANY TRANSFERS NOW ?
XX
 1
HOW MANY CALL INS ?
WAITING LINE HAS 50 PATS
XX

IF YOU WISH TO CANCEL ANY SCHEDULED PATIENTS ENTER BELOW
MED SUR
 XX  XX

1 P.M. :
DISCH (11-1) :     3 (TOT DISCH= 24 )
EMER ADM(11-1) :  0
SCH MED ADM :     3
= CENSUS : 193
AVAIL. BED CAPACITY : 211
STILL TO COME .....
SCHED SURG : 11
EXPECTED EMER AFTER 1PM :  4
EXP EMPTY BEDS =   3
(INCLUDING ALL CALL INS & TNANS.)
ICU/CCU CENSUS :  11

2ND FLOOR ACTIVITY
DISCH  :  6
OB ADM(AM) :  1
= CENSUS :  8
STILL TO COME...
GYN SCHED :  4
EXP OB : 2.5
HOW MANY GYN TO 3,4,5 ?
XX

GYN CANCELLATIONS ?
XX

HOW MANY ADDITIONAL CALL INS ?
YOU HAVE ALREADY CALLED   0
XX
 3
DO YOU WISH TO CANCEL ANY SURGICAL PATS ?
ENTER NUMBER BELOW
XX

NUMBER OF PATS CALLED IN :    3
NUMBER OF PATS CAME IN :      3
EMER ADM AFTER 1PM :  3
```

```
NUMBER OF PATS CALLED IN :     3
NUMBER OF PATS CAME IN :       3
EMER ADM AFTER 1PM :  3
ICU ADMISSIONS :  1
OB ADMISSIONS(PM):  3

   TUESDAY
MID-NITE CENSUS...
3,4&5 FLOORS                 210
2ND FLOOR                     15
ICU/CCU                       12

EMER ADM (7-9)  :  1

 9 A.M. :
CENSUS = 211
PATS AWAITING TRANSFER FROM ICU :  1

EXPECTATIONS TO-DAY ...
DISCHARGES : 21 (MAX= 28,MIN= 15)
SCHED.MED :   3
SCHED.SUR :  14( INCL GYN EXP ADM = 2)
EMER.ARRIV :  5 (MAX=  8,MIN=  2)
ISOLATION BEDS :  1
EMPTY BEDS :  3 (MIN= -6,MAX= 13)
FOR AVAIL. BEDS = 213
(TRANSFERS NOT INCLUDED)

OB/GYN...
EXP. DISCH. :  7 (MIN=  3, MAX= 11)
EXP. OB ADM = 5 AND GYN ADM = 2

HOW MANY TRANSFERS NOW ?
XX
 1

DISCH. TOMORROW : 31

11 A.M. :
DISCH TILL 11AM : 10
EMER ADM(9-11) :   0
= CENSUS : 202
HOW MANY CALL INS ?
WAITING LINE HAS 53 PATS
XX

IF YOU WISH TO CANCEL ANY SCHEDULED PATIENTS ENTER BELOW
MED SUR
 XX  XX

1 P.M. :
DISCH (11-1) :    6 (TOT DISCH= 16 )
EMER ADM(11-1) :  0
SCHED ADM :       3
= CENSUS : 199
AVAIL. BED CAPACITY : 213
STILL TO COME .....
SCHED SURG : 13
EXPECTED EMER AFTER 1PM :  4
EXP EMPTY BEDS =  -3
(INCLUDING ALL CALL INS & TRANS.)
ICU/CCU CENSUS :  11
```

```
EXP EMPTY BEDS
(INCLUDING ALL CALL INS & TNANS.)
ICU/CCU CENSUS :  11

2ND FLOOR ACTIVITY
DISCH  :  5
OB ADM(AM) :  3
= CENSUS : 13
STILL TO COME...
GYN SCHED :  1
EXP OB : 2.5
HOW MANY GYN TO 3,4,5 ?
XX

GYN CANCELLATIONS ?
XX

HOW MANY ADDITIONAL CALL INS ?
YOU HAVE ALREADY CALLED   0
XX

DO YOU WISH TO CANCEL ANY SURGICAL PATS ?
ENTER NUMBER BELOW
XX

EMER ADM AFTER 1PM :  1
EMER. OVERFLOW FROM 3,4&5 :  1
HOW MANY OVERFLOW TO ICU ?
XX
 1
ICU ADMISSIONS :  2
INCLUDED OVERFLOW :  1
OB ADMISSIONS(PM):  2


  WED-SDAY
MID-NITE CENSUS...
3,4&5 FLOORS                213
2ND FLOOR                    16
ICU/CCU                      13

EMER ADM (12-7) :  1

 9 A.M. :
CENSUS = 214
EMER AWAITING ADM :  1
PATS AWAITING TRANSFER FROM ICU :  3


EXPECTATIONS TO-DAY ...
DISCHARGES : 23 (MAX= 31,MIN= 16)
SCHED.MED :   3
SCHED.SUR :  14( INCL GYN EXP ADM = 2)
EMER.ARRIV :  5 (MAX=  8,MIN=  2)
ISOLATION BEDS :  1
EMPTY BEDS :  1 (MIN= -9,MAX= 12)
FOR AVAIL. BEDS = 213
(TRANSFERS NOT INCLUDED)

