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ABSTRACT

This dissertation begins with a description of some methods employed in making public-sector resource-allocation decisions, with conclusions on the appropriateness of each method for evaluating the ongoing programs of a school system. The second section has been rewritten and published as "A Comprehensive Theory of Cost-Effectiveness" (EA 002 920). This section develops the theoretical substantiation for cost-effectiveness analysis which can serve as the groundwork for evaluation of ongoing school systems and which may be used for planning as well as evaluation, taking the decision maker's preferences into account. A case study is then considered which generates the data systems required by the model. The model provides outputs, whose utility for the decision maker is discussed. The sensitivity of model outputs to various changes in the decision maker's value system is also explored. The final section provides specific recommendations to decision makers as a result of the case study and presents a more general set of cautions and recommendations. Suggestions for future research are presented, and a 61-entry bibliography is attached. (Author/DE)

ADMINISTERING FOR CHANGE PROGRAM

PROFESSIONAL PAPER

A COST-EFFECTIVENESS EVALUATION APPROACH TO IMPROVING RESOURCE ALLOCATIONS FOR SCHOOL SYSTEMS (REPRINT)

RESEARCH FOR BETTER SCHOOLS INC.

INTRODUCTION

Research for Better Schools, Inc. since its inception in 1966, has pressed for improvements in methods used for planning and decision-making in schools. Dr. Sanford Temkin has focused major attention upon this problem in the more than three years he has been a professional staff member at RBS. His doctoral dissertation presents a planning and decision-making method which holds great promise for application after more is learned about change itself as well as about the changes which are imposed on schools as they assimilate planning methods. The method presented in his dissertation rests firmly on three foundations: statistical and mathematical modeling, economic theory, and experience in education and educational administration.

The preeminent reason for reprinting this dissertation is the contribution it has made to RBS in the development of a new program. This new program, the Administering for Change Program, was formally created during the summer of 1968. One of its major goals is to help local school administrators make it possible to bring about the changes they deem necessary.

RBS takes both pleasure and pride in presenting Dr. Temkin's work with the hope it may be as useful to others as it has been to us.

Frederick E. Tanger

Frederick E. Tanger, Director
Administering for Change Program
Research for Better Schools, Inc.
January 21, 1970.

A COST-EFFECTIVENESS EVALUATION APPROACH TO IMPROVING RESOURCE ALLOCATIONS FOR SCHOOL SYSTEMS

Sanford Temkin

A DISSERTATION

in

BUSINESS AND APPLIED ECONOMICS

Presented to the Faculty of the Graduate School of Arts and Sciences of the University of Pennsylvania in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy.

1969

Morris Hamburg
Supervisor of Dissertation

James E. Walter
Graduate Group Chairman

To my wife, Maxine, who is not certain
that the present value of net benefits
of a dissertation is positive.

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I would like to express my appreciation to Professor Morris Hamburg, my dissertation supervisor, and the other members of my Committee, Professors Richard Clelland, Robert Jones, and Donald Morrison for their comments, suggestions and assistance.

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I. THE PROBLEM AND ITS SETTING

A. Background

Schools exist to provide services for children. School programs (e.g. arithmetic curriculum; lunch program) are the products which the school system produces in an effort to meet the needs of the pupil population.

One of the major problems which confronts the school system is the problem of resource allocation since demands for resources are greater than the supply of resources determined by the current operating budget level. This presupposes that the school decision-maker[1] does not generally have a budget of sufficient size to allow for the implementation of all the programs he deems necessary. Further, it implies that there is an opportunity cost associated with running the system's programs, since a given amount of resources expended for one program restricts the amount of resources available for use by others. The economic problem is to allocate the given level of resources to programs in such a way that the maximum contribution to the system's objective function is realized.

The magnitude of the problem is considered by Leonard Lecht in a recent book. Lecht states that expenditures for education were in the neighborhood of $30 billion in 1962. Assuming increasing costs and intensified emphasis on educational goals, Lecht predicts that more than $80 billion will be required by 1975 (in 1962 dollars).[2]

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[1]In this study reference is made interchangeably to the decision-maker and school superintendent.

[2]Leonard A. Lecht, Goals, Priorities, and Dollars: The Next Decade, (New York: The Free Press, 1966), p. 140.

Alexander Mood, former Assistant Commissioner of Education, referring to the cost of the nation's educational system, said:

> It is a very expensive element too; any contribution that can be made to its effectiveness or efficiency will pay handsome returns.[3]

This is narrowed to the specific domain of public school resource allocation in a study by Abt Associates.

> Millions of dollars are spent every day in the United States to improve the public schools, yet the quantity and quality of education available to many is believed inadequate to meet public demand. Since national human and physical resources potentially usable in the improvement of the schools are competed for by other national needs, only limited resources are available for schools. When improvements are desired and only limited amounts of the necessary resources are available the efficiency of resource allocation becomes a critical problem.[4]

Before the author suggests a specific direction for helping school systems, it is necessary to understand some of the problems school decision-makers face when contemplating resource allocation. One of the difficulties concerns public response to educational innovation. Charles Benson discusses this situation.

> ...The public schools are local monopolies and hence cannot in fairness make any kind of radical change which would be repellent to some groups of parents. Second, inventions and innovations cost money. They are processes involving risk, in the sense that the 'payoff' is uncertain, with respect to whether any good thing will occur and, if so,

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[3]Alexander M. Mood and R. Powers, Cost-Benefit Analysis of Education, Paper presented at Washington Operations Research Council's Second Cost-Effectiveness Symposium, (Washington: March 1967), p. 1.

[4]Design For an Elementary and Secondary Education Cost-Effectiveness Model: Volume I Model Description, for the U.S. Office of Education (Cambridge: Abt Associates, June, 1967), p. 1.

> when it will occur. It follows that expenditures on development, broadly considered, are hard to defend against the attacks of the zealous skeptic.[5]

Again, it is Benson who states that school resource allocation decisions tend to be made on ad hoc bases, primarily by committee, augmented in some instances by teachers and consultants.[6] Planning of this type and the resulting decision-making generate a high degree of suboptimization. Suboptimization is usually taken to mean optimization in ignorance of higher order considerations, but it could be thought of in the parallel sense, e.g. a research program, trying to develop better ways to teach a one year course in trigonometry while the Mathematics Coordinator tries to reduce the amount of time devoted to trigonometry to four school weeks.

In terms of the marketplace having an influence on the production of school services, we find that the consumers of these services do not directly purchase the amounts they desire. Consequently, their preferences are not reflected in market prices. In addition, there is little reason to assume that these consumers possess the abilities to make rational selections from among the available educational products. The conclusion that educators know very little about the educational production function does not enhance the outlook for efficient allocation.[7] These factors, coupled with the absence of competition, indicate that outside of public response and limited resources there is little pressure brought to bear on schools to produce educational outputs more efficiently.

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[5] Charles S. Benson, The Economics of Public Education, (Boston: Houghton-Mifflin Co., 1961), p. 327.

[6] Benson, op. cit., p. 359.

[7] This conclusion has been drawn by numerous authors. An example is found in: Jesse Burkhead, Thomas B. Fox, and John W. Holland, Input and Output in Large-City High Schools, (Syracuse: Syracuse University Press, 1967).

B. The Purpose and Plan of This Study

The general economic problem is to allocate the given level of resources in such a way that the system's outputs are maximized. It is clear, however, that any improvement in the way schools allocate their resources can be important. The purpose of this study is to develop a general model for evaluating resource allocations and apply it to the ongoing programs of a school system.

The plan of this study begins in this chapter with a description (section C) of some of the methods employed in making public sector resource allocation decisions. A conclusion is drawn relative to the appropriateness of each method for evaluating the ongoing programs of a school system.

In the second chapter a nine-case structure is developed and analyzed in order to lay the groundwork for the evaluation of ongoing school systems. The analysis of these cases leans heavily on indifference curve theory, certainty-equivalence theory, and statistical theory.

Chapter III considers the problems encountered in an application of the model to the Health and Physical Education Sub-System of the Radnor Township School District. As a case study it develops the data systems required by the model. The next chapter provides model outputs and considers the utility of these for the decision-maker. Chapter V uses the cost-effectiveness data derived earlier and considers the output implications of selected budget strategies for the pilot school sub-system. In addition, this chapter explores the sensitivity of model outputs to various changes in the decision-maker's value system.

The final chapter provides specific recommendations to the decision-maker as a result of the case study and also extends a more general set of cautions and recommendations. Finally, suggestions for future research are presented.

C. Systematic Analysis and Resource Allocation Decisions

The problem of allocating resources to programs can be viewed in two ways with regard to the time dimension. If no programs exist and there is a budget to allocate, then the analyst provides an a priori decision framework. If, on the other hand, programs do exist, then the viewpoint of this dissertation is that the analyst should consider an a posteriori or evaluative framework. Evaluation is constrained by the realities of an existing system of ongoing programs and, therefore, programs are to be evaluated so that recommendations for subsequent period program modifications can be made.

Much of the literature dealing with public sector resource allocation decision has tended to adopt an a priori methodology. That is, the authors have focused on the selection of a program(s) from a set of alternatives, but in advance of the actual operation of any programs.[8] If we were contemplating the design and development of a completely new school system, we would first come to agreement as to our objectives. Then we would consider anticipated costs and benefits associated with the respective programs contributing to the system objectives. This type of situation would lend itself to a priori decision models.

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[8]Some examples of carefully structured general analyses are:
Morris Hamburg, Statistical Decision Theory and Benefit-Cost Analysis for Preferredness of Choice Among Alternative Projects, a paper presented at the 12th International Meeting of the Institute of Management Sciences (Vienna: September, 1965).
Arthur Smithies, Government Decision-Making and The Theory of Choice, (Santa Monica: The Rand Corporation, 1964).

However, the evaluation of ongoing school systems is different. Some of the reasons for this difference are those which explain the tendency for institutions to perpetuate themselves. In addition, even if school systems could be systematically designed and developed, one is not sure whether enough is understood about the political, social, and economic forces that interact to comprise the often subtle environment within which schools perform.

Literature devoted to resource allocation decisions in the public sector has been quite diverse in terms of area of application. Some of the fields of application have been recreation, public health, weapons systems, highway construction, water resource development, food irradiation, and education. Studies, mostly in the format of methodological proposals, have been referred to as benefit-cost analysis, cost-effectiveness analysis, Program Planning Budgeting Systems (PPBS), input-output analysis, etc. The remainder of this section describes these models. Each description is a generalization, in that studies purporting to use a given method (e.g. benefit-cost analysis) often have little in common. When possible, the method is described as it is commonly applied to school systems.

1. Benefit-Cost Analysis

This approach derives from early work in the 1920's, primarily in the field of water resource development. Methodologically it aims at the selection of one or more projects from a set of alternatives. Each is viewed as a capital investment and the analysis focuses on the benefits and costs.

One of the initial steps involves a statement of goals or objectives and a subsequent translation into operational terms. On these operational bases, dollar valuations are assigned to benefit and cost components. Several studies attempting to assess lifetime earnings as a function of various present-period programs have been conducted. Educators have been reluctant to embrace conclusions deriving from the studies partly because they see an open society. That is, children who are educated in the present-period are likely to migrate from the school district. Many immediate pressures for the school decision-maker, coupled with a rational lack of concern for the distant future, cause him to overemphasize the importance of present-period consumption of school services at the expense of future-oriented production considerations.

Cost problems are also complex, but cost estimation is less complex than benefit estimation due to several factors: 1) there are specialists such as business managers, accountants, and cost estimators who have experience in working with costs, 2) historical cost data are often available for use as a base for projections, and 3) most costs can be reduced to a common denominator of dollars.

The benefit-cost criterion has several forms. For the sake of discussion the formulation commonly referred to as the "present value of net benefits criterion" is presented below.

Let

B_t = project benefits for year t

C_t = project costs for year t

T = the project duration (i.e. the number of years project benefits and costs are to be explicitly included in the analysis)

$$V = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+i)^t}$$

i = discount rate

V = net present value of the project.

Many of the controversies and arguments arise from attempts to operationally define these symbols under realistic conditions. Higher order arguments focus on the nature of the overall criterion. Controversy derives from the insistence by most experts that benefit-cost ratios are poor criteria. When benefits can be reduced to a dollar unit of measurement there is little argument, but in many public sector instances this is not feasible. Otto Eckstein, the leading proponent of the ratio, explores the nature of project rankings by using ratios and present value of net benefits discounted by the internal rate of return. Eckstein's arguments and his explicit assumptions can be found in a lengthy effort comparing the two criteria as bases for ranking projects.[9]

Most discussions of overall benefit-cost criteria are quick to point out that there is no universal criterion. The "Green Book" [10] suggests the criterion of maximization of net benefits for comparing different projects. The problem of the ratio is treated in detail in Appendix A in conjunction with an analysis of an argument between Roland McKean and Eckstein.

Another argument centers on the selection of the appropriate discount rate. Roland McKean provides an extensive discussion of this topic.[11] He indicates that under conditions of no capital rationing

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[9]Otto Eckstein, Water Resource Development, (Cambridge: Harvard University Press, 1958), pp. 55-57.

[10]This is common terminology for Proposed Practices for Economic Analysis of River Basin Projects, Report to the Federal Inter-Agency River Basic Committee prepared by the Sub-Committee on Benefits and Costs, (Washington: 1950).

[11]Roland N. McKean, Efficiency in Government Through Systems Analysis, (New York: John Wiley & Sons, Inc., 1958),pp. 76-92.

(ie. borrowing for projects is possible) the agency should invest in projects until the next project in line is expected to yield no more than the cost of borrowing (i). The expected yield of a project is called its internal rate of return (r), i.e. that rate of discount which makes its present value equal to zero. Therefore, investment in projects should continue as long as $r > i$ and the interest rate can be viewed as the marginal internal rate of return.

In the capital rationing instance, the budget could be such that the relationship between r and i is not relevant. Therefore, under conditions of scarce capital, McKean argues for the use of the marginal internal rate of return as the appropriate discount factor. The internal rate of return is the yield that could be earned in the next-best opportunity available to the investor.

The examples given by McKean treat such considerations as reinvestment of receipts, resale value of the investment, consumption of the receipts, etc.

The benefit-cost literature abounds with other types of arguments. Some of these are:

1. The selection of the project's duration of planning horizon (T in the formulation given previously) is usually arbitrary, but the ranking of projects is sensitive to this choice.

2. There is considerable disagreement as to the choice of the appropriate opportunity cost (discount rate) in a given field.[12]

3. The use of "shadow prices"[13] to enable the analyst to value benefits in dollar units due to the inapplicability of market prices in most public sector domains is a problem. Also related

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[12] John V. Krutilla and Otto Eckstein, Multiple Purpose River Development, Resources for the Future, Inc., (Baltimore: The Johns Hopkins Press, 1958), pp. 125-127.

[13] Roland N. McKean, "The Use of Shadow Prices," Samuel B. Chase, Editor, Problems in Public Expenditure Analysis, (Washington: The Brookings Institution, 1968), pp. 33-34.

to this are the problems of treating intangibles and incommensurables.

4. The treatment of uncertainty in estimating benefits and costs, which is not unrelated to the choice of planning horizon, is troublesome and usually neglected quantitatively although considered generally in study conclusions.

5. Suboptimization resulting from attempts at optimizing within components of the system so as to make the analysis manageable is, in general, a necessary danger.

In summary, it is clear that benefit-cost analysis has no consistent format or prescription. Objectives are defined and alternatives are structured and analyzed in terms of benefits and costs. The attitude seems to be strictly a priori investment, with an implication, if one reads between the lines, that a benefit-cost analysis generates sequential decisions, especially in the constrained budget case (capital rationing). The major advantage seems to be the explicitness demanded by analysis of public sector investments within a framework provided by private sector investment theory.

The applications of this method to education have been sparse. Most of the applied efforts have centered on a comparison of programs based on the net present value of a stream of lifetime earnings.[14]

2. Cost-Effectiveness Analysis

This approach derives from military systems analysis where the problem is to select a system design from a set of alternatives designed

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[14] For example: Theodore W. Schultz, The Economic Value of Education, (New York: Columbia University Press, 1963).

Burton A. Weisbrod, "Preventing High School Dropouts," Robert Dorfman, Editor, Measuring Benefits of Government Investments, (Washington: The Brookings Institution, 1963).

to meet one or more objectives. In this framework the analysis focuses on the effectiveness and cost of the respective alternatives. It is a natural substitute for benefit-cost analysis for situations in which the benefits are incommensurable and inappropriate for dollar valuation.[15]

The situation is often viewed as one of finding a minimum cost outlay for a given level of effectiveness across system objectives (although actual applications usually deal with a single objective and a single measure of effectiveness). Major problems arise out of efforts to have criteria to stand in proxy for measures of the extent to which objectives have been met.

Some operational definitions of effectiveness are interesting. In an Air Force problem, the objective was to "optimize the bomber effectiveness by trading off reliability, maintainability, performance, and cost factors." Here, two criteria were developed and a term "strategic effectiveness" was defined as the probability of success in terms of meeting each criterion.[16]

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[15]Another such approach is "cost-utility" analysis, although Gene Fisher says

> Attempting to define cost-utility analysis poses somewhat of a semantics problem. Numerous terms are in current use which convey the same general meaning, but which have important different meanings to different people: cost-benefit analysis, cost-effectiveness analysis, systems analysis, operations research, operations analysis, etc. Because of such terminological confusion, in this chapter all of these terms are rejected and instead, 'cost-utility analysis' is employed.

This paragraph appears in: G. H. Fisher, The Role of Cost-Utility Analysis In Program Budgeting, (Santa Monica: The Rand Corporation, 1964), p. 3.

[16]Cost-Effectiveness Optimization, (Technical Supplement), Final Report Task Group IV, Weapon System Effectiveness Industrial Advisory Committee, Headquarters, Air Force Systems Command, Andrews Air Force Base, Maryland, (January, 1965), pp. 24-29.

A paper presenting a model which relates policies to costs argues for establishing cost-effectiveness trade-offs by simulation when effectiveness is defined as performance.[17]

One proposal suggests that a production function be defined in the form

$$A = F(X,Y,Z, \ldots, Z_k)$$

where A is an achievement score for an individual
X is a vector of non-school variables
Y is a vector of non-teacher characteristics of the school
Z_i is a teacher attribute

Under certain assumptions (F is convex to the origin and continuous throughout its domain with positive first order partial derivatives and negative second order partial derivatives) and with a budget constraint, the author suggests the familiar equality

$$\frac{\partial A/\partial Z_i}{P_i} = \ldots = \frac{\partial A/\partial Z_k}{P_k}$$, P_i is price of teacher attribute i

as the relationship which produces the most for a given child. When the ratio of $\partial A/\partial Z_i$ is constant for all k teacher attributes then an increase or decrease in Z_i will lose in terms of achievement for the individual. Although the author does not pursue the analysis to indicate implications for schools, he does attempt to measure empirically some input-output values by multiple regression techniques.[18]

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[17]Blanning,Robert W.,Opportunity Cost and Effectiveness Analysis by Simulation,Management Science Center,Wharton School of Finance and Commerce, University of Pennsylvania,(Philadelphia:April 1967).

[18]Henry M. Levin, Cost-Effectiveness Analysis and Educational Policy-Profession, Confusion, Promise, Research and Development Memorandum No. 41, Stanford Center for Research and Development in Teaching, Stanford University (Stanford: December, 1968), pp. 5-6.