OB/GYN...
EXP. DISCH. :  7 (MIN=  3, MAX= 12)
EXP. OB ADM = 5 AND GYN ADM = 2

HOW MANY TRANSFERS NOW ?
XX
```

THE SUMMARY STATISTICS OF THE WEEK...

AVE. CENSUS	206.14
AVE OCCUPANCY	96.33
TOT SURGICAL ADMISSIONS	59.
TOT MEDICAL ADMISSIONS	58.
AVE NO. OF EMER. ADMISSIONS	6.14
TOT. MEDICAL CANCELLATIONS	0.
TOTAL SURGICAL CANCELLATIONS :	3.
TOTAL EMER. TURNED AWAY 12-7 AM :	0.
TOTAL EMER. TURNED AWAY 1-12 PM :	0.
TOTAL PATS FAILED TO BE TRANSFERRED FROM UNIT:	0.
TOTAL PATS NEEDED TO BE TRANSFERRED FROM UNIT:	15.
TOTAL PATS ADMITTED THRU CALL INS :	31.
TOTAL PATS FAILED TO BE ADMITTED THRU CALL INS :	3.
TOTAL UNUSEABLE BEDS :	18.

OB/GYN FLOOR STATISTICS....

AVE. CENSUS	18.00
AVE. OCCUPANCY	50.00
TOTAL OB ADM	31.
TOTAL GYN ADM TO 2 FLOOR	12.
TOTAL GYN ADM TO 3,4&5	0.
TOTAL GYN CANCELLATIONS	0.
TOTAL OB CANCELLATIONS	0.

ICU/CCU STATISTICS...

AVE. CENSUS	14.00
AVE. OCCUPANCY	87.50
TOTAL ICU ADM	18.
TOTAL OVERFLOW TO ICU	1.
TOTAL ICU CANCELLATIONS	0.

NUMBER OF SIMULATED DAYS... 7

DO YOU WISH TO CONTINUE FOR ANOTHER WEEK ?
WRITE YES OR NO
no

NUMBER OF SIMULATED WEEKS... 1

III. B. III.

INTRODUCTION TO NETWORK PLANNING TECHNIQUES

The Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) are both very powerful management tools for analyzing and planning large and complex projects. Both were developed in the late 1950's and are quite similar since both are based on a graphical portrayal of the interrelations between jobs. The minor differences between them are of no significance, as will be shown later on, but this text will use the notation of CPM.

CPM is a planning technique for any project which has a beginning and an end. A project, as used here, is made up of many jobs or tasks. It can be used on any project from getting up and off to work in the morning, to building a battleship, and to the planning of a water pollution survey. The method allows a planner to conceive and plot the entire project without initial regard to time. The planner concentrates his attention on arranging the various jobs within the project into the most logical or best sequence to complete the project.

For example, the project may be "getting up and off to work in the morning." If one considers the various jobs making up this project as non-concurrent and arranges them in logical order, one may end up with a straight line sequence as shown below in Figure 1.

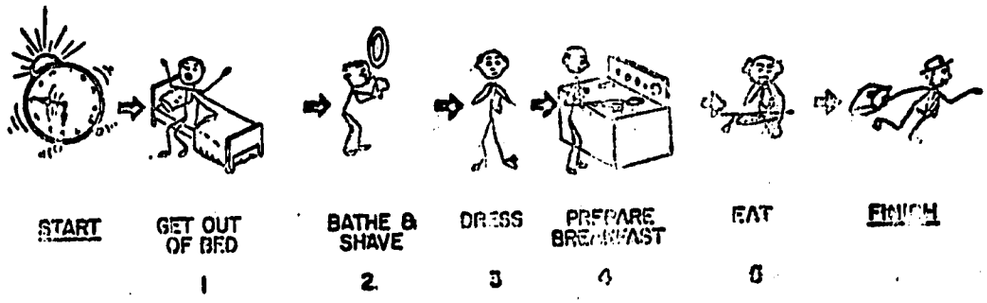


Figure 1.

There are altogether five jobs, each dependent upon the one immediately proceeding. Job 5 can not start until job 4 has been completed. One can not eat breakfast until breakfast has been prepared. This basic concept is the heart of the CPM.

Now if the little man in the illustration could get his little woman to get up and fix him his breakfast, one would have some concurrent jobs in the project and the sequence might be as illustrated below in Figure 2.

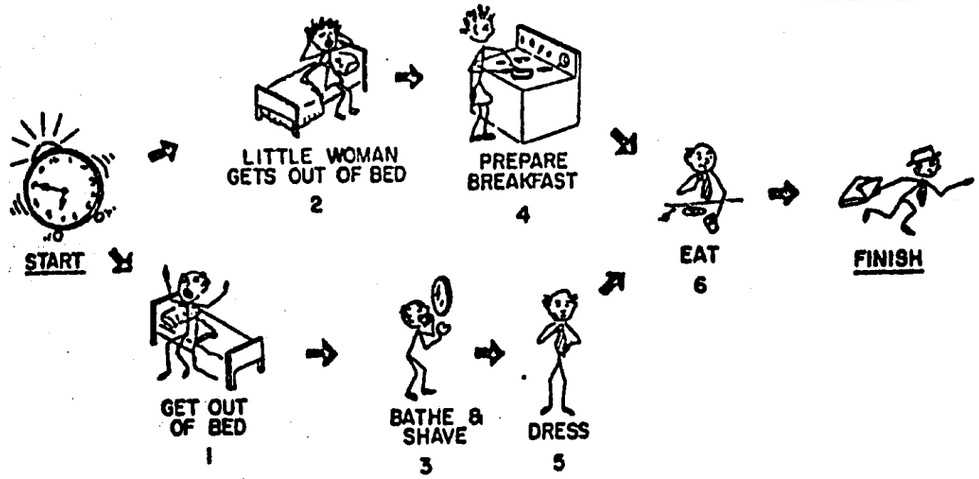


Figure 2.

Drawing these illustrations requires quite some artistic talent (which not every manager has) and time, and therefore an abstraction of the problem is in order. Let a circle indicate a job or task, and let an arrow indicate the sequence in which they have to be performed. This will lead to a graph or network as shown in Figure 3.

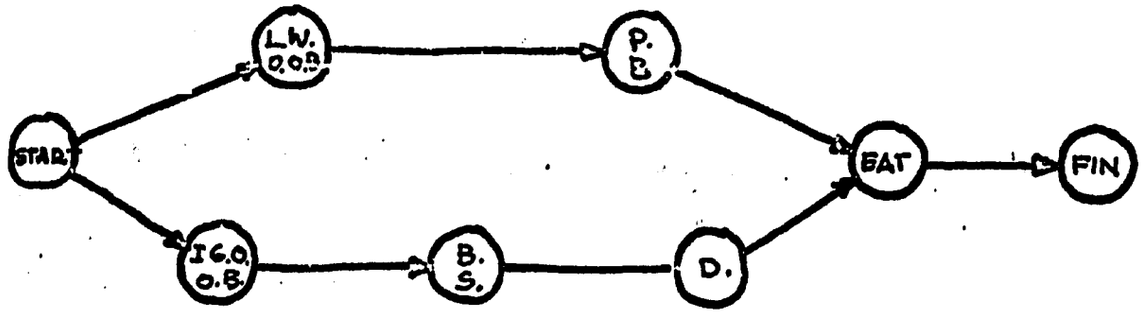


Figure 3.

One thing becomes obvious. The drawing of the graph or network is relatively easy, but writing the full description of the individual task is difficult due to space limitations. The two possibilities are: one, to abbreviate the description of the job as done in Figure 3, or two, to just use a unique number for each job which is referenced in a table.

Job number	Job description
0	Start
1	Get out of bed
2	Little woman out of bed
3	Bathe and shave
4	Prepare breakfast
5	Dress
6	Eat breakfast
7	Finish

Before proceeding any further the logic of the network should be checked. This can be done by taking each job at a time and asking three questions:

1.) Have any jobs been overlooked which have to be accomplished before this one can be done and are those shown correct?

2.) Have any jobs been overlooked which can be done concurrently and are those shown correct?

3.) Have any jobs been overlooked which follow this job and are those shown correct?

Once the network passes this check, a time estimate must be assigned to each job. This time estimate must be expressed in the same time units for each job within the project. Depending on the project, this may be years, months, days, hours or minutes. Whichever best suits the situation should be used. In the example here minutes will be used. If one enters this time in the circle below the identification number, the network as shown in Figure 4 will result.

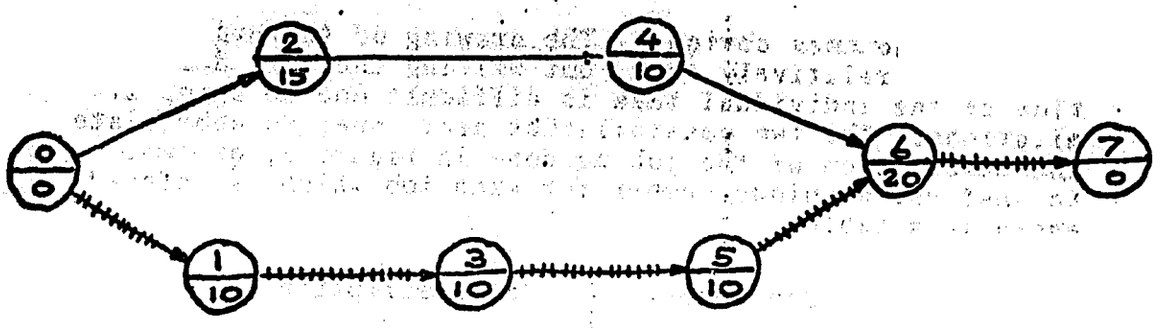
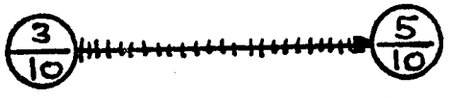


Figure 4.

Now, irrespective of how the CPM diagram looks like; however simple or complicated -- there must be one sequence of jobs that takes the longest time between start and finish. In this project, it can readily found to be the sequence of jobs 0, 1, 3, 5, 6, & 7. This then represents the shortest completion time possible since the project cannot be finished any sooner than the total time it takes to perform the jobs on the path, one after another. This sequence of jobs, called the CRTICIAL PATH, is defined as the series of consecutive jobs which takes the longest time to complete in the project. One can indicate the activities on the critical path by drawing slashes through the connecting arrows:



It follows then that the time for the entire project can neither be shortened or lengthened, unless one or more of the individual jobs on the critical path are either shortened or lengthened. Also, if one or more of the jobs of the critical path are lengthened, a new critical path and a new total time for the project may result. For example, if it takes the little woman twenty minutes to get out of bed, the critical path will change and we may be late getting to work.

Now, let the project be changed a little. Suppose there is a house guest, who also wants to go to work at the same time. He can be added to the diagram in the following way:

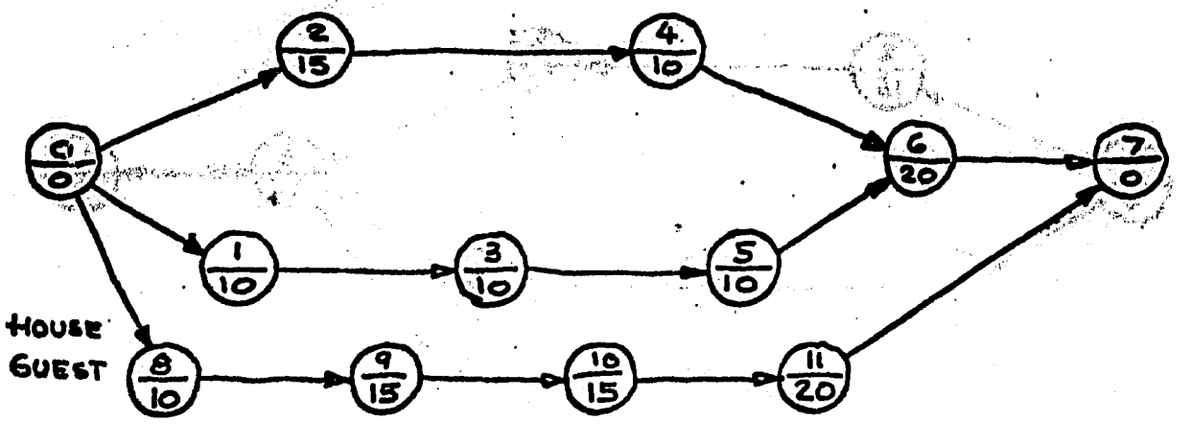


Figure 5.

Note that the following jobs have been added

Job number	Job description	Job time
8	house guest gets up	10
9	house guest bathes	15
10	house guest dresses	15
11	house guest eats	20

Checking this diagram, it appears to be advantageous to eat breakfast together. This can be taken care of by combining the individual jobs into one. At the same time an error in the diagram can be corrected. The error is that the diagram does not show that breakfast has to be prepared before the house guest can eat.

What about the bathroom situation? If there is only one bathroom, then its use must be scheduled properly. I suppose the house guest is allowed into the bathroom only after I have finished, this will require the introduction of the arrow from 3 to 10. Introduction of this branch puts now all jobs in the proper and logical order. This network is shown in Figure 6.

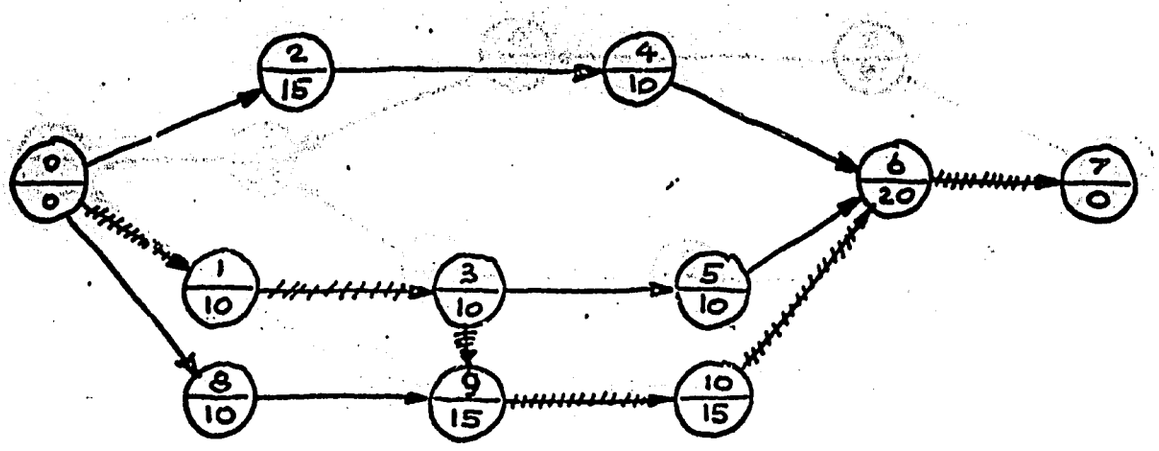


Figure 6.

Earlier it was mentioned that the critical path was made up of the series of consecutive jobs which takes the longest time to complete the project; looking at Figure 6 it can be seen that this path goes through the jobs 0, 1, 3, 9, 10, 6 & 7. By adding the time for each job along this path a total of seventy (70) minutes will be obtained. This is the time it will take to complete the project.

In this very simple example shown here it was not difficult to find the critical path and it was found by mere inspection. However, when the number of jobs is in the hundreds, an inspection will not suffice and a more formal procedure to find the critical path will be necessary. At the same time these calculations will reveal some very interesting other information.

To start this computational procedure, place two boxes to the left and the right of each job in the network. The two boxes to the left of each job will contain the earliest and latest starting time, and the boxes to the right will contain the earliest and latest finish times. Two paths will be made through the network; in the forward path, the earliest starting and finishing times will be computed; in the backward path the latest starting and finishing times will be determined.

A formal description of the two algorithms is as follows:

A. <u>Earliest Start (ES) and Earliest Finish (EF) Times</u>

Suppose the starting time or date for a project is given (denote it by S), then there exists for each job an earliest starting time (ES), which is the earliest possible time that a job can begin, if all its predecessors are also started at their earliest starting times. If the time it takes to finish a job is denoted by t, then the earliest finish time (EF) is equal to ES+t.

To compute the ES and EF times of each job of a project refer to the project graph. Proceed as follows:

1. Mark the value of S to the left and to the right of START

2. Consider any unmarked job all of whose predecessors have been marked and mark to the left of the job the largest number marked to the right of any of its immediate predecessors. This number is the earliest start time (ES) of this job.

3. Add to the ES time the time it takes to finish the job and mark the resulting earliest finish time (EF) EF = ES+t to the right of the job.

4. Continue until FINISH has been reached.

   Having finished then all calculations each job will have been marked; on the left side of the job is the earliest starting time and on the right side the earliest finish time. The number appearing to the right of the last job, FINISH, is the earliest finish time for the entire project.

B. Latest Start (LS) and Latest Finish (LF) Times

Suppose now that a target time (T) is given at which the project must be finished. This usually will be a calendar date. Then the question arises as to what the latest time is that the project can be started and still finished in time. Off course, T must be greater (later) than or equal to F, otherwise the project can never be finished in time. Assuming then that T is greater than F one can determine the latest time at which a job must be finished (LF) without delaying the total project beyond target time. By analogy, then one can calculate also a latest start time (LS) LS = LF - t for each job.

The computations leading to LS and LF are similar to the previous ones, except that one works from the end of the project graph. Proceed as follows:

1. Mark the value of T to the right and left of FINISH.

2. Consider any unmarked job all of whose successors have been marked and mark to the right of the job the smallest LS time marked to the left of any of its immediate successors. This number is the latest finish time (LF) of this job.

3. Subtract from the LF time the time it takes to complete the job and mark the resulting latest start time (LS) LS = LF - t to the left of the job.

4. Continue until START has been reached.

   At the end of these calculations each job will have a LS and LF time; the number LS associated with START is the latest time at which the entire project can be started and still be finished at target time T.

C. Total Slack (TS) and Free Slack (FS)

The total slack (TS) of a job is defined as the difference between LS and ES (or LF-EF) and denotes the time that a job can be delayed without delaying the project. Free slack (FS) is the amount of time a job can be delayed without delaying the early start of another job. It is defined as the difference between the job's EF time and the smallest (earliest) of the ES times of all its immediate successors. The free slack is always smaller than or equal to the total slack.

The description of these computations sounds very difficult, but is actually very simple once one gets the "hang of it". Refer to Figure 7 and the forward path through the network. Assuming a starting time of zero, we place a zero in both earliest start and finish time of the job START. The earliest time jobs 1, 2 and 8 can be started is time zero, and therefore we place a zero in the appropriate box. And the earliest finish times are then 10, 15, and 10, respectively. The earliest starting time of job 3 is then 10, and its earliest finish time is 20. Now let's look at job 9. The earliest starting time is the latest of the earliest finish times of the two preceeding jobs, namely 8 and 3. And thus the earliest starting time of job 9 is 20, and its earliest finish time is 35. Proceeding in this manner further through the network will indicate that the earliest starting time of the "dummy job" finish is 70 minutes.

Now we proceed to calculate the latest finish and starting times. Assume that 70 minutes are available. We therefore place a 70 to both sides of the job "Finish", and a 50 and 70 to the left and right of job 6 (eat breakfast). The latest finish times of jobs 4, 5 and 10 are then 50, and their latest start times are 40,40 and 35, respectively. The latest finish time of 9 is 35, and therefore the latest starting time is 20. Now consider job 3. The latest finish time for job 3 is the smallest of the latest start times of jobs 5 and 9; in this case it is the time of job 9, namely 20. Proceeding further in this fashion will result in the network and numbers as shown in Figure 8.

Now the slack times may be calculated. It should be noted that all jobs along the critical path have zero slack, that is they must be performed exactly on time. The total slack times for jobs 8, 5, 2, and 4 are 10, 20, 25 and 25 minutes, respectively. They are calculated as the difference between earliest and latest start, or earliest and latest finish.

The so-called free slack is the difference between a jobs earliest finish time, and the earliest of all starting times of all successors. It is always smaller than, or at most equal to the total slack. Thus for example, the free slack of job 8 is 10 minutes, which means that the house guest may delay his getting up for 10 minutes (but no more) without affecting any other job. Similarly, the free slack of jobs 4 and 5 are 25 and 20 minutes, respectively.