Another effectiveness concept is weighted effectiveness. This is found in a discussion of how to handle the problem of two or more objectives.[19]

Interestingly, Ackoff suggests expected value as a way to define effectiveness in a posteriori cases. He indicates that expected effectiveness is optimal only if the value function in relation to the scale is linear and monotonically increasing.[20]

There are other ways in which effectiveness has been defined, but applications to educational problems have been sparse. For the most part, analyses have focused on before-the-fact system design, and not after-the-fact system evaluation. Cost-effectiveness offers possibilities since it overcomes the problem of incommensurable units, provided another common denominator or value system can be substituted.

3. Program Planning Budget Systems

This approach received its principal impetus from the studies conducted in the Department of Defense under Secretary McNamara. The method attacks the resource allocation problem through the system's accounting-fiscal mechanisms. It is an attempt to integrate planning (setting objectives and policies), programming (specifying what is to be done to accomplish the objectives), and budgeting (specifying intended allocations of resources in given intervals of time -- in the typical PPBS situation one usually encounters a five-year planning interval).

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[19] Russell L. Ackoff, Shiv K. Gupta, and Sayer J. Minas, Scientific Method, (New York: John Wiley & Sons, Inc., 1962), pp.76-77.

[20] Ackoff, et. al. ibid., pp. 103-104.

The Intermediate Unit Planning Study of the Fels Institute of Local and State Government, University of Pennsylvania, is presently trying to develop a PPBS model for educational administrative areas (Intermediate Units) in Pennsylvania. A paper by Wilson and Gupta in connection with this study reviews the literature on the application of systems analysis techniques to the managing of a school system. They indicate that research in this respect can be sorted in three gross categories:

1. PPBS efforts in some school systems.
2. Systems analysis applications to school system supportive functions.
3. Attempts to describe the educational process aiming toward the development of predictive tools.

They further indicate that the magnitude of the problems associated with the application of a PPBS model for a school system has caused some school systems to terminate their efforts as unfeasible. In addition, no school system seems to have progressed past beginning efforts due to problems encountered in generating the quantity and quality of data required and the need for explicitness of goals and objectives.[21]

The method of PPBS is, as was said earlier, extremely flexible. The central feature is the attitude it attempts to convey, which is the design and plans for programs and program alternatives based on consideration of the extent to which objectives will be met at various levels of funding, and, at the same time, the integration of the program activities over an extended time interval (e.g. 5 years).

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[21] Thomas Wilson and Shiv Gupta, Review of Research and Projects with Content Relevant to the Study. Unpublished document for the Intermediate Unit Planning Study, Fels Institute of Local and State Government, University of Pennsylvania, (Philadelphia: November, 1967), pp. 2-3.

One of the essential elements for a system of planning such as this, in addition to a specification of goals, programs, and program objectives, is an accounting system which can relate costs to program activities. This represents a departure from the line-item accounting systems prevalent in school systems. Accrual accounting procedures are also important so that expenditures can be tied to time in a more realistic fashion.

Some of the recommendations for PPBS indicate that systematic analysis, such as benefit-cost analysis or cost-effectiveness analysis, should be included within the scope of PPBS. The elements attributed to PPBS are the same as those which generally define (for example) benefit-cost analysis -- objectives, alternatives and selection from these alternatives.

In summary, it appears that PPBS is no more than the label assigned to efforts aimed at applying systematic analysis (e.g. cost-effectiveness analysis) to ongoing systems in a fixed time frame.

4. Input-Output Analysis

This work derives from the input-output studies of Leontief. As was mentioned earlier, the efforts to relate inputs to outputs in education are empirical in nature, and almost totally unsupported by theory. Some studies have attempted to relate educational inputs (e.g. achievement test scores; delinquency rates) in an effort to determine the technical coefficients which link them.[22]

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[22]For example: The Feasibility of Cost-Effectiveness Analysis for Title I Public Law 89 - 10. Technomics, Inc. (Santa Monica: 1966).

Thomas, James, J. Alan Thomas and Harold J. Dyck, Wealth Expenditure and Decision-Making for Education, School of Education, Stanford University (Stanford: June 30, 1963).

While the Kershaw and McKean article[23] seems to be the first of the proposals from non-educators to study input-output relationships, the work of Paul Mort predates this. Mort examined levels of expenditures and various policy positions in relation to criteria he designed reflecting school system "quality." Mort was able to describe gross relationships and draw conclusions.[24]

Kershaw and McKean wanted to examine input combinations and their effects (or, more accurately, associations) with school outputs. They proposed that empirical input-output studies be conducted, and, if the findings produced suitable hypotheses, that these hypotheses be tested by means of alternative educational systems.

Roger Sisson at the University of Pennsylvania has approached this problem, but he has paused to place more emphasis on the process by which inputs help produce outputs. His work in this area also considers models of the school system.[25]

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[23] Joseph A. Kershaw and Roland N. McKean, Systems Analysis and Education, (Santa Monica: The Rand Corporation, 1959).

[24] In 1946, Mort, William S. Vincent, and Clarence A. Newell developed "The Growing Edge", which was an instrument designed to measure the quality of education in specific school environments. Many studies and dissertations were published by the Bureau of Publications of Columbia University as a result of the efforts of Mort and his colleagues. They were primarily empirical studies concerning themselves with the sensitivity of school quality to alternative input levels.

[25] Roger L. Sisson, A Model of a School, Educational Intermediate Unit Study, Management Science Center, University of Pennsylvania, (Philadelphia: September, 1968); Roger L. Sisson, "Can We Model The Educational Process?" paper presented to Symposium on Operations Analysis of Education for U. S. Office of Education,(Washington, D. C.: December 1967).

5. Summary Comments on Selected Methods

Benefit-cost analysis seems appropriate for selecting projects from among alternatives when investment is clearly the spirit of the decision, and when inputs and outputs can fairly be measured in dollar terms. Cost-effectiveness analysis appears to be applicable to the selection of alternative designs aimed at the same goal or goals. In addition, an effectiveness measure substitutes for a benefit measure in the analysis, and, generally, time is treated as less important.

Program Planning Budget Systems are attempts to bring systematic analysis to ongoing systems by integrating programs and program plans with consideration of the gains and costs of the activities. This is reflected by a 5-year budget, which is revised annually.

Input-output analysis is openly aimed at gaining knowledge by studying which input combinations are associated with the presence of various desired outputs. The endeavor could probably gain significantly if more attention would be extended to the relations that exist between inputs and process on one hand, and process and outputs on the other hand. Input-to-process and process-to-output relationships are fundamental to explaining why certain inputs are related to certain outputs. The process, it can be hypothesized, may, in some instances, be the major explanatory factor in the analysis.

Exhibit 1 describes these previously discussed methodological approaches which have been suggested for application to education problems. The message that filters out of the literature[26] is that what

[26] Research for Better Schools, Inc., published in November, 1968, a bibliography titled, An Annotated Bibliography of Benefits and Costs in the Public Sector. This publication includes approximately 2700 references and comments on articles, books, reports, etc., in the domain of economic and quantitative analysis in the public sector.

is needed for education is a systematic method for evaluation of ongoing educational systems so that future-period allocations can be made with full awareness of the appropriate decision inputs.

Chapter II structures and analyzes nine decision frameworks. The analysis leads up to Case 9, which is the evaluation of ongoing systems pursuing multiple objectives by means of multiple activities.

Exhibit 1

Comparison of Selected Public Sector Analytic Methods

Method of Analysis	General Problem Framework	Benefit Measure	Planning Horizon
Benefit-Cost	*A priori* selection of projects	Discounted net dollar benefits	An arbitrary horizon based on project factors
Cost-Effectiveness	*A priori* selection of systems	Effectiveness	A complete operation of the system
PPBS	*A priori* with annual feedback for updating programs and budget packages	A variety of measures e.g. Benefit-Cost Cost-Utility	Generally five years
Input-Output	*A posteriori*	Usually multiple output criteria	Variable from one year to several years, depending on purposes.

II. RELATED DECISION CASES

This chapter describes a set of related decision situations. Nine cases are developed and criteria are specified to assist selection decisions in the *a priori* cases, and to improve allocations for existing programs in the *a posteriori* cases. The purpose of the analysis is to structure a general model framework which is applicable to the evaluation of ongoing systems. The next chapter treats the specific problems of adapting and applying the general evaluation model to an ongoing educational system.

Exhibit 2 outlines the logic of the classification system. It is interesting to note that within the system of classification only one of the nine cases (Case 8) is a cost-effectiveness decision case and one (Case 9)is a cost-effectiveness case, in an after-the-fact evaluation sense.

A. The Nine Cases

The format for the development and analysis of each case is given below:

1. Case structure

    a) The number of objectives (single or multiple)

    b) The number of activities (single or multiple)

    c) The decision framework (*a priori*, i.e. activities are to be selected or *a posteriori*, i.e. activities were selected and are to be evaluated)

    d) The level of resources (unlimited, limited, or known)

    e) A discussion and a statement of the decision-maker's objective

EXHIBIT 2

A CASE CLASSIFICATION OF LOGICALLY RELATED DECISION PROBLEMS

CASE	STRUCTURE	DECISION FRAMEWORK	RESOURCE LEVEL	COMMENT
1.	Single objective with set of activity-designs; one to be selected.	A priori	Unlimited	A utopian research and development problem.
2.	Single objective with set of activity-designs; one to be selected.	A priori	Limited	The constraint limits admissable alternatives; but still no incentive to economize.
3.	Evaluation of Cases 1 and 2.	A posteriori	Known	A performance evaluation involving a partition of outcome space.
4.	Single objective with set of activity segments; several to be selected as a package.	A priori	Unlimited	A more complex version of Case 1;still utopian.
5.	Single objective with set of activity segments;several to be selected as a package	A priori	Limited	The constraint limits admissable alternatives as in Case 2;still no incentive to economize.
6.	Evaluation of Cases 4 and 5.	A posteriori	Known	A more complex version of Case 3.
7.	Multiple objectives with sets of activities;several to be selected.	A priori	Unlimited	A much more complex version of Cases 1 & 4; the relative weight of objectives becomes important.
8.	Multiple objectives with sets of activities;several to be selected.	A priori	Limited	The general cost-effectiveness case; the only case meeting the necessary and sufficient conditions for cost-effectiveness analysis.
9.	Evaluation of Case 8	A posteriori	Known	The general program evaluation case;provides cost-effectiveness evaluations for present year and inputs for next year's budget.