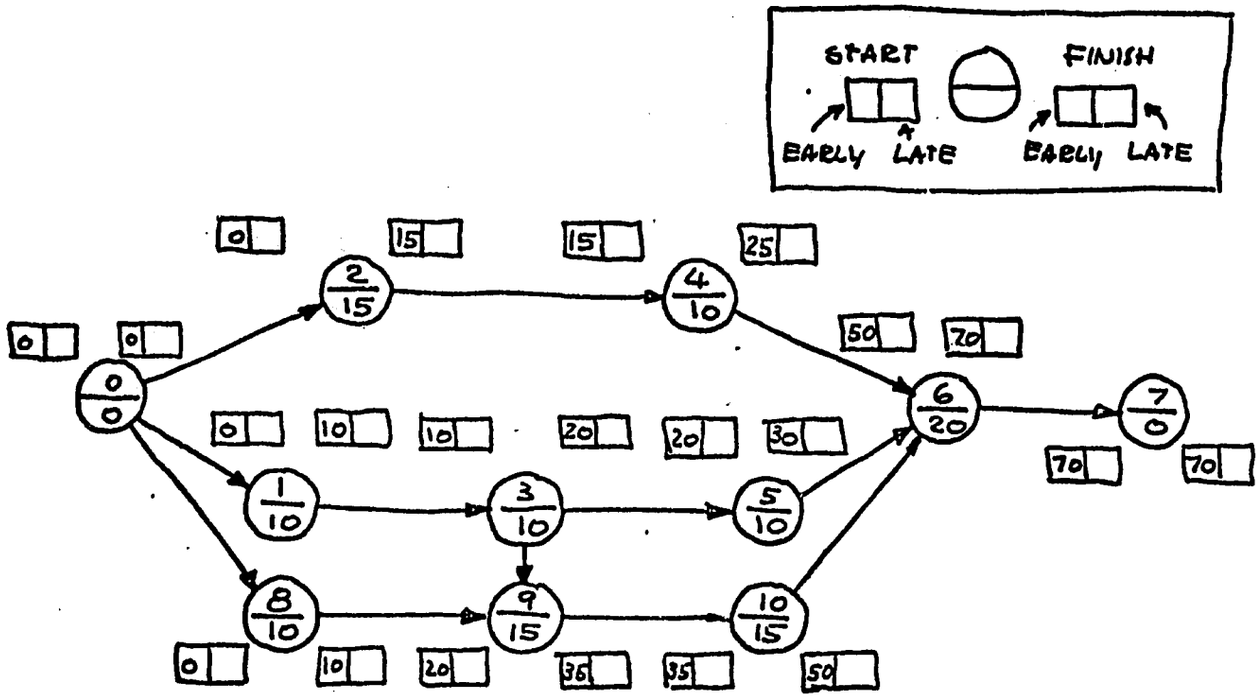


Figure 7.

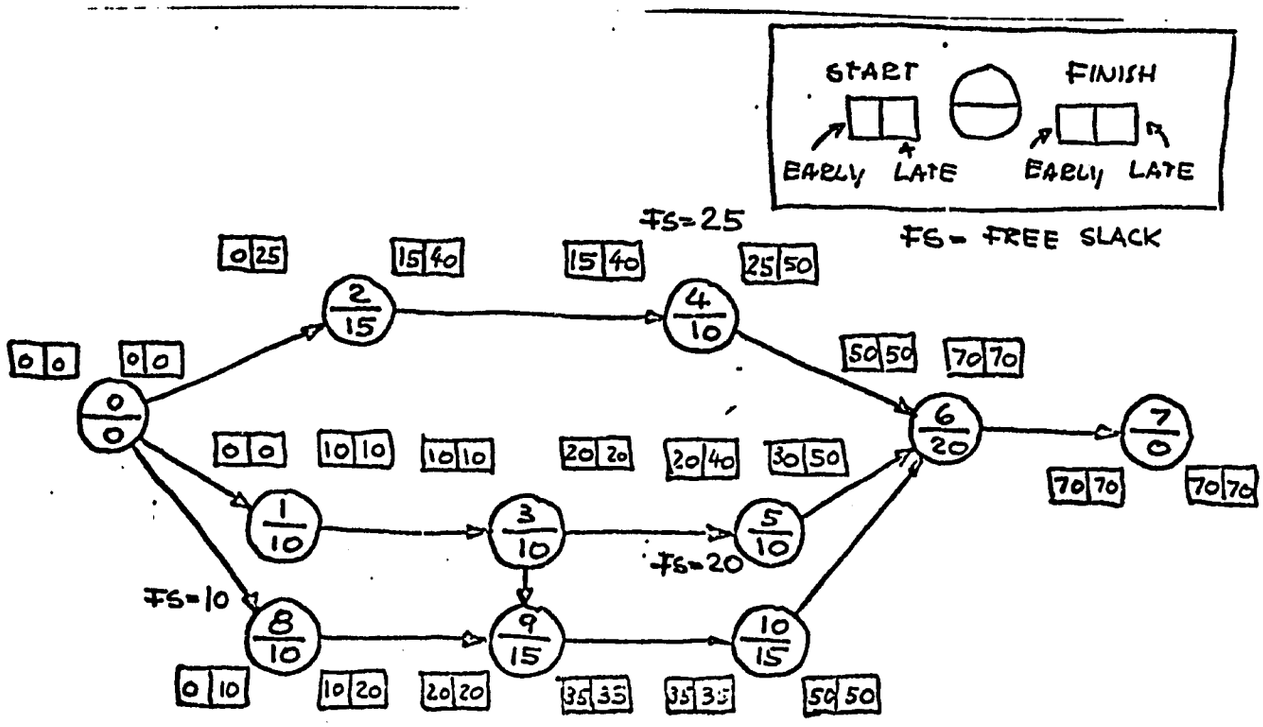


Figure 8.

All these figures may now be summarized conveniently as shown in Table 1. Rather than using the word "job" for each individual activity, we will use the word "activity."

Activity No.	Duration	Earliest Start	Latest Start	Earliest Finish	Latest Finish	Slack Total	Slack Free
0	0	0	0	0	0	0*	0
1	10	0	0	10	10	0*	0
2	15	0	25	15	40	25	0
3	10	10	10	20	20	0*	0
4	10	15	40	25	50	25	25
5	10	20	40	30	50	20	20
6	20	50	50	70	70	0*	0
7	0	70	70	70	70	0*	0
8	10	0	10	10	20	10	10
9	15	20	20	35	35	0*	0
10	15	35	35	50	50	0*	0

* Indicates activity on critical path.

TABLE 1.

We have now completed all basic CPM calculation. We now have enough data to make a specific schedule. Certain of the activities are critical and must be done at a fixed time. Others can be delayed within the "slack." We must now schedule these activities with these "slacks" in mind.

Let's make our schedule in simple bar chart style. Since the critical path activities are already "scheduled", we can draw them in first. This only leaves us with four activities to actually decide where we want to schedule the activity. Since we will have to use some judgement when we schedule these activities, we should include a description of what the activity is in the schedule.

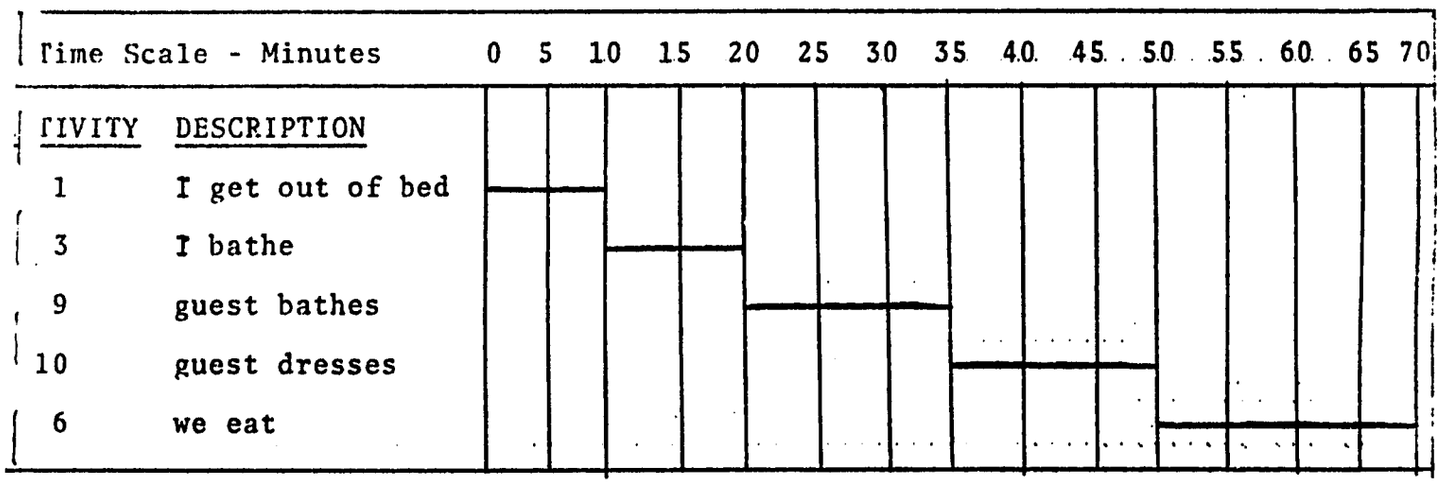


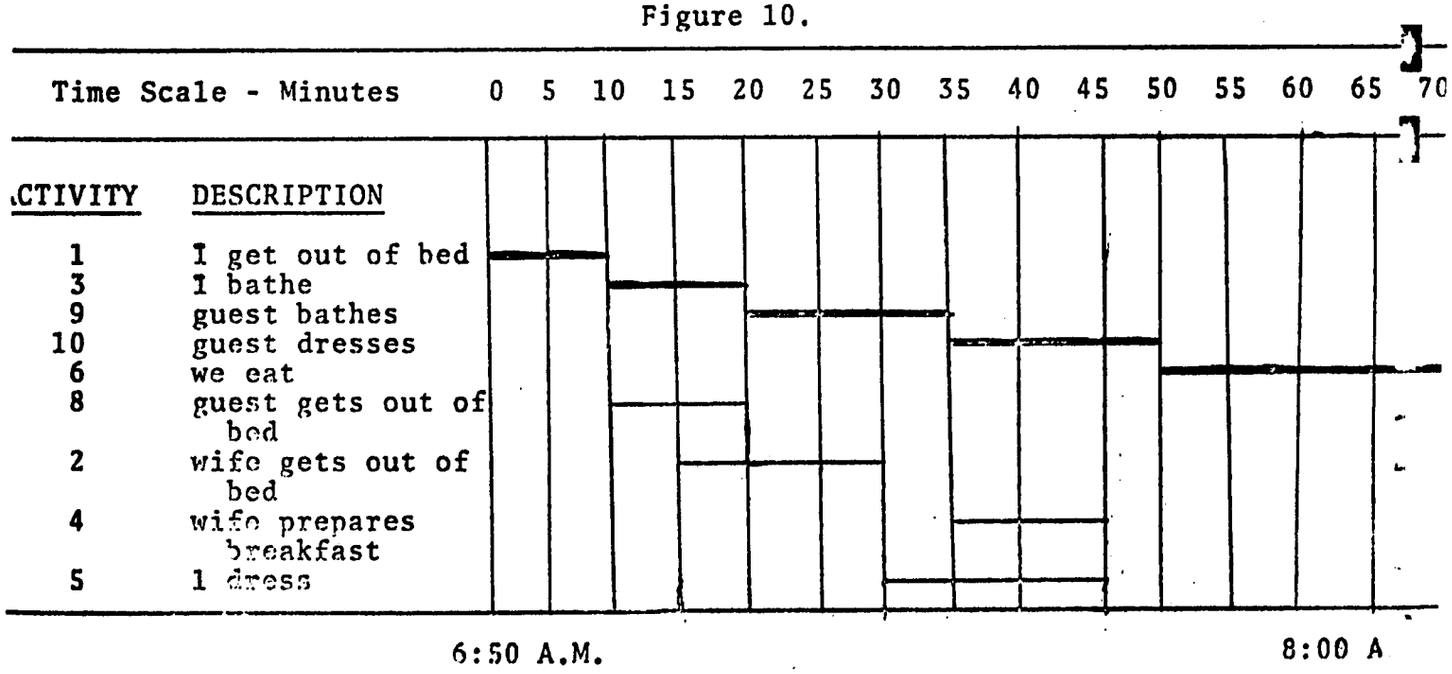
Figure 9.

Now, let's try to schedule activity 8, "Guest Gets Out of Bed". Checking our Activity Table, we see this activity has Free Slack of 10. This means that this activity can be delayed 10 minutes without delaying our project. He would probably appreciate it if we scheduled his getting out of bed for the latest time, so that he can use his "slack" to lie in bed after the alarm has gone off. Note, however, this makes the activity critical. If he takes longer than 10 minutes to get out of bed after laying there for 10 minutes, he will delay the completion of the project.

Now, let's look at activity 2, "Wife Gets Out of Bed". This activity has Total Float of 25. This means she could lay in bed 25 minutes after the alarm goes off without delaying completion. However, Free Slack is zero. This means that any delay will delay by the same amount the earliest start of the following activity. The following activity is 4, "Wife Prepares Breakfast." Activity 4 has Total and Free Slack of 25. If I let my wife prepare breakfast at the Earliest Times, our eggs are going to be mighty cold by the time we eat. The best thing to do is to leave about 5 minutes of Free Slack between the time we eat and when breakfast has been prepared. Likewise, we will leave 5 minutes in between the time she gets up and starts preparing breakfast. This allows her to lie in bed an extra 15 minutes. She will like me for this. This leaves one more activity to schedule. Activity 5, "I Dress", and Total and Free Float of 20 minutes. It becomes obvious now that I would have time for fixing breakfast, and my wife would not have to get up. If my wife sees this, that is just what will happen. The best schedule from my point of view will be to give myself an extra 15 minutes to get dressed. This will leave only 5 minutes Free Float, which isn't enough for me to prepare breakfast.

To complete our schedule, we can assume that we leave the house at 8:00 A.M. and indicate 70 on our time scale as 8:00 A.M. Working back, we find that we should set our alarm for 6:50 A.M.

Figure 10.



SUMMARY

Summarizing, the following should be noted. To do a CPM analysis on any project, it must have two essential characteristics:

A) The project consists of a well defined collection of jobs (activities) which when completed mark the end of the project.

B) Jobs are ordered - they must be performed in a certain technological sequence.

It is largely an arithmetic procedure which, based on the project graph, identifies the relative importance of each job.

The benefits of such an analysis are:

1. It gives discipline in planning, scheduling and controlling long range projects.

2. It has become a standard method of documenting a project - communicating project plans, schedules, times, costs, etc.

3. It identifies the critical elements and focuses attention on the few jobs that are critical.

4. It serves as a framework to illustrate the effects of technical and procedural changes.

Example Problem: Building a House

Consider now the project of building a house. While a contractor might want a more detailed analysis, we will be satisfied with a list of the major jobs together with their estimated time and ordering. These jobs are shown in Table 2. In this table the column "immediate predecessors" determines the sequence relationships of the jobs and enables us to in draw the project graph as shown in Figure 9. To identify each job a letter (rather than a number) has been chosen and is shown insider every circle; the number shown in the circle indicates the job time.

Following the steps described before, the earliest starting and finishing times are calculated. It can be seen that the critical path passes through the jobs a, b, c, d, j, k, l, n, t, s, x with a total time of 34 days. Suppose now that altogether 37 days are available for the completion of the project, then the latest start and finish times may be calculated. Also, the free slack times may now be determined. All this is shown in Figure 10. Several conclusions may be drawn:

1.) The contractor could postpone the starting of construction by three days and still complete it on schedule. However, this would reduce the total slack for all critical jobs to zero.

2.) Several jobs have free slack. The contractor could delay the completion of i (rough wiring) by two days, g (the basement floor) by one day, h (rough plumbing) by four days, r (storm drains), by 12 days, and so on - without affecting succeeding jobs.

3.) The series of jobs e (brickwork), p (roofing), g (gutters), v (grading), and w (landscaping) have a large amount of total slack (nine days). The contractor would use these and other slack jobs and juggle them around to smooth the workload on his crew.

Again, as in the example before, the critical path analysis focuses attention on those jobs which are critical, and clearly identifies those which may be scheduled with a certain amount of flexibility.

Suppose now the house would have to be finished in less than 34 days. Clearly, one or more of the jobs along the critical path have to be shortened. Assume that the house has to be finished in 32 days. In a first attempt to meet this deadline, the contractor might decide to assign more carpenters to job d (wooden frame) and reduce the time from 4 days to 2 days. What would happen? The earliest finish time of job d would then be at time 8, rather than 10. But the earliest starting time of j, the one following along the critical path,is determined by the latest of the earliest finish time of the two predecessors which in this case is time 9 of job g.

Thus we see, that if we shorten the time required for job d by two days, the overall reduction in the critical path and completion time would be only one day, since the critical path has now shifted and no longer passes through d, but passes through the jobs f, g and j. Therefore, if job d should be shortened, it should be shortened by at most one day, and some other job on the critical path should be shortened.

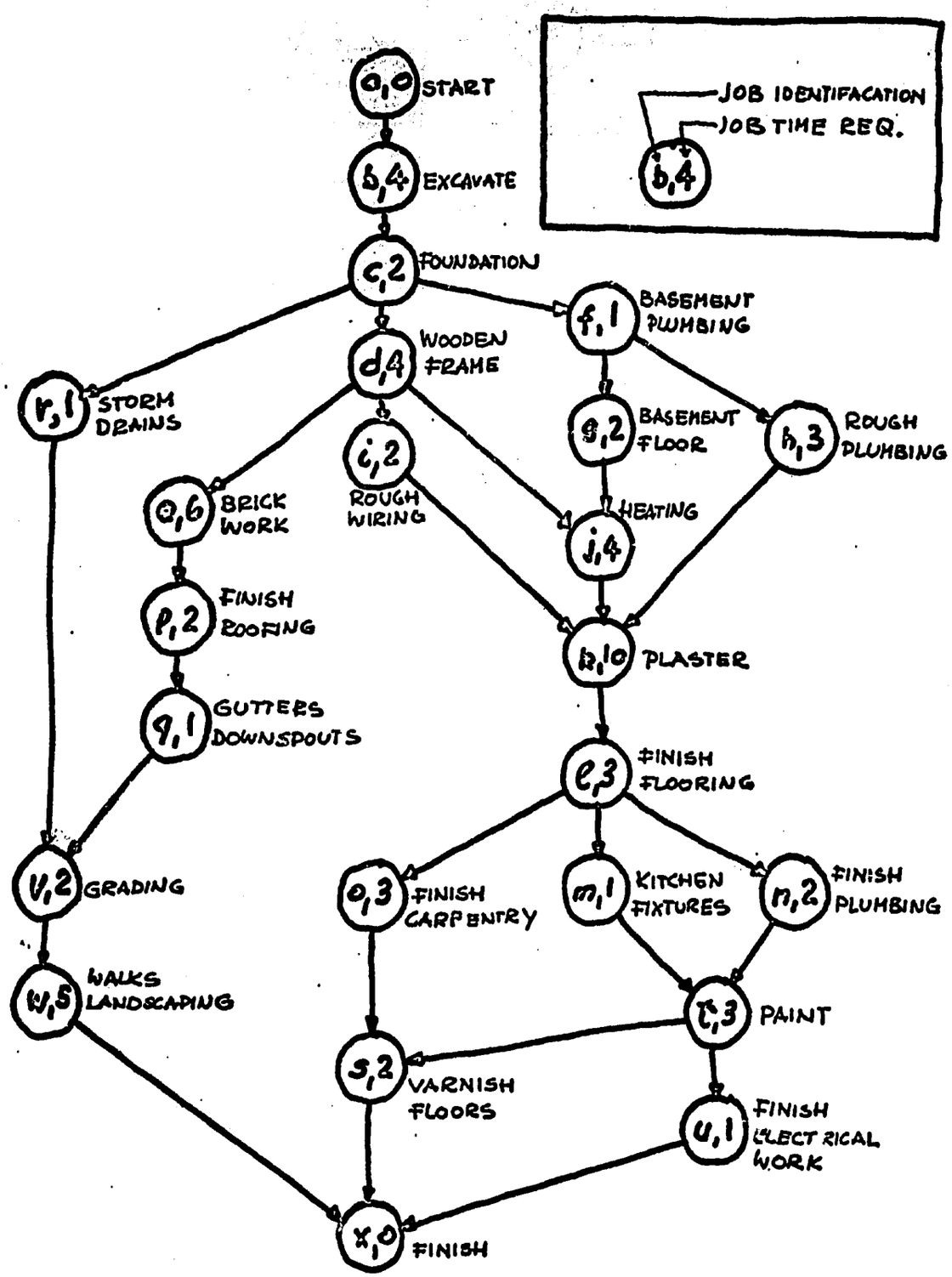
This kind of analysis raises a whole series of questions regarding the costs of shortening individual jobs and the overall project, which will be dealt with in a later paragraph.

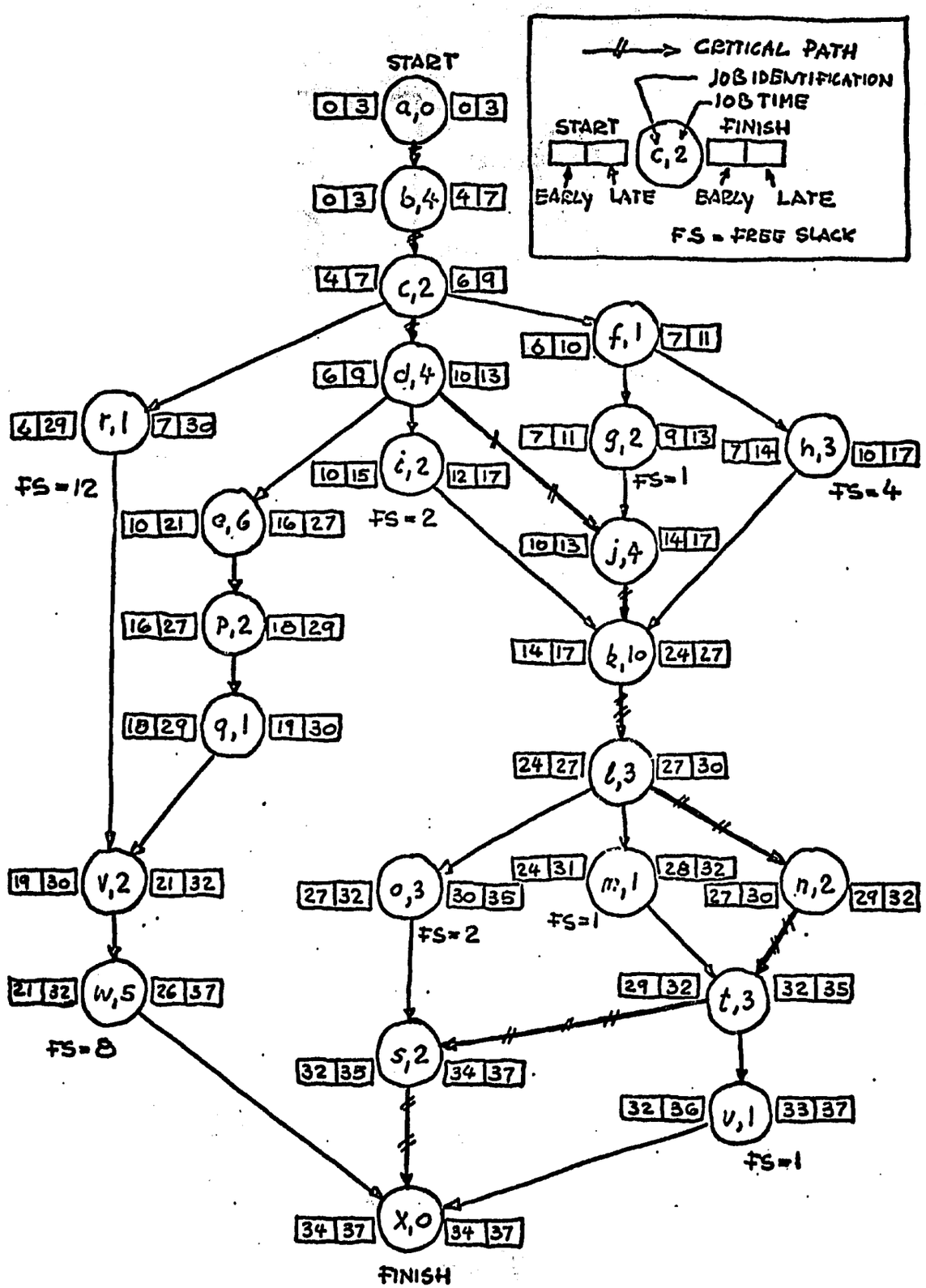
TABLE 2

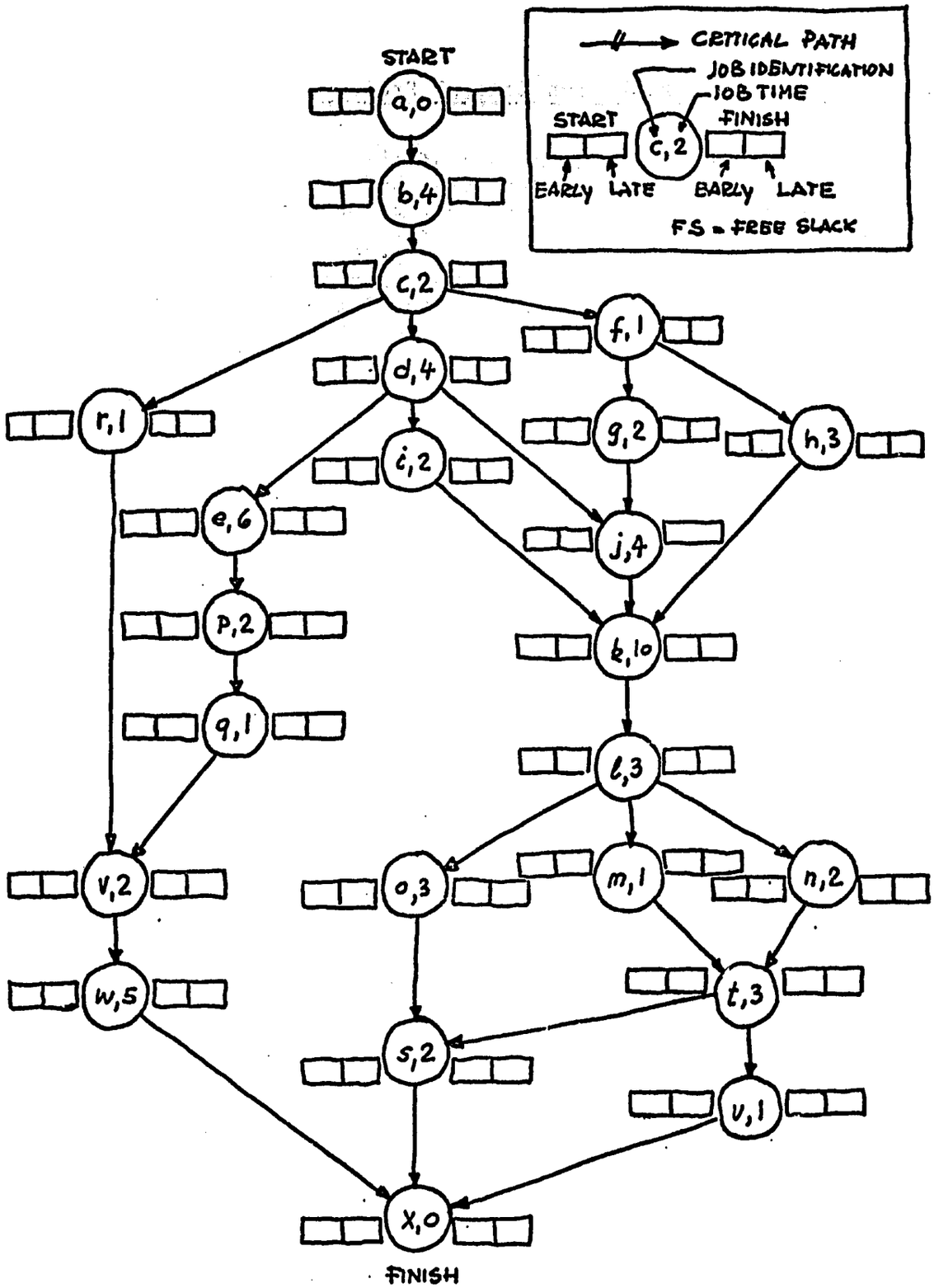
Sequence and Time Requirements

Job. No.	Job description	Immediate Prede-cessors	Job Time (days)
a	Start		0
b	Excavate, pour footer	a	4
c	Pour concrete foundation	b	2
d	Erect wooden frame, rough roof	c	4
e	Lay Brickwork	d	6
f	Install Basement drains	c	1
g	Pour basement floor	f	2
h	Install rough plumbing	f	3
i	Install rough wiring	d	2
j	Install heating, ventilating	d,g	4
k	Install drywall, plaster	i,j,h	10
l	Lay flooring	k	3
m	Install kitchen fixtures	l	1
n	Finish plumbing	l	2
o	Finish Carpentry	l	3
p	Finish roofing, flashing	e	2
q	Fasten gutters, downspouts	p	1

Job. No.	Job description	Immediate Prede-cessors	Job Time (days)
r	Lay storm drains for rainwater	c	1
s	Sand and varnish floors	o,t	2
t	Paint	m,n	3
u	Finish electrical work	t	1
v	Finish grading	q,r	2
w	Pour walks, complete landscape	v	5
x	Finish	s,u,w	0


a,0
START
b,4
EXCAVATE
c,2
FOUNDATION
d,4
WOODEN FRAME
f,1
BASEMENT PLUMBING
r,1
STORM DRAINS
g,2
BASEMENT FLOOR
h,3
ROUGH PLUMBING
i,2
ROUGH WIRING
o,6
BRICK WORK
j,4
HEATING
p,2
FINISH ROOFING
k,10
PLASTER
q,1
GUTTERS DOWNSPOUTS
l,3
FINISH FLOORING
v,2
GRADING
o,3
FINISH CARPENTRY
m,1
KITCHEN FIXTURES
n,2
FINISH PLUMBING
w,5
WALKS LANDSCAPING
t,3
PAINT
s,2
VARNISH FLOORS
u,1
FINISH ELECTRICAL WORK
x,0
FINISH
JOB IDENTIFACATION
JOB TIME REQ.
b,4


CRITICAL PATH
JOB IDENTIFICATION
JOB TIME
START
FINISH
EARLY
LATE
EARLY
LATE
FS = FREE SLACK
START
a,0
b,4
c,2
d,4
f,1
g,2
h,3
i,2
j,4
k,10
l,3
m,1
n,2
o,3
p,2
q,1
r,1
s,2
t,3
v,1
w,5
v,2
x,0
FS=12
FS=2
FS=1
FS=4
FS=2
FS=1
FS=8
FS=1
FINISH


CRITICAL PATH
JOB IDENTIFICATION
JOB TIME
START
FINISH
c,2
EARLY
LATE
EARLY
LATE
FS = FREE SLACK
START
a,0
b,4
c,2
f,1
d,4
r,1
g,2
h,3
i,2
e,6
j,4
p,2
k,10
q,1
l,3
v,2
o,3
m,1
n,2
w,5
t,3
s,2
u,1
x,0
FINISH

A Pollution Control Project

Probably the best known example of the use of CPM in a pollution control project is described in a short paper by Vaughn* which is reprinted in the appendix. Briefly, the paper is concerned with the Detroit River - Lake Erie study, a study with the purpose of defining levels of pollution, sources of pollution, and plans for the improvement of the situation in the greater Detroit area. As a manager of this study, Vaughn had to hire personnel, find laboratory and office spaces, buy laboratory equipment, and plan the general sequence of investigations. Figure 11 shows the beginning of the network describing the overall activities, which was too large to be reproduced here in its entirety.

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*Use of the Critical-Path Method in a Pollution Control Project, by R.D. Vaughn, Journal, Am. Water Works Assoc., September 1964.

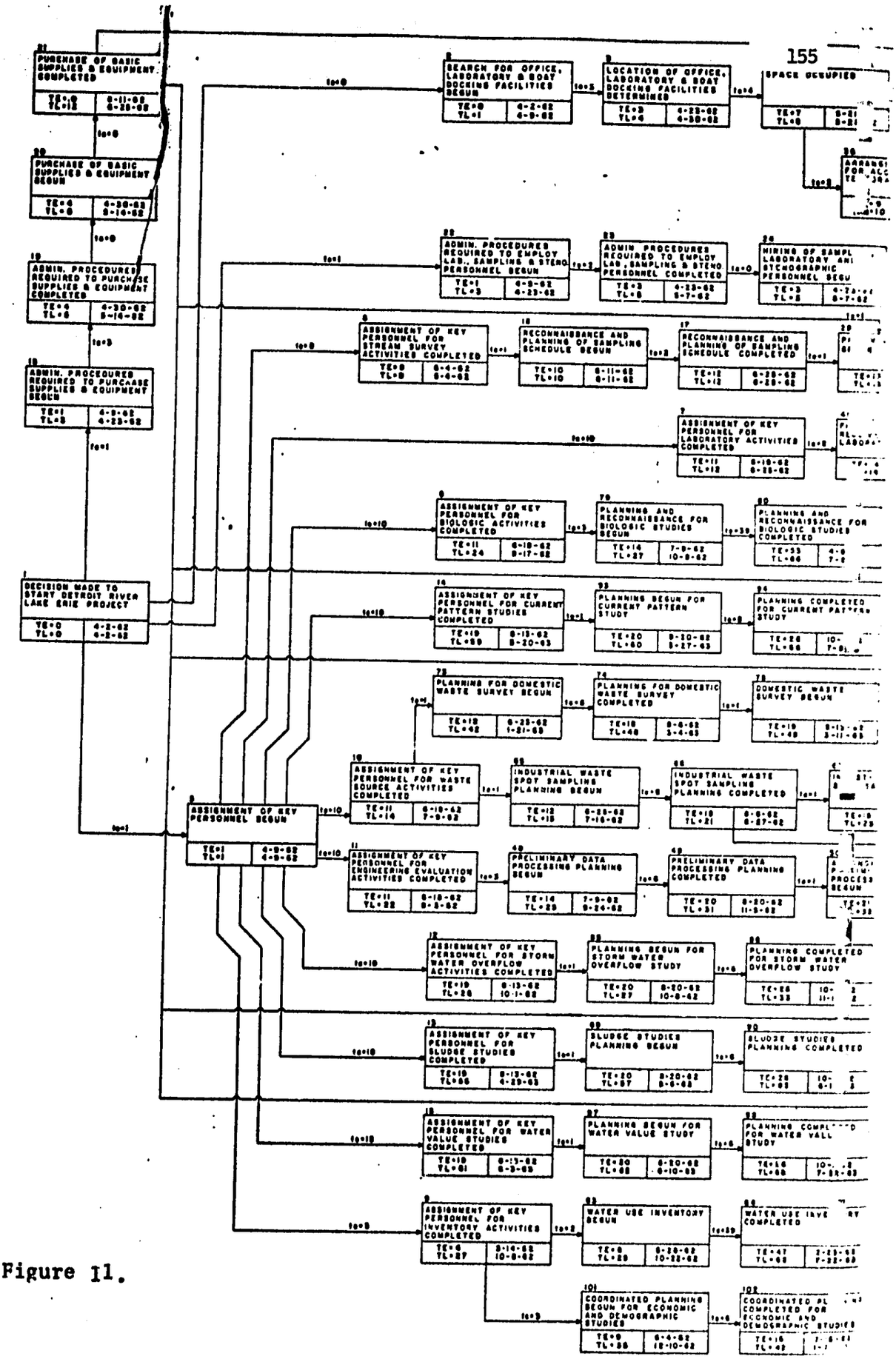

DECISION MADE TO START DETROIT RIVER LAKE ERIE PROJECT
PURCHASE OF BASIC SUPPLIES & EQUIPMENT COMPLETED
PURCHASE OF BASIC SUPPLIES & EQUIPMENT BEGUN
ADMIN. PROCEDURES REQUIRED TO PURCHASE SUPPLIES & EQUIPMENT COMPLETED
ADMIN. PROCEDURES REQUIRED TO PURCHASE SUPPLIES & EQUIPMENT BEGUN
SEARCH FOR OFFICE, LABORATORY & BOAT DOCKING FACILITIES BEGUN
LOCATION OF OFFICE, LABORATORY & BOAT DOCKING FACILITIES DETERMINED
SPACE OCCUPIED
ADMIN. PROCEDURES REQUIRED TO EMPLOY LAB., SAMPLING & STENO. PERSONNEL BEGUN
ADMIN PROCEDURES REQUIRED TO EMPLOY LAB., SAMPLING & STENO PERSONNEL COMPLETED
ASSIGNMENT OF KEY PERSONNEL FOR STREAM SURVEY ACTIVITIES COMPLETED
RECONNAISSANCE AND PLANNING OF SAMPLING SCHEDULE BEGUN
RECONNAISSANCE AND PLANNING OF SAMPLING SCHEDULE COMPLETED
ASSIGNMENT OF KEY PERSONNEL FOR LABORATORY ACTIVITIES COMPLETED
ASSIGNMENT OF KEY PERSONNEL FOR BIOLOGIC ACTIVITIES COMPLETED
PLANNING AND RECONNAISSANCE FOR BIOLOGIC STUDIES BEGUN
ASSIGNMENT OF KEY PERSONNEL FOR CURRENT PATTERN STUDIES COMPLETED
PLANNING BEGUN FOR CURRENT PATTERN STUDY
PLANNING COMPLETED FOR CURRENT PATTERN STUDY
PLANNING FOR DOMESTIC WASTE SURVEY BEGUN
PLANNING FOR DOMESTIC WASTE SURVEY COMPLETED
DOMESTIC WASTE SURVEY BEGUN
ASSIGNMENT OF KEY PERSONNEL FOR WASTE SOURCE ACTIVITIES COMPLETED
INDUSTRIAL WASTE SPOT SAMPLING PLANNING BEGUN
INDUSTRIAL WASTE SPOT SAMPLING PLANNING COMPLETED
ASSIGNMENT OF KEY PERSONNEL BEGUN
ASSIGNMENT OF KEY PERSONNEL FOR ENGINEERING EVALUATION ACTIVITIES COMPLETED
PRELIMINARY DATA PROCESSING PLANNING BEGUN
PRELIMINARY DATA PROCESSING PLANNING COMPLETED
ASSIGNMENT OF KEY PERSONNEL FOR STORM WATER OVERFLOW ACTIVITIES COMPLETED
PLANNING BEGUN FOR STORM WATER OVERFLOW STUDY
PLANNING COMPLETED FOR STORM WATER OVERFLOW STUDY
ASSIGNMENT OF KEY PERSONNEL FOR SLUDGE STUDIES COMPLETED
SLUDGE STUDIES PLANNING BEGUN
SLUDGE STUDIES PLANNING COMPLETED
ASSIGNMENT OF KEY PERSONNEL FOR WATER VALUE STUDIES COMPLETED
PLANNING BEGUN FOR WATER VALUE STUDY
ASSIGNMENT OF KEY PERSONNEL FOR INVENTORY ACTIVITIES COMPLETED
WATER USE INVENTORY BEGUN
COORDINATED PLANNING BEGUN FOR ECONOMIC AND DEMOGRAPHIC STUDIES

Figure 11.

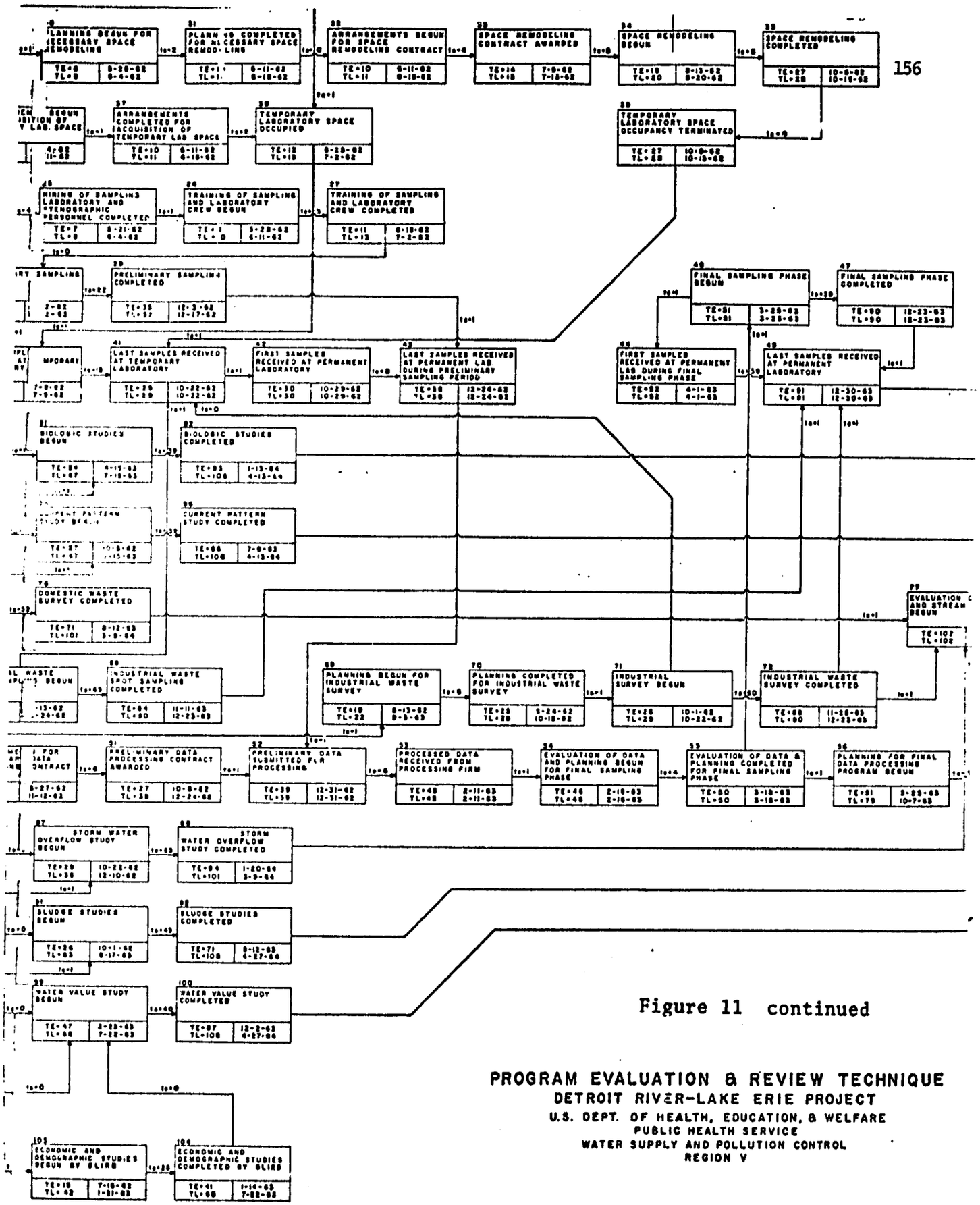
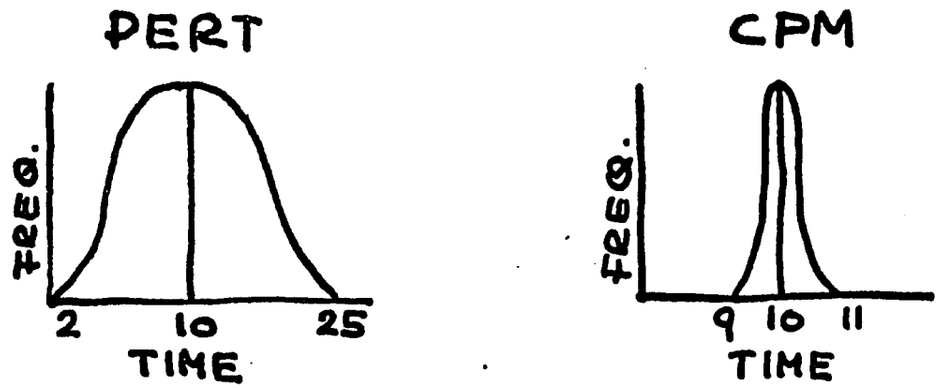


Figure 11 continued

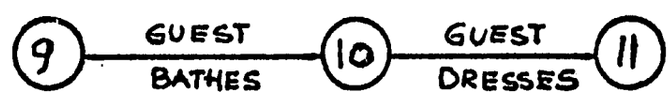
PROGRAM EVALUATION & REVIEW TECHNIQUE
DETROIT RIVER-LAKE ERIE PROJECT
U.S. DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
WATER SUPPLY AND POLLUTION CONTROL
REGION V

Differences between PERT and CPM

The major difference between PERT and CPM is the estimation of the time for each individual job. In CPM a rather deterministic outlook prevails, that is one assumes that the time estimate can be developed with a very narrow variance. In contrast PERT has a probabilistic outlook and attempts to define the probability distribution of the time estimate for each activity. Graphically, this may be best portrayed in the following way:



Another minor difference is that in PERT the activity is not denoted by a circle, but by the actual branch, and that the beginning and end nodes of a branch denote the so-called event times - beginning and ending. For example, consider the sequence of two activities below. The node 9 denotes beginning of the activity "guest bathes", and node 10 denotes the ending of this activity and the beginning of activity "guest dresses". But the basic algorithms for solving these networks are the same.



Extensions of PERT/CPM