2. Case analysis

The decision-variable is structured and analyzed. A proof is given, when necessary, to show that the preferred value of the decision-variable is best in terms of meeting the objective(s) of the decision-maker, given the case assumptions and conditions.

Case 1

This situation is described by a single objective for which the decision-maker is presented a set of alternative activity-designs prepared by his engineers. An activity-design is a proposed plan for an activity. The decision framework is *a priori* and resources are unlimited. Only one activity-design can be selected by the decision-maker.

This does not constitute a cost-effectiveness problem[27] in that resources are unlimited. Instead, the decision-maker is confronted with a utopian research and development problem for which a solution is to be engineered.

The apparent criterion is to select that alternative promising the highest expected performance, $\overline{K}_i$. Activity-design i has a distribution of performance estimates, K_i, which reflect the engineer's perception of the performance after implementation and the engineer's biases. A bias for or against a particular activity-design affects $\overline{K}_i$ but not the standard deviation of the distribution of K_i, since a constant added to or subtracted from every value of a variable cannot influence the standard deviation of the variable. The decision-maker's aim is to

[27] The presumption is that benefits deriving from the pursuit of the objective may not be reducible to dollar terms, especially if intangibles are involved. Therefore, cost-effectiveness is general since it is independent of any arbitrary unit system.

select that alternative which promises a preferred balance between estimated average performance and the variability of the distribution.

The standard deviation, σ, has been used as a measure of uncertainty in some studies dealing with investment decision models.[28] The key ideas center on the assumption that an increase in risk (variability) in the return on an investment can be made acceptable to the decision-maker, provided there is sufficient compensation in terms of an increase in the expected level of return, μ. Also assumed is the notion that risk or uncertainty is undesirable. A certainty-equivalent function is an indifference curve that is the locus of combinations of $\{\mu, \sigma\}$, for which the decision-maker is indifferent. Specificity is given to an indifference curve by the certainty equivalent (usually a monetary value). If the decision-maker is allowed to choose from among the $\{\mu, \sigma\}$ points on a curve or elect to receive the monetary value for the curve, he should be indifferent to all.

Two comments are in order. First, risk and uncertainty were used synonymously in this description. Second, the usual way indifference curves are used is to indicate the rate of exchange for two commodities as a function of a set of preferences. The curve is negatively sloped reflecting that it takes an increased amount of one commodity to offset the loss of an amount of the other commodity. The slope of the curve at any point is called the marginal rate of substitution.

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[28] For example, Donald E. Farrar, The Investment Decision Under Uncertainty, (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1962), pp. 25-26.

How does this relate to the selection of the activity-design? Assume the engineer can provide, for each proposed activity-design i, an estimate of $\bar{K}_i$ and S_i where

$$\bar{K}_i = \int_{K_o}^{\lambda_i} K_i f(K_i) dK_i \qquad , K_o \leq K_i \leq \lambda_i ,$$

and

$$S_i^2 = \int_{K_o}^{\lambda_i} (K_i - \bar{K}_i)^2 f(K_i) dK_i \qquad , K_o \leq K_i \leq \lambda_i .$$

It is assumed that performance is defined over the range 0 to 1.0. The initial task for the decision-maker is to select a level of performance, K_o, below which performance is unacceptable. The λ_i upper limit is based on the engineer's estimate of a level of performance which "cannot" be surpassed by the activity-design. Once K_o has been established, the decision-maker considers variability values which are equally preferred to the receipt of K_o. These points define an indifference curve which is independent of any data received from the engineer. That is, the curve is defined solely on the basis of the decision-maker's preference for combinations of the two variables.[29]

Figure 1 indicates the general nature of this indifference curve, denoted $I_{(K_o)}$. The curve indicates the relationship of average performance values to variability values. This is explained by the assumption that the decision-maker would elect to avoid risk. Therefore, as S increases the response required of $\bar{K}$ is greater in order for the decision-maker to remain indifferent. In the extreme, there is a value

[29] If the preferences of the decision-maker were not used then he would be unnecessary and the engineer could make the selection strictly on his own criteria.

of S as perceived by the decision-maker which is so high that he will not accept anything less than the receipt of perfect performance with certainty. It should also be pointed out that two indifference curves cannot intersect, since this would mean there are two certainty equivalents for the same point.

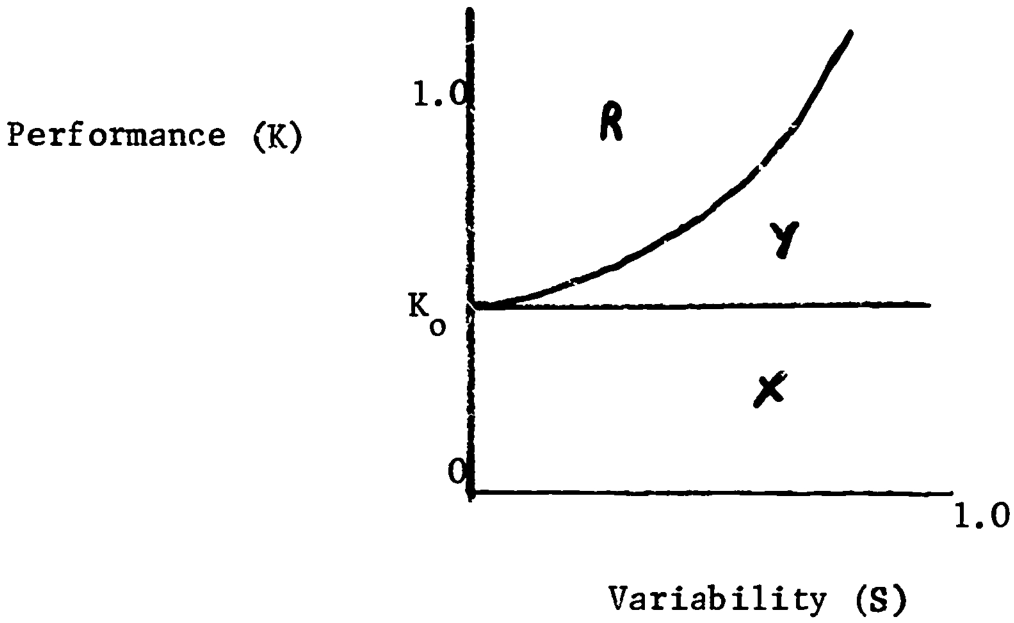

Figure 1. Indifference Curve of K_o

The X region of Figure 1 contains points for activity-designs which have expected performance levels below the minimum acceptable level, K_o.[30] The Y region contains points that are acceptable with respect to expected performance, but due to the assumption that increases in variability require increasingly greater responses in performance, these points are dominated by any point on $I_{(K_o)}$.

Figure 2 shows a group of indifference curves. The curve $I_{(K_o)}$ indicates a sharp response to what presumably is the decision-maker's uneasiness over the high level of variability in the neighborhood of $S = 0.5$. Suppose a parabola of form $S = a + bK + cK^2$ is used to describe

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[30]They also lie on indifference curves with certainty equivalents less than K_o, since the curves cannot intersect.

these relationships. Since three constants are to be determined, three sets

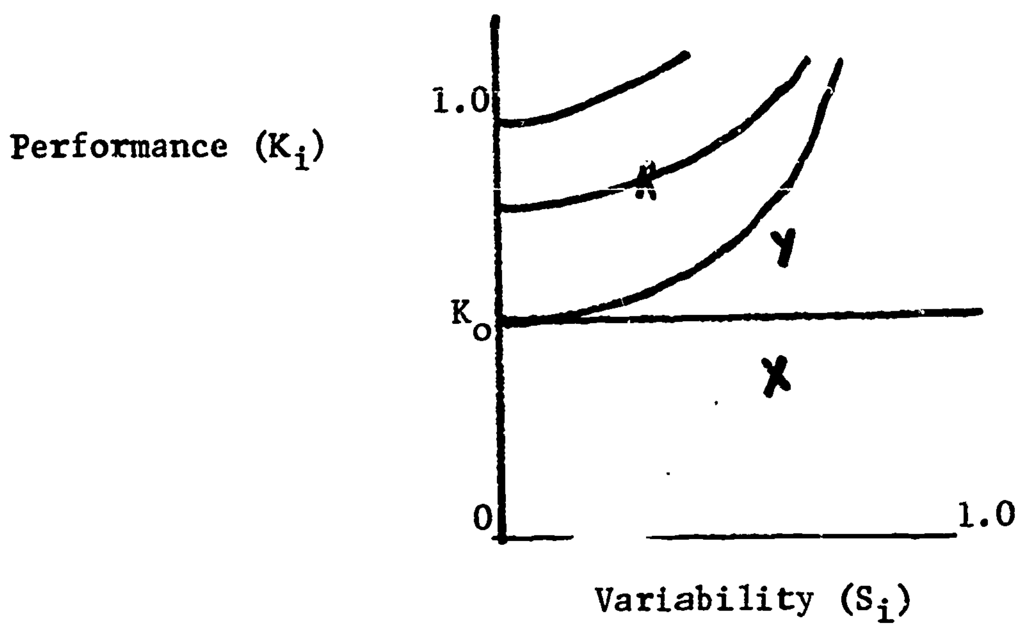

Figure 2. Several Indifference Curves

of coordinates are required. For instance, $\{K_o = 0.4,\ S_i = 0\}$, $\{\overline{K}_i = 0.6,\ S_i = 0.3\}$, and $\{\overline{K}_i = 1.00, S_i = 0.6\}$ satisfy the function $S_i = 0.10 - 0.75\overline{K}_i + 1.25\overline{K}^2$. In general, $\overline{K}_i$ values can be obtained for the quadratic form using the formula