Because of their great potential both CPM and PERT have received extensive developments in the past years. Most of the extensions are in the area of resource allocation, scheduling of multiple projects, and general cost considerations.

Thus, for example, RAMPS, a system developed by CEIR, which is an acronym for Resource Allocation and Multi-Project Scheduling, does just what its name implies.

PERT/COST adds the consideration of resource costs into the schedules produced by PERT, and will give best schedules for various projects.

PECOS, and acronym for Project Evaluation and Cost Optimization System, will determine the optimal and least cost schedules for project networks and determines the optimum time-cost curves of a project.

Literature on PERT/CPM

There are virtually thousands of articles and reports on PERT/CPM, each providing its own variation of the basic concept, which can by nicely summarized by the slogan:

FIRST PLAN THE WORK, THEN WORK THE PLAN.

For those wishing to read more about it, the following may serve as a guideline:

Project Management with CPM and PERT, Moder and Phillips, Reinhold Publishing Corporation, N.Y., 1964.

CPM in Construction Management, O'Brian, McGraw-Hill Book Co., N.Y., 1964.

Industrial Scheduling, Muth and Thompson, Prentice-Hall, Inc., 1963.

PERT Fundamentals, A programmed instruction manual, U.S. Government Printing Office, 1963.

Health Program Implementation through PERT, American Public Health Association, 1966.

III. C. Analytic (Optimization) Models

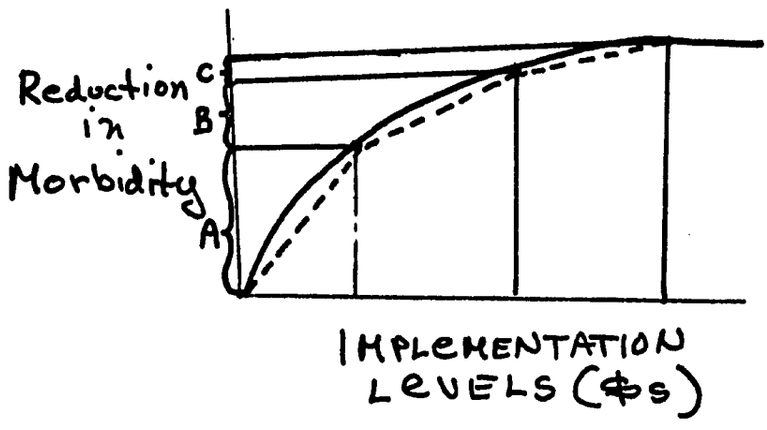
I. Linear Programming Techniques

Linear programming is concerned with optimally allocating limited resources under conditions of certainty. The word "programming" is a synomyn for "planning" and has nothing to do with computer programming. "Programming" derives from "program" in the sense of a schedule of activities . A mathematical model describes a problem usually involving the integration of many variables subject to various constraining conditions. Objectives, such as costs, profits, or measures of effectiveness are obtained in the best possible, or "optimal" fashion subject to restraining conditions-generally budgetary or physical limitations. In addition, in the course of finding a solution, it reveals the effects of the constraints imposed. The restrictions must be represented by a system of simultaneous equations or inequalities. The model is static and deterministic. Thus, "how much of what to do when" is sought. The output is seldom an explicit formula like $A=\pi r^2$, but is usually an algorithm - a numerical procedure. An example would be performing long division, where a fixed set of operations is repeated until the appropriate answer is produced.

"Linear" means all mathematical relationships in the model are straight-line functions: For example if the cost to produce one hospital bed-day is $40, a linear assumption results in $80 to produce two bed-days. Furthermore, if an expenditure of $1 million on vaccines yields a reduction of 10,000 days of illness, spending $5 million would reduce 50,000 days. Realistically, there are often "economics-of-scale" and diminishing returns on investments so that non linear objective

functions exist. In other words, cost is not strictly linear with units of production, and unit prices are not consistent with all ranges of production. Therefore, a clinic purchasing department could pay $100 for the first five pieces of equipment and $500 for additional pieces after a certain number at $1000 have been purchased. However, a linear framework through piecewise linear approximation is possible. A diminishing level of morbidity with increased expenditures is diagrammed in Figure 1 below [Piece-wise linear approximations are added]. With increased expenditures, a diminishing reduction of morbidity is obtained (C < B < A).

EFFECTIVENESS MODEL



In addition to the linearity or proportionality assumption, all coefficients must be deterministic. That is, the numbers in the model are known constants. In reality, this is rare. Often they are guesses or

random variables with known and unknown distributions. The solution will only be as good as the coefficients.

Also, in order to have a linear objective function, the activities must be additive. If there is interaction between competing products or variables, linearity may no longer hold.

Finally, the unknowns or decision variables are meaningful, generally, only if they have integer values, (the devisibility assumption), but the solution procedure doesn't guarantee that the solution will be an integer. If an optimal solution, for example, indicates assigning 2.3 nurse aids, rounding to 2 or 3 is necessary. If 66.3 personnel are called for, one may safely round to 66. At present, there are no efficient procedures available which solve integer programming problems with the speed and convergence of comparable linear programming problems.

As sub-components of the allocation problems, scheduling, distribution, assignment, and product mix problems are "solvable" by linear programming technics. Assignment problems aim to match personnel (nurses, M.D.'s) to facilities (clinics, wards, etc.) so as to minimize the overall costs of assignments. The usual constraints are availability of personnel by type and the costs associated with different assignment mixes.

Perhaps the most sophisticated attempt to utilize linear programming in the health field has been the work of M. Feldstein, Piot,

and Sundaresan. (Supplement to Vol. 48, Bulletin of the World Health Organization, #48) (1973). Linear programming is used to integrate health sector planning, mainly health personnel activity analysis, and epidemiologic modeling with economic development. The objective is to allocate funds among distinct control programs to yield optimal outputs valued in $ terms of reduced mortality, morbidity and community economic loss.

The optimization algorithm, a linear activity analysis, relates activity sets of inputs and outputs. Each activity is defined by sets of conditional probabilities, has constrained inputs and populations served. The problem is to derive the intensity with which each activity is to be operated as each activity has a mix of potential services leading to service outputs (death, impairment, and economic loss reductions) to individuals and the community.

A resource allocation model then, is utilized to determine the intensity of activity levels subject to constraints so that community benefits are maximized. The "dual" formulation seeks to assign marginal values (shadow prices) to the constrained inputs. This value is the amount of additional benefit that would result if one extra unit of that resource were available.

The use of such a model aids planners and health officials to, at least, conceptually understand the structure of the problem of health planning: the ways in which preferences, population, structures, disease incidence and prevalence, scarce resources, and technologies are inter-related in determining the optimal set of activities. This frame-

Transferring the tool to other health problems is possible but costly. Twenty years of TB epidemiologic experimentation, thinking, and practice has been "sunk" into the model. Data was painstakingly gathered at considerable cost. Replication would be quite costly. The major value of such efforts lies in the utility of structuring health planning analysis. Internalization of this thinking process by decision-makers is the most valuable benefit of such studies.

Other linear programming examples within the health facility sector have generally been in the less global areas of hospital location, personnel staffing, and menu planning. None of the studies have reached the practical application stage.

Menu planning has been applied as the problem is easy to formulate with the objective to minimize food costs, nutrition requirements and food items the constraints. However, these models aid dietician judgment but doesn't guarantee a mathematical optimum.[1]

In nurse staffing problems, the resources are hours of personnel time, and the demands are the tasks needed to be done. Tangible and intangible costs (level of patient care estimates) are the objectives to be minimized. Tasks and unit times are developed and measured. Again, considerable technical manipulating is required to supply the relationships and assumptions. The task values of a staffing model are shown in Table 1.[2]

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1. See J. Balintfy, "Experiment with Computer assisted Menu Planning", Hospitals 40, #12 (1966).

2. Wolfe and Young, "Staffing the Nursing Unit,", Nursing Research, 14, #4, (1965).

TABLE 1

Nursing Care Task Values

Task Complex	Head Nurse	Assistant Head Nurse	General Staff Nurse	Licensed Practical Nurse	Nursing Aide	Ward Clerk
Technical						
Task 1						
Class I	$ 8.52	$ 7.92	$ 7.56	$ 5.28	$ 4.32	$∞
Class II	14.10	13.10	12.50	8.80	8.50	∞
Class III	9.87	9.17	8.75	7.49	9.24	∞
Technical						
Task 2						
Class I	1.41	1.31	1.25	1.01	∞	∞
Class II	5.64	5.24	5.00	4.28	∞	∞
Class III	5.64	5.24	5.00	5.36	∞	∞
Preparatory						
Care 1	33.84	31.44	30.00	21.12	17.76	43.92
Preparatory						
Care 2	14.30	13.30	12.50	12.30	∞	∞
Clerical Task 1	8.46	7.86	7.50	5.28	4.32	8.88
Clerical Task 2	20.86	19.46	18.62	13.44	20.72	9.80
Clerical Task 3	5.64	5.68	6.24	6.76	∞	∞
Housekeeping Duties	12.69	11.79	11.25	7.92	6.39	14.94
Escort and Errand	14.10	13.10	12.50	9.10	8.40	13.40
Supervising and Teaching	4.23	4.35	4.68	5.13	∞	∞
Evaluation and Assignment	32.43	34.50	39.79	44.26	∞	∞
Maintenance Checking & Ordering supplies	4.23	3.93	3.75	2.64	4.17	2.10

Source: Wolfe and Young "Staffing the Nursing Unit," *Nursing Research* 14, no. 4, (1965) p. 3 38.

Note: Infinite costs were assigned where performance of a task by a given skill level was considered to be impossible or unsafe.

Variations in demand for services are considerable within the hospital and accomodations through "pooling" staff has the advantage of matching the fluctuations with available personnel.

The "transportation problem" variant of linear programming is concerned with dispersion from different sources to different destinations. Grundy and Reinke apply the technique to the problem of transferring dispersed clinic patients to seperate hospitals.[1] Table 2 shows 5 clinics "serving" three hospitals. The objective is to establish the least costly referral pattern as shown in Table 3.

Table 2 Data for determining optimal referral pattern

Hospital	Unit cost of transport from clinic to hospital				
	Clinic A (monthly referral load: 30)	Clinic B (monthly referral load: 50)	Clinic C (monthly referral load: 40)	Clinic D (monthly referral load: 60)	Clinic E (monthly referral load: 30)
X (capacity: 90)	10	20	5	9	10
Y (capacity: 40)	2	10	8	30	6
Z (capacity: 80)	1	20	7	10	4

Table 3 Optimal referral pattern based on data of Table 3

To hospital	From clinic				
	A	B	C	D	E
X	—	—	40	50	—
Y	—	40	—	—	—
Z	30	10	—	10	30

1. Grundy and Reinke, op. cit., p. 58.

To demonstrate the algebraic and graphic process as well as the application of linear programming to a water related problem the following somewhat artificial and oversimplified example, will be considered:

A farmer is concerned with growing two types of products, corn and oats. His farm has a total acreage of 160 acres. It takes 1 unit of water per acre to grow oats and 3 units of water per acre to grow corn. The total amount of water available to him is 240 units. Net profits for oats are $20 per acre and $40 per acre for corn. How many acres of oats and corn should the farmer grow in order to maximize his profit?

Let x_1 = acres of oats

x_2 = acres of corn

The first restriction to be considered is that the number of acres of corn and oats can not exceed 160 acres. One can therefore write

$$x_1 + x_2 \leq 160$$

Note, that this is an inequality and says that the total acreage of oats and corn must be <u>less than or equal</u> to 160 acres. If this inequality would have been written as equality, this would mean that all 160 acres <u>must</u> be used. This would be an unnecessary restriction of the choice the farmer has.

Similarly, the restriction on water is:

$$x_1 + 3x_2 \leq 240$$

Again, this inequality says that the amount of water applied to the acreage of oats and corn must be <u>equal to or less than</u> 240 units.

Since a negative x_1 or x_2 does not make any sense, two further restrictions are required, namely

$$x_1 \geq 0$$
$$x_2 \geq 0$$

Finally, if x_1 acres of oats and x_2 acres of corn are grown, the farmer will realize a net profit of

$$20\ x_1 + 40\ x_2$$

Summarizing now all inequalities, the Farmer's Problem stated mathematically is:

maximize	$20\ x_1 + 40\ x_2$	(1)
subject to	$x_1 + x_2 \leq 160$	(2)
	$x_1 + 3\ x_2 \leq 240$	(3)
	$x_1 \geq 0$	(4)
	$x_2 \geq 0$	(5)

This is a typical linear programming problem, namely to find the maximum of a linear function subject to linear inequalitites and non-negativity constraints.

Consider now the graphical solution of the Farmer's Problem. The constraints (4) and (5) restrict the values of x_1 and x_2 to the first quadrant of a cartesian coordinate system. To graph the other constraints they will be treated momentarily as equality. Thus, inequality (2) written as equality

$$x_1 + x_2 = 160$$

can be traced as a straight line passing through the points A (160,0) and B (0,160). Inequality (3) can be written as equality

$$x_1 + 3x_2 = 240$$

and thus gives a straight line passing through the points C (240,0) and D(0,80). These lines are shown in Figure 1.

Now, since all points to the "left" of the line AB satisfy the inequality $x_1 + x_2 \leq 160$, the triangle OAB describes a region in which any point satisfies (2). The triangle OCD describes the collection of points which satisfy inequality (3). But since both inequalities must be satisfied simultaneously, the quadrangle OAED describes the region whose points are satisfying all inequalities (2) - (5). The problem now is to find a point within the quadrangle or on its boundary which maximizes the objective function $20x_1 + 40x_2$.