$$\overline{K}_i = \frac{-b \pm \sqrt{b^2 - 4c(a - S_i)}}{2c},\ c \neq 0.$$

Some checks on the equation would involve seeing that $0 \leq S_i \leq 1$ and $K_o \leq K_i \leq 1$. The slope of the function can be interpreted as the rate of substitution of $\overline{K}_i$ for S_i, that is, $\frac{d\overline{K}}{dS}$;

$$\overline{K} = \frac{-b \pm \sqrt{b^2 - 4c(a-S)}}{2c} = \frac{-b}{2c} \pm \frac{1}{2c}\left[b^2 - 4c(a-S)\right]^{\frac{1}{2}}$$

$$\frac{d\overline{K}}{dS} = \left(\frac{1}{2c}\right)\left(\frac{1}{2}\right)\left[b^2 - 4c(a-S)\right]^{-\frac{1}{2}}(4c)$$

$$\frac{d\overline{K}}{dS} = \pm\left[b^2 - 4c(a-S)\right]^{-\frac{1}{2}}.$$

This indicates that the change in performance per unit of variability at the point S = 0.5 in the previous function is 0.53 (-0.53 is not meaningful). This means that the rate of change of the function when $S = 0.50$ is $0.53\ \bar{K}$ per unit of S. At $S = 0.6$ the derivative is 0.57 indicating the increase in the response of $\bar{K}$ to changes in S.

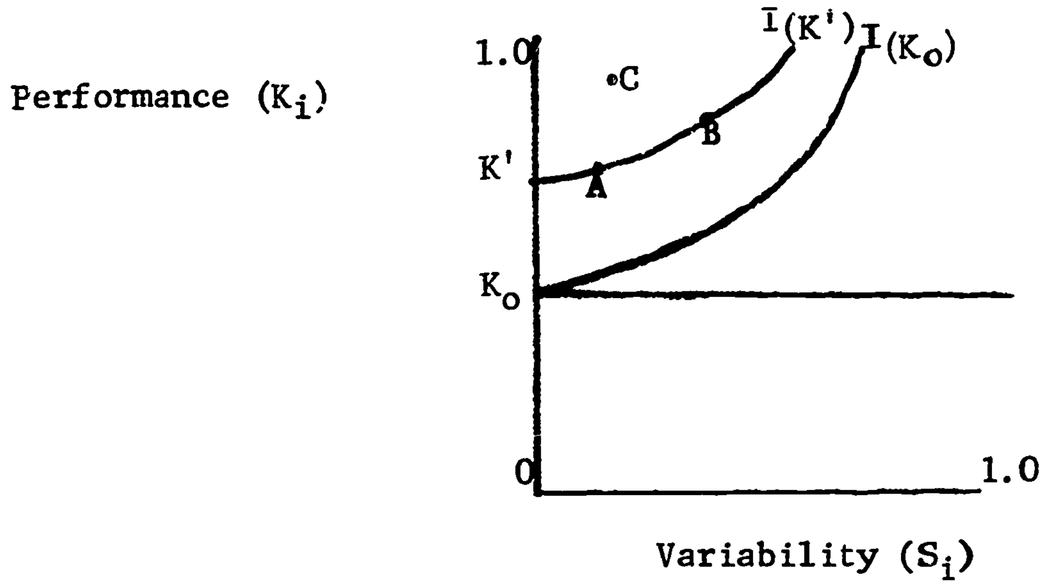

Figure 3. Selecting a Preferred Point.

The logic that allows the preferred point to be selected is not complex. The ideal point is $\{\bar{K}_i = 1, S_i = 0\}$. Figure 3 shows an indifference curve and three points. Points A and B are equally preferred since they lie on $I_{(K')}$. Point C is preferred to A or B since it has a higher performance value than some points on $I_{(K')}$ having the same level of variability as Point C. Point C is also preferred to any point on $I_{(K')}$ having the same level of performance as C. The preferred activity-design is the one with a point lying on or above the uppermost indifference curve.

The main lesson of Case 1 is that the decision-maker should introduce his preferences as to combinations of performance and variability. If not, expected performance is the criterion and his preferences for risk are ignored.

Case 2

This case differs from Case 1 in one important respect: resources are limited. Again there is a single objective with multiple activity-designs from which only one is to be selected in an *a priori* framework. If the decision-maker is being perfectly rational, he will select that activity-design which promises the highest certainty equivalent he can afford. When he does not elect to behave in this manner then he has implicitly introduced a second objective. It may be a personal objective such as the desire to be efficient under any circumstances or he may entertain some vague notion of future possibilities developing for investment. But the point remains that in Case 2 he has no alternative goals in competition with the attainment of the single, given objective.

Consequently, Case 2 reverts to a modified Case 1. His decision rule is to select the activity-design represented by the point on or above the highest indifference curve provided it falls within the limitations of his budget. Instead of treating the three variables in a three dimensional drawing, the decision graph can be viewed as two dimensional by using the certainty equivalent in place of $\bar{K}_i$ and S_i. Figure 4 shows this with the ordinate indexing values of the certainty equivalents and the abscissa indicating estimated costs[31] associated with the candidate

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[31]Costs are assumed to be point estimates with no accompanying measure of variability. Therefore, the decision-maker should be cognizant of this since designs with estimates less than, but close to C_{max} may exceed C_{max} if they are selected. How he views this is a function of how binding C_{max} is to him. If, for instance, there is some room for leeway he may not be troubled by the possibility of exceeding C_{max}. This is especially true in subsequent cases since provision for this contingency is generally in the overall budget structure.

activity-designs. The candidate points are points for which $C_i \leq C_{max}$, and $\bar{K}_i \geq K_o$. In order to select the preferred point the decision-maker

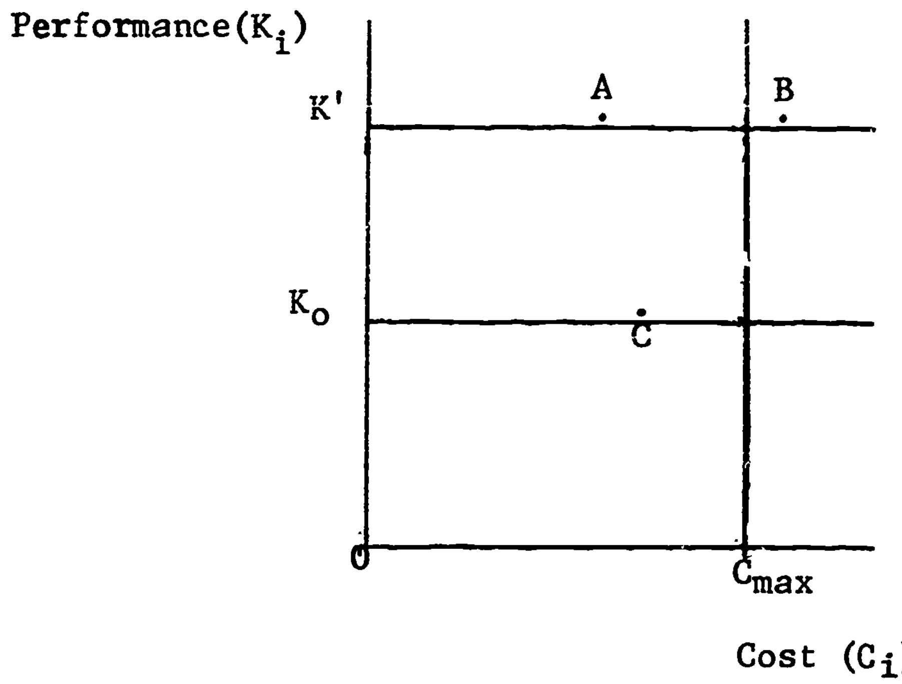

Figure 4. Selecting a Preferred Point with a Cost Constraint

locates the point on or above the highest certainty equivalent with a $C < C_{max}$. If there are two or more candidate points on the highest line then the decision-maker can select the least cost point (although according to the structure and assumptions of Case 2 he is unable to use a partially unexpended budget). The net result of adding the budget limitation is that points such as B in Figure 4 are eliminated from consideration. In the Figure 4 example he would be compelled to select Point C over Point B if Point A did not exist. This indicates the potential importance of a budgetary restriction.

Case 3

Situations which are characterized by the structures of Cases 1 and 2 result in the selection and implementation of an activity-design. Soon the decision-maker is faced with an evaluative problem -- given that the activity has been conducted, how well did it do? Case 3, therefore, is the *a posteriori* evaluation of Cases 1 and 2.

At first it might appear that the problem should be structured as a test of a statistical hypothesis. This is not required, however, since possible performance outcomes can be partitioned without statistical consideration. Figure 5b shows the range of possible performance outcomes partitioned into several decision segments. In order to appreciate this partition it is necessary to consider the distribution of K_i as perceived, a priori, by the engineer. This is shown in Figure 5a.

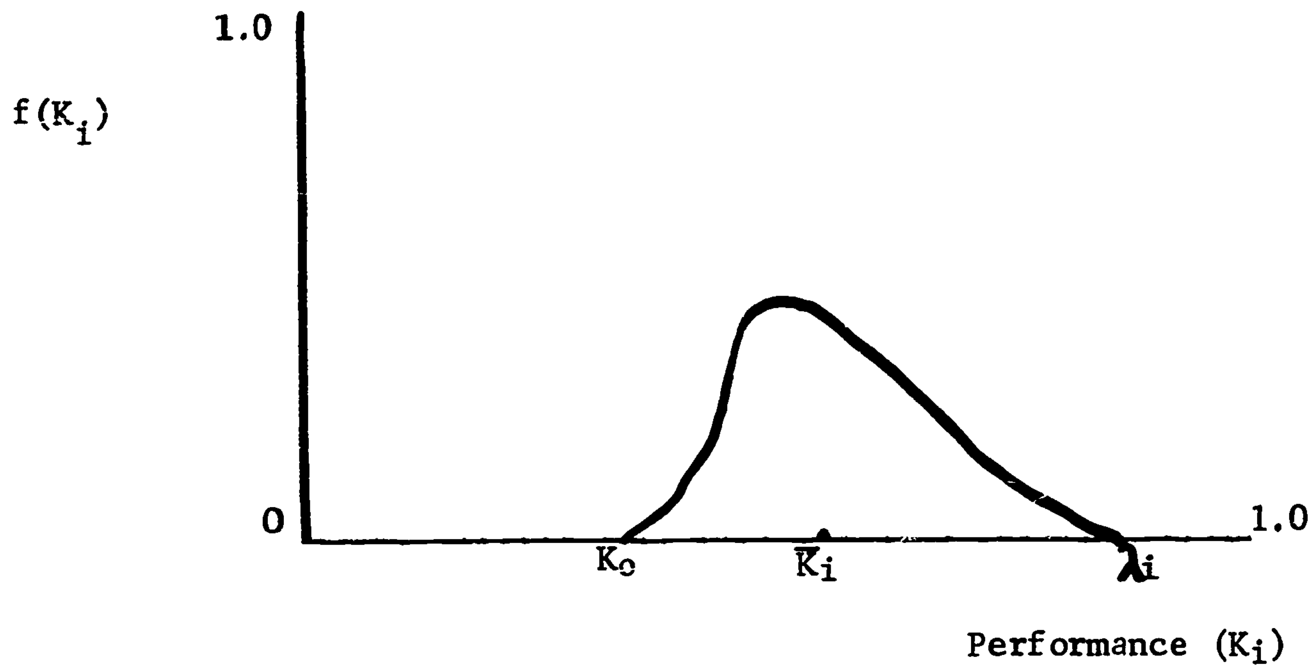

Figure 5a. Prior Distribution of K_i

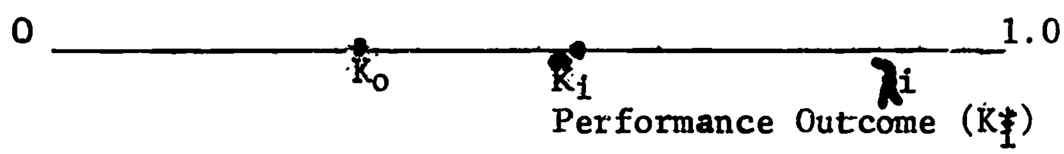

Figure 5b. Posterior Partition of K_i^*

When actual performance, K_i^*, falls below the level of K_o (i.e. $0 \leq K_i^* < K_o$), the engineer has not necessarily made a miscalculation. This could be attributable to factors which he could not possibly predict a priori. It should also be noted that K_o is a certainty equivalent and the probability of $K_i < K_o$ is dependent in part on the density of K_i^*.

The decision-maker may re-evaluate the engineer's ability to design and estimate and the engineer may evaluate his methods, but the previous cautions should be noted.

If actual performance, K_i^*, falls between K_o and λ_i (the engineer considered this to be certain before the activity was implemented), then it is within the range deemed acceptable. The engineer should evaluate his methods to be sure that he has minimized the probability of getting the right answer for the wrong reason.

When actual performance exceeds the upper boundary of the prior distribution (i.e. $\lambda_i < K_i^* \leq 1.0$), then the engineer has miscalculated on the favorable side. Nevertheless, this "pessimism" could rule out other activity-designs which should be selected for implementation. The decision-maker should re-evaluate the engineer's ability to estimate and the engineer should evaluate his methods.

When considering actual outcomes, the decision-maker should understand that the main benefits derive from discovering improved methods for

1. designing future activities,
2. estimating the potential for what is designed in the future, and
3. implementing future activities as they are designed.

The problems of implementing a newly designed activity often require a technology that is not understood. A preferred system can be perfect in terms of technical design, yet the implementation people may not be able to introduce the initial parts due to the nature of the changes required.[32]

[32] A few educational organizations are studying the concept of change with an objective of developing a technology for school systems that enables them to bring about the changes they deem necessary in a more orderly fashion.

The reason for introducing this apparent digression on change is that it is fully possible that the engineer can design an activity with good potential only to see performance fall below K_o due to problems arising out of the way the operation was implemented. Better communication between the engineer and the implementer may provide some help.

Case 4

Cases 4, 5, and 6 closely parallel Cases 1, 2, and 3. The difference is that Cases 4, 5, and 6 permit the decision-maker to select a package of activity segments in order to achieve his single objective.

Case 4, then, considers a decision-maker pursuing a single objective and having unlimited resources. The framework is a priori and he is able to select a set of activity segments.

Previously, there was an implied assumption that, in the interval K_o to λ_i, changes in worth to the decision-maker were proportional to changes in performance.[33] That is,

$$\frac{\Delta K_{AB}}{\Delta w_{AB}} = \frac{\Delta K_{BC}}{\Delta w_{BC}} = \cdots = \frac{\Delta K_{XY}}{\Delta w_{XY}}, \text{ where,}$$

ΔK_{AB} = the change in performance from K_A to K_B, where both points are between K_o and λ_i, and

Δw_{AB} = the change in worth associated with ΔK_{AB}.

[33] It can also be assumed that below K_o (the minimum level of performance set by the decision-maker), the same performance-worth relationship exists, but the decision-maker feels that an inadequate level of worth would result for performances in this interval. The same reasoning holds for $K_i^* > \lambda_i$ as in the interval. This assumption is carried through Case 6.

The reason for introducing the notion of worth, w_{iJ}, is that the respective segments within an activity-design do not contribute equally to the overall objective. Worth will be used to weight performance, and expected weighted performance will serve as the decision-variable.

The situation confronting the decision-maker of Case 4 is that he requires a package of activity segments. Some of the segment outputs are independent of the outputs of previous segments and others are not. The decision-maker can ask his engineers to repackage segments in any way possible in order to generate an improved way of attacking the objective. In addition, the decision-maker perceives segments as potentially contributing unequally to the overall objective. The problem is to select that package of segments promising the largest expected worth.

Theoretically, the engineer would structure a multivariate joint density function describing the outcomes and associated probabilities for each activity-design or package,

$$f(K_{i1}, K_{i2}, \ldots, K_{im})$$

In the statement above K_{oiJ} would refer to the minimum performance acceptable for certain for segment J of activity-design i, and λ_{iJ} would refer to the "maximum performance possible" for segment J of activity-design i.

Then the engineer would be able to derive marginal density functions by integrating the joint density with respect to the other variables over their full ranges (e.g. K_{oiJ} to λ_{iJ} for the general term). For instance, the marginal density of segment 1 is

$$f_1(K_{i1}) = \int_{K_{oi2}}^{\lambda_{i2}} \int_{K_{oi3}}^{\lambda_{i3}} \cdots \int_{K_{oim}}^{\lambda_{im}} f(K_{i1},K_{i2},\ldots,K_{im})dK_{i2}dK_{i3}\cdots dK_{im};$$

$$f_J(K_{iJ}) \geq 0.$$

Also the joint distribution of segments 1 and 2 is

$$g_1(K_{i1},K_{i2}) = \int_{K_{oi3}}^{\lambda_{i3}} \int_{K_{oi4}}^{\lambda_{i4}} \cdots \int_{K_{oim}}^{\lambda_{im}} f(K_{i1},K_{i2},\ldots, K_{im})dK_{i3}dK_{i4}\cdots dK_{im},$$

$$f_J(K_{iJ}) \geq 0.$$

If the outcomes of segment 2 are independent of segment 1 outcomes, then their joint density function would be equal to the product of their marginal densities.[34] From $g_1(K_{i1},K_{i2})$ the engineer would obtain the conditional density of segment 2 outcomes given those of segment 1 by regarding K_{i1} as a constant over its range of values.[35]. This is defined as

$$h_2(K_{i2} | K_{i1}) = \frac{g_1(K_{i1},K_{i2})}{f_1(K_{i1})}, \quad f_1(K_{i1}) > 0.$$

As was indicated in footnote 35 the engineer could, if the decision-maker requested, answer such questions as "what is the probability that performance in segment 2 will take on a value $\overline{K}_{i2}$ or more given that

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[34]In a general sense, independence can be assumed when the joint density can be factored into marginal densities each involving only one variable and with the limits of each not involving another of the variables.

[35]Or for that matter, over any part of its range. If the range of K_{i1} is restricted then the conditional density of K_{i2} will be restricted to being conditioned upon outcomes of K_{i1} in the restricted range only.

performance in segment 1 was also $\bar{K}_{i1}$ or more?" This would be structured as

$$h_2(K_{i2} \geq \bar{K}_{i2} \mid K_{i1} \geq \bar{K}_{i1}) = \frac{\int_{K_{i1}=\bar{K}_{i1}}^{\lambda_{i1}} \int_{K_{i2}=\bar{K}_{i2}}^{\lambda_{i2}} g_1(K_{i1}, K_{i2}) dK_{i1}, dK_{i2}}{\int_{K_{i1}=\bar{K}_{i1}}^{\lambda_{i1}} f_1(K_{i1}) dK_{i1}}, f_1(K_{i1}) > 0.$$

And if the sequential outcomes are independent, then

$$h_2(K_{i2} \geq \bar{K}_{i2} \mid K_{i1} \geq K_{i1}) = f_2(K_{i2} \geq \bar{K}_{i2}).$$

The preceding type of analysis would be possible from the multivariate density level down to the univariate level if the engineer were capable of providing a distribution of such complexity. In all fairness to the engineer, however, it is assumed for the remainder of this analysis that he cannot develop distributions more complex than bivariate densities.