In order to graph the objective function assume arbitrarily that it has a value of 800. The equation

$$20x_1 + 40x_2 = 800$$

THE FARMERS PROBLEM

GRAPHICAL SOLUTION

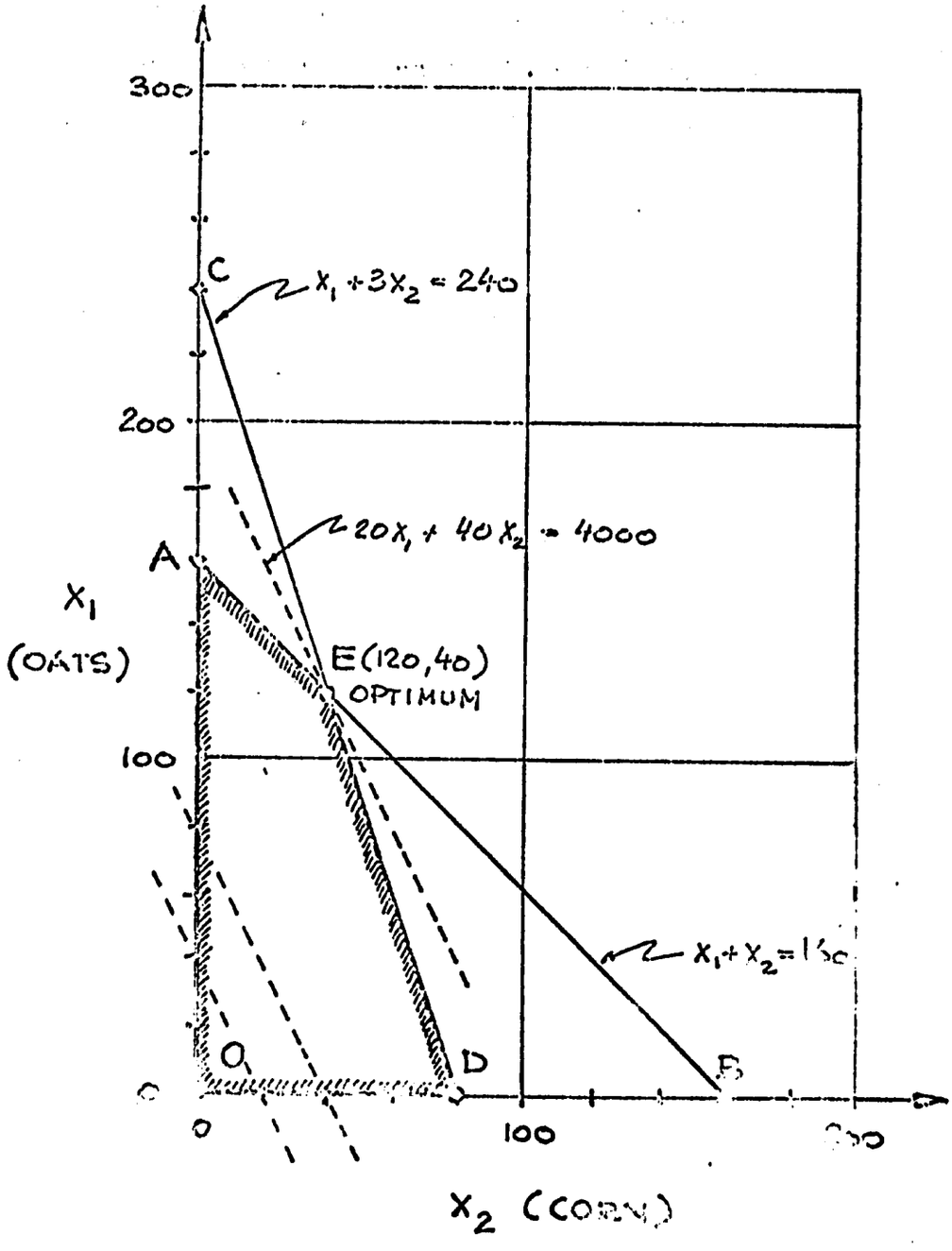

FIGURE 1

can be shown as a straight line passing through the points (40,0) and (0,20). If one chooses a value of 1600, the line

$$20x_1 + 40x_2 = 1600$$

will pass through the points (80,0) and (0,40). It can be seen that the lines are parallel. A line which is parallel to both and yields the highest value of the objective function, but still has one point in the constraint region can be drawn through point E. The equation of this line is

$$20x_1 + 40x_2 = 4000$$

Thus the point ($x_1 = 120$, $x_2 = 40$) is the one which maximizes the objective function. The answer to the Farmer's Problem is:

> He should grow 120 acres of oats and 40 acres of corn which will yield the maximum net profit of 4000 dollars.

In general, the solution procedure is therefore to draw a number of parallel lines and find the one which has <u>at least one</u> point in the region which satisfies all constraints and at the same time has the greatest distance from the origin.

EXAMPLE II:

A manufacturing plant can produce finished goods that sell for a unit price of 10.0 at a unit cost of 2.7. Unfortunately, in the manufacturing process 3.0 units of waste are generated for each unit of goods. In addition to deciding what level of output, x_1, at which to operate, the decision maker must decide how much of this waste he should discharge untreated into a nearby water course and how much he should pass through an existing waste-water treatment plant that diminishes the wasteload by 85 per cent. Of course, some expense will be sustained in treating the waste (.5 per unit of influent waste), and his treatment plant is limited by size to accept not more than 9 units of waste.

Two other considerations are pertinent to his decision: there is an "effluent tax" imposed on the waste discharged to the watercourse (1.76 for each unit), and in any case the pollution-control authority has specified an upper limit on the amount of waste any manufacturer may discharge (2.25 units of waste). This situation is shown schematically in Figure 3. The purpose of this problem is to select x_1, the amount of goods produced, and x_2, the amount of waste discharged untreated, so that the profits minus the costs of manufacture, waste treatment and effluent taxes are maximized, while not exceeding the limitations imposed by the regulatory agency on the amount of waste discharged or the capacity of the existing waste treatment plant.

This linear-programming problem may be stated mathematically as follows: Find non-negative values of x_1 and x_2 that maximize

f = profits <u>minus</u> manufacturing costs <u>minus</u> waste treatment costs <u>minus</u> effluent charges;

that is,

$$f = +10.0x_1 - 2.7x_1 - 0.5(3x_1 - x_2) - 1.76\,[x_2 + 0.15(3x_1 - x_2)]$$

or

$$f = 5x_1 - x_2,$$

subject to the following constraints:

(1) Flow of waste through treatment plant must not exceed plant capacity,

$$3x_1 - x_2 \leq 9$$

(2) Total waste discharged, untreated, plus residual treated, must be less than the level specified by regulatory agency,

$$x_2 + 0.15(3x_1 - x_2) \leq 2.25.$$

Rearranging,

$$0.45x_1 + 0.85x_2 \leq 2.25.$$

(3) Direction of waste flow must be toward watercourse,

$$3x_1 - x_2 > 0$$

This constraint arises from the fact that the difference of two non-negative variables can be negative; this would imply that waste flows from the treatment plant toward the man-

ufacturing process.

Figure 4 shows a graphical solution of the problem. The optimal solution is found to be $x_1 = 3.3$ and $x_2 = .9$. The value of the objective function is $f = 15.6$.

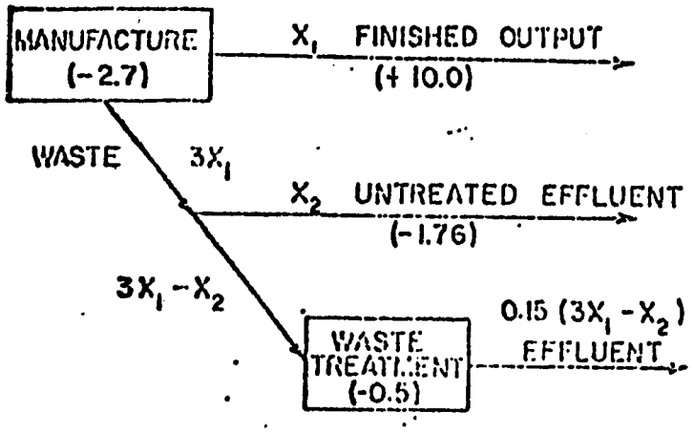

FIGURE 1: SIMPLE MANUFACTURING DECISION MODEL

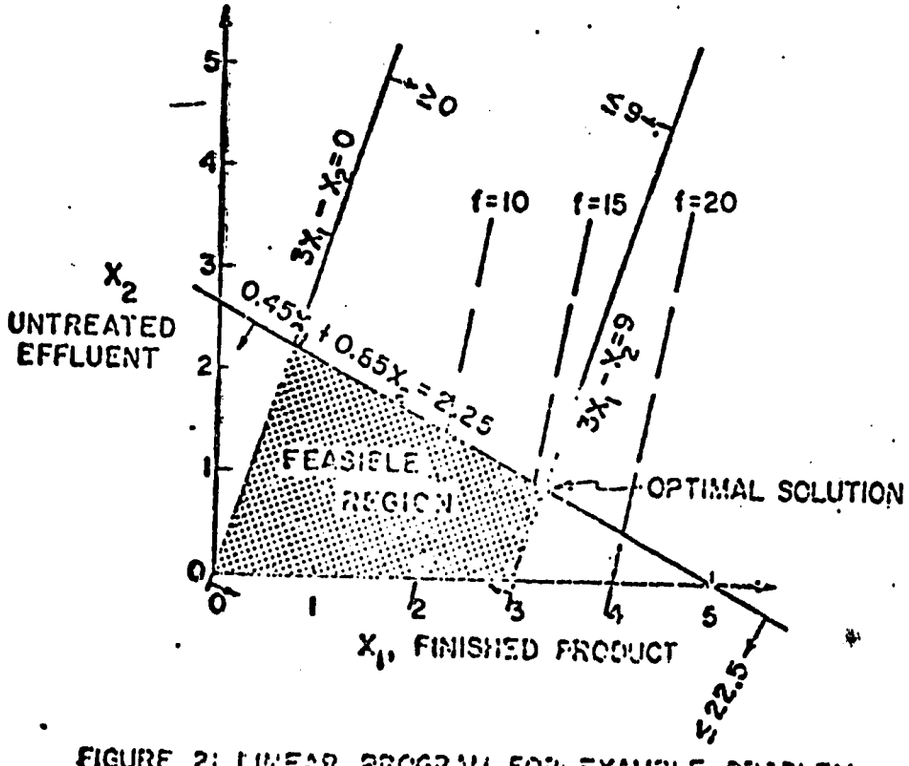

FIGURE 2: LINEAR PROGRAM FOR EXAMPLE PROBLEM

III. C. II. Other Mathematical Programming Techniques

In addition to linear programming, integer and quadratic are used depending on the mathematical nature of the objective function. All of them, however, are solved for a single period of time or stage. When parameters change overtime, the outcome of a decision at one stage affects the next stage and dynamic programming is used to determine the combinations of decisions at various levels to optimize an objective. Health applications include construction scheduling and facility investment problems and inventory and replacement problems. The applications are quite complex and costly in terms of data requirements and interpretation.

Markov models are dynamic - they treat random occurrences where the past influences prediction. Systems are analyzed as to the location and movements of phenonema (such as health status or patient location,) at a given time. The process is probalistic with outcomes in different stages. In a stockastic process, the prediction of the next experiment is not affected by the knowledge of the outcomes of any precedding experiment, while in a Markov process, immeidate past knowledge influences predictions. At any given time, the system is in N states. At different time periods if known probability based shifts (transitions) occur; the "behavior of the system" is determined.

While considerable data needs to be collected, application of these techniques is possible.

Dahl, in Chile, took untrained administrators, taught and applied the techniques to estimate patient flows (a Quasi-Markovian flow model) within the health delivery "system" and a linear programming resource allocated model to incorporate the resource flows. Sample output is shown in Table 4.

TABLE 4

Patient Flows: Applying the 1969 Model Results

I. *Number of People Entering the System*	1967	1968	1969	1970	1971
Population to emergency (P_U)	43,114	44,091	45,051	46,045	46,991
Population to peripheral clinics (P_{CP})	53,721	54,938	56,134	57,373	58,551
Population to specialist clinics (P_{CEE})	2,152	2,201	2,249	2,299	2,346
Total	98,987	101,230	103,434	105,717	107,888
II. *Number of People Leaving the System*					
Emergency to population (U_P)	4,318	4,416	4,512	4,612	4,706
Peripheral clinics to population (CP_P)	89,906	91,943	93,945	96,018	97,990
Specialist clinics to population (CEE_P)	4,253	4,349	4,444	4,542	4,636
Hospital deaths (H_D)	492	503	514	525	536
Emergency deaths (U_D)	18	19	19	20	20
Total	98,987	101,230	103,434	105,717	107,888
III. *Number of People Not Entering the System*	72,647	74,293	75,910	77,585	79,178
IV. *Total Legal Population*	171,634	175,523	179,344	183,302	187,066
V. *Distribution between Stations*					
Hospital (H)	3,214	3,287	3,359	3,433	3,504
Specialist clinics (CEE)	5,956	6,091	6,224	6,361	6,492
Hospital outpatient clinics (CEH)	2,002	2,047	2,092	2,138	2,182
Emergency room (U)	43,301	44,282	45,246	46,245	47,194
Peripheral clinics (CP)	94,083	96,215	98,309	100,479	102,542
Deaths (D)	871	891	910	930	949
Total	149,427	152,813	156,140	159,586	162,863

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