Since the decision-maker wants to be able to compare alternative packages of segments so as to select that package promising the highest expected worth, he must consider several things. He has the engineer derive the marginal probability density for each segment from the bivariate density linking each segment and the preceding segment.[36] Then

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[36]The implicit assumption is that dependency is an appropriate consideration for adjacent segments only. This means, for instance, if segment 3 outcomes depend on those of segment 1 the dependency would be ignored by this analysis. A more general case would involve considering all segment combinations. In this instance, C_2^m relationships would result but as will be seen later, expected worth is a function of the marginal distribution alone. Consequently, the extension is only appropriate when considering particular probability questions.

he assigns a worth value w_{iJ} to each segment, where $0 \leq w_{iJ} \leq \theta_{ij}$. Lastly, he must consider the relationship of w_{iJ} to performance outcomes, K^{*}_{iJ}, of the respective segments.

The procedure involves taking the respective bivariate densities and integrating out the marginal probability density, $f_J(K_{iJ})$, for each segment. Then $f_J(K_{iJ})$ is transformed into $W_J(w_{iJ})$, and the expected worth for the entire package can be found by aggregating over the respective segments in the package. For the sake of illustration, let the following information be given for activity-design i.

$$g_1(K_{i1},K_{i2})$$

$$g_2(K_{i2},K_{i3})$$

When these bivariate densities are factored into their component probability densities

$$g_1(K_{i1},K_{i2}) = f_1(K_{i1})\ f_2(K_{i2})$$

$$g_2(K_{i2},K_{i3}) = f_2(K_{i2})\ h_3(K_{i3} \mid K_{i2}),$$

$$= f_3(K_{i3})\ h_2(K_{i2} \mid K_{i3}).$$

The transformation of K_{iJ} into w_{iJ} is linear in all cases and is

$$w_{i1} = b_{i1}K_{i1} + a_{i1} \quad , \quad 0 \leq w_{i1} \leq \theta_{i1} \ ,$$

$$w_{i2} = b_{i2}K_{i2} + a_{i2} \quad , \quad 0 \leq w_{i2} \leq \theta_{i2} \ ,$$

and

$$w_{i3} = b_{i3}K_{i3} + a_{i3} \quad , \quad 0 \leq w_{i3} \leq \theta_{i3} \ .$$

Solving for K_{iJ} in terms of w_{iJ}, we obtain

$$K_{i1} = \frac{w_{i1}-a_{i1}}{b_{i1}} \quad , \quad b_{i1} > 0,$$

$$K_{i2} = \frac{w_{i2}-a_{i2}}{b_{i2}} \quad , \quad b_{i2} > 0,$$

and

$$K_{i3} = \frac{w_{i3}-a_{i3}}{b_{i3}} \quad , \quad b_{i3} > 0.$$

The differentials of K_{iJ} are

$$dK_{i1} = \frac{dw_{i1}}{b_{i1}} ,$$

$$dK_{i2} = \frac{dw_{i2}}{b_{i2}} ,$$

$$dK_{i3} = \frac{dw_{i3}}{b_{i3}} .$$

Since the outcomes of segment 2 are assumed to be independent of segment 1 outcomes, the expected worth integration involves obtaining the marginal densities, transforming performance into worth, and generating the first moment. The marginal density of K_{i1} is $f_1(K_{i1})$, and it is a probability distribution. That is

$$\int_{K_{o_{i1}}}^{\lambda_{i1}} f_1(K_{i1})dK_i = 1, \qquad f_1(K_{i1}) \geq 0.$$

The marginal density of w_{i1} is $W_1(w_{i1})$, and it is a probability distribution.[37] That is

$$\int_{w_{i1}=b_{i1}K_{o_{i1}}+a_{i1}}^{w_{i1}=b_{i1}\lambda_{i1}+a_{i1}} W_1(w_{i1})dw_{i1} = 1, \qquad W_1(w_{i1}) \geq 0.$$

The expected worth, $\bar{w}_{i1}$, of segment 1 is

$$\bar{w}_{i1} = \int_{b_{i1}K_{o_{i1}}+a_{i1}}^{b_{i1}\lambda_{i1}+a_{i1}} w_{i1}W_1(w_{i1})dw_{i1} .$$

---

[37]The limits of integration for W_1, are not, in general, 0 and θ_{i1} since the scale of K_{i1} ranges from 0 to 1.0 with $K_{o_{i1}}$ and λ_{i1}, generally, within this interval.

The identical procedure for segment 2 will yield $\bar{w}_{i2}$, but segment 3,which is related to segment 2 in terms of performance outcomes,requires a consideration of the conditional relationship. The expected value of K_{i3} given a particular value of K_{i2} is an arithmetic mean. If, however, the expectation of K_{i3} over the entire range of K_{i2} is desired, then this is a function of K_{i2} and what is needed is the expectation of the distribution of expectations.

That is,

1) $E(Y|x)$ is in general a function of x. Let u(x) denote this function and h(x) be the probability density of x. Also X and Y denote the random variables and x and y values of the random variables.

2) $$E[E(Y|X)] = E[u(x)]$$
$$= \int_{-\infty}^{\infty} u(x)h(x)dx = \int_{-\infty}^{\infty} E(Y|x)h(x)dx$$
$$= \int_{-\infty}^{\infty}\left[\int_{-\infty}^{\infty} y\ g(y|x)dy\right]h(x)dx$$
$$= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} y\ g(y|x)h(x)dydx$$
$$= E(Y) = \bar{y}$$

The proof is taken from Mood and Graybill[38] and it shows that the conditional expectation of $Y|X$ is equal, in general, to the mathematical expectation of the marginal density of Y. Consequently, $\bar{w}_{i3}$ is equal to the expected value of $W_3(w_{i3})$. From this example it is seen that,

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[38]Alexander M. Mood and Franklin A. Graybill, Introduction to the Theory of Statistics, 2nd edit. (New York: McGraw Hill Book Company, Inc., 1963), p. 118.

in general, the expected worth of activity-design i is the sum of the expected worths for the segments in the activity-design. That is,

$$\sum_{J=1}^{m} E\left[W_J(w_{iJ})\right] = \sum_{J=1}^{m} \int_{w_{iJ}=b_{iJ}K_{o_{iJ}}+a_{iJ}}^{w_{iJ}=b_{iJ}\lambda_{iJ}+a_{iJ}} w_{iJ}W_J(w_{iJ})dw_{iJ} \quad ; \; W_J(w_{iJ}) \geq 0.$$

As in Case 1, the decision-maker compares alternative packages and selects the one with the preferred value of the decision variable.[39] In this instance it is the overall expected worth since he is unconstrained by resources and does not have alternative outlets for expenditures. Case 4 has introduced several features into the analysis. The certainty equivalence structure was abandoned due to the advantages of using probability distributions for multivariate situations. In addition, mathematical expectation played a critical role since the need to reflect the unequal potential contribution of segments was apparent. The decision variable, weighted performance, was obtained by means of transformation. While the transformation was treated as linear, the analysis is not restricted to linear transformations. The perspective needed to transform performance into worth, in a given situation, can only be supplied through an understanding of the real importance of performance outcomes to the desired outputs of the enterprise.

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[39] Implied in the summation of $\bar{w}_{ij}$ is an assumption that the scale of w_{iJ} is an interval scale. This means the scale is unique up to a positive linear transformation. That is, a new scale, Y, can be made by a linear transformation of the X scale ($y = a + bx$; $b>0$) and not distort the underlying relationships. See, for instance, Torgerson, Warren, Theory and Methods of Scaling, (New York: John Wiley & Sons,Inc., 1958), pp. 19-20.

Case 5

This case brings a cost restriction to the structure of Case 4. Here the decision-maker strives for a single objective by selecting one activity-design (i.e. package of segments) in an a priori framework.

Again, as in Case 2, the problem does not have cost-effectiveness overtones since there are no alternative ways to use unexpended resources. The only restriction the budget constraint places on the decision-maker is that the package he selects on the basis of the expected worth criterion may have a lesser mathematical expectation than that of Case 4. This argument is completely consistent with the Case 1 - 2 parallel.

Graphically, this is seen in Figure 6 which is structured identically to Figure 4. The difference between the two figures is that in Figure 6 the ordinate indexes expected worth, while Figure 4's ordinate indexes values of the certainty equivalent. The reasoning is perfectly analogous. The candidate points lie in the region where $C_i \leq C_{max}$ and $\sum_{J=1}^{m} \bar{w}_{ij} \geq \bar{\bar{w}}(K_o)$. Before continuing, it is appropriate to define $\bar{\bar{w}}(K_o)$. In Case 4 it was seen that each segment had a minimum performance level which was set by the decision-maker and the engineer. This value, $K_{o_{iJ}}$, was actually a concept carried forward from the certainty

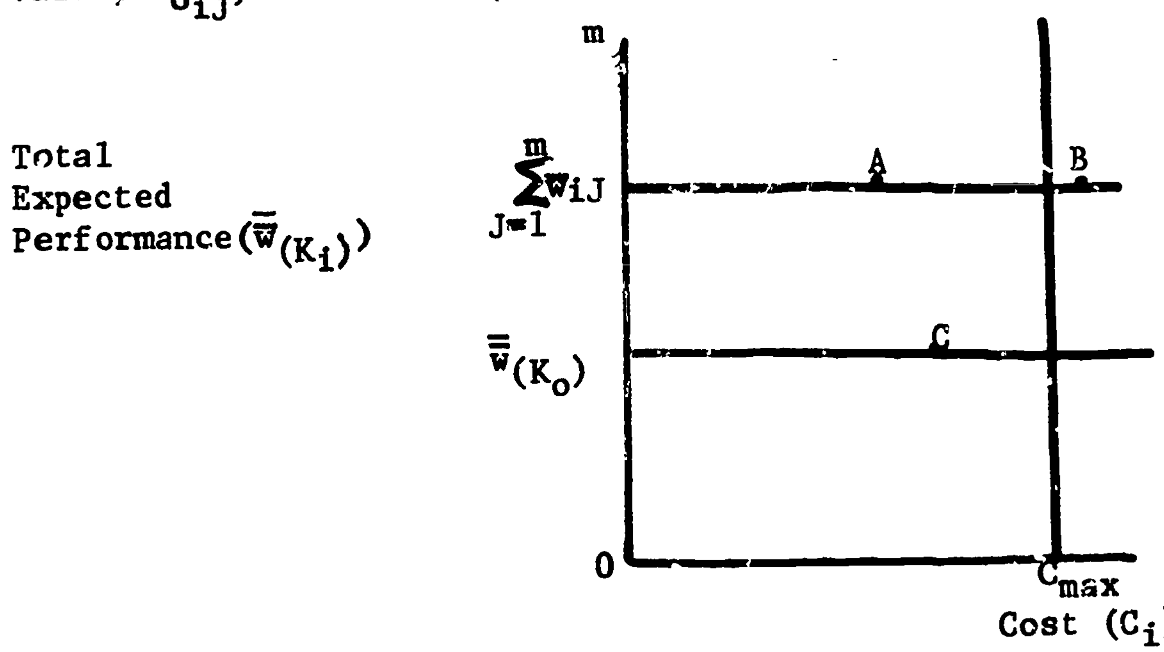

Figure 6. Selecting a Preferred Package with a Cost Constraint

equivalent analysis of earlier cases. At a higher order level there is still an overall K_0 which the decision-maker sets. It was assumed that $\frac{w_{oiJ} - a_{iJ}}{b_{iJ}}$ was the transformed value of K_{oiJ}. Therefore $\sum_{J=1}^{m} w_{oiJ}$ is assumed to be equivalent to the worth corresponding to the overall K_o. This implies that $\sum_{J=1}^{m} w_{oiJ}$ is a constant for all activity-designs, although the condition is not necessary for the analysis.

An additional complication arises in that the decision-maker considers the advisability of allocating the budget among the segments of the preferred activity design. (The stance taken here is that this consideration should be delegated to the manager of the implementation team. The feeling is that this is fundamental and in the best interests of all concerned, since it is the implementation manager who accepts the implementation responsibilities.) The problems associated with the human interfaces between the decision-maker, the engineer, and the implementation manager have been referred to earlier and are brought out again.

Case 6

Situations which are characterized by the structures of Cases 4 and 5 result in the selection and implementation of an activity-design. At the end of a period of time the decision-maker is faced with an evaluation problem --given that the activity-design has been put into operation, how well did it do? Case 6, therefore, is the a posteriori evaluation of Cases 4 and 5.

The rationale employed in this evaluation is similar to that of Case 3. The purposes of the evaluation are to discover improved ways of designing activities, estimating the potential performance of the design and implementing the package as it was designed.

The present case has two levels of evaluation. At the higher order or overall level the decision-maker wants to look at the overall performance and compare it to K_o. It is allowable to think in terms of performance or worth depending on the type of question being considered. If an overall comparison is required, it is probably more satisfying to transform the produced worth, based on the observed performance outcomes of the respective segments, into an overall performance variable, K* . Two points of this relationship are given from the analysis. They are

overall performance	produced worth
K_o	$\bar{\bar{w}}(K_o) = \sum_{J=1}^{m} w_{o_{iJ}} = \sum_{J=1}^{m} b_{iJ} K_{o_{iJ}} + a_{iJ}$
λ	$\bar{w}(\lambda) = \sum_{J=1}^{m} w_{\lambda_{iJ}} = \sum_{J=1}^{m} b_{iJ} \lambda_{iJ} + a_{iJ}$

The points connecting $\sum_{J=1}^{m} w^*_{iJ}$ and K* are required of the decision-maker in order for him to be able to make the overall evaluation. For the most part this evaluation is an overall comment on the manager of the implementation team. The engineer also is interested in the outcomes, since it was his design that was implemented. The interrelationship of responsibilities can cause problems for all parties involved. Therefore, the emphasis should be on improvement of methods rather than assignment of blame.

The second level of evaluation focuses on performance of the respective activity segments. Here the emphasis is directed more to the engineer's estimating methods, the decision-maker's worth assignments, and the members of the implementation team. These evaluations are similar to those of Case 3 and are not repeated here.[40]

Case 7

The structure of Case 7 introduces multiple objectives which will be referred to as overall system objectives. The decision-maker is faced with the *a priori* selection of activity-designs with unconstrained resources.

For the first time, there are alternative competing objectives but since there is no restriction on level of resources, the decision-maker will select a system of activity-designs which, when implemented, should contribute as much as possible to the overall system objectives. As was implied in Cases 1 and 4, the limitations on ultimate system performance are a function of the engineer's imagination, the state of the technological arts and the abilities of the implementation team.

Let O_A, O_B, ..., O_{ℓ} ..., O_R denote the overall system objectives. Since the activities selected will ultimately be evaluated in the basis of how well they contribute to these objectives, it is important to

---

[40] Each segment has its own probability density. Since only one outcome is observed, the distribution of outcomes for segment J is $f_J(K_{iJ})$. This, however, is from an *a priori* point of view. The fact that some "impossible" outcomes can occur, i.e. $K^*_{iJ} > \lambda_{iJ}$ or $K^*_{iJ} < K_{o_{iJ}}$, is a clear indication that the notion of a posterior distribution of K^*_{iJ} is appropriate. Bayesian extensions to the analysis of the nine cases are not developed, but further work within this type of framework could include such analysis.

value them[41]. The values afford the decision-maker the opportunity to consider trade-offs for the overall system objectives. The common frame of reference or dimension is, of course, value. The assumptions underlying this assignment of values are identical to those for assignment of worth in Case 4. This value function supplants the worth function which was used to weight outcomes so that a common frame of reference could be developed. The value function, developed in Case 7, provides a uniform basis for assessing outputs prior to, as well as subsequent to, the operation of these activities. These values are denoted $V(O_A)$, $V(O_B), \ldots, V(O_i), \ldots, V(O_R)$.

Each activity or activity segment has a potential for contributing to one or more of the overall system objectives. This indicates that the value of overall objective O_i is the maximum that can be produced by the system with respect to the end. If all overall objectives were produced perfectly, then the system would have produced the maximum value possible, i.e., $\sum_{i=A}^{R} V(O_i)$.

The extent to which a particular activity contributes to a particular overall system objective is a function of two variables -- potential for contribution and actual performance. That is, $E_{mi} = e_{mi}\left[K^*_{mi}, V(a_{mi})\right]$,

[41]Russell Ackoff,et.al., show that for systems with two mutually exclusive, totally exhaustive objectives,the maximization of expected value is accomplished by maximizing performance. (Actually they label performance as efficiency and define expected value as $\sum_J E_{iJ} V_J$, where E_{iJ} is performance on objective J by method i and V_J is the value of objective J).An extensive proof is given for the case with three or more objectives. This maximization requires performance and values.

Russell L. Ackoff, Shiv K. Gupta, and J. Sayer Minas,Scientific Method, (New York: John Wiley & Sons, Inc., 1962),pp. 93-97.

where E_{mi} = the effectiveness of the mth activity toward the ith overall system objective,

$V(a_{mi})$ = the maximum value that the mth activity could produce with respect to the ith overall system objective,

and $\hat{K}^*_{mi}$ = the adjusted performance score.

The maximum value, $V(a_{mi})$, that the mth activity could produce with respect to the i^{th} overall system objective is a function of how important that activity is relative to the other activities aiming at O_i. Here the decision-maker makes a relative value assignment such that the sum of the relatives is equal to $V(O_i)$. Were there only one overall objective, there would be no need for $V(a_{mi})$ and Case 7 would reduce to Case 4. The distribution of overall value to the activities is represented as follows.

Activity aimed at O_i	Relative importance	Maximum value possible
a_{1i}	$\ell(a_{1i})$	$\ell(a_{1i})V(O_i) = V(a_{1i})$
a_{2i}	$\ell(a_{2i})$	$\ell(a_{2i})V(O_i) = V(a_{2i})$
.	.	. .
.	.	. .
.	.	. .
	$\sum^{m} \ell(a_{mi}) \leq 1.0$	$\sum \ell(a_{mi})V(O_i) \leq V(O_i)$

Based on this distribution of potential value, $V(O_i)$, to the activities, it is possible to determine effectiveness at the activity level. In order to do this several performance concepts need definition.

The decision-maker and the engineer establish a criterion that can be used to assess the activity's performance. Then they list the possible outcomes and relate these possibilities to index scores for the criterion. For instance, let us suppose that the activity was aimed at "getting eligible people to pass Examination Five". One criterion might be the number of eligible people passing the examination expressed

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as a percentage of the total number of eligible people. The index could be formed by the percentage points. In this context, K^*_{mi} is the index score (percentage) reflecting the performance of activity m toward overall system objective i. The decision-maker, however, may not feel that each percentage point is entitled to one percent of the potential value of a_{mi}. In this case K^*_{mi} is transformed into $\hat{K}^*_{mi}$. The relationship between K^*_{mi}, $\hat{K}^*_{mi}$, and $V(a_{mi})$ is depicted in Figure 7. When $\hat{K}^*_{mi}$ is brought together with $V(a_{mi})$ the result is E^*_{mi} or effectiveness. Effectiveness is defined as weighted performance. That is, $E^*_{mi} = \hat{K}^*_{mi} \cdot V(a_{mi})$).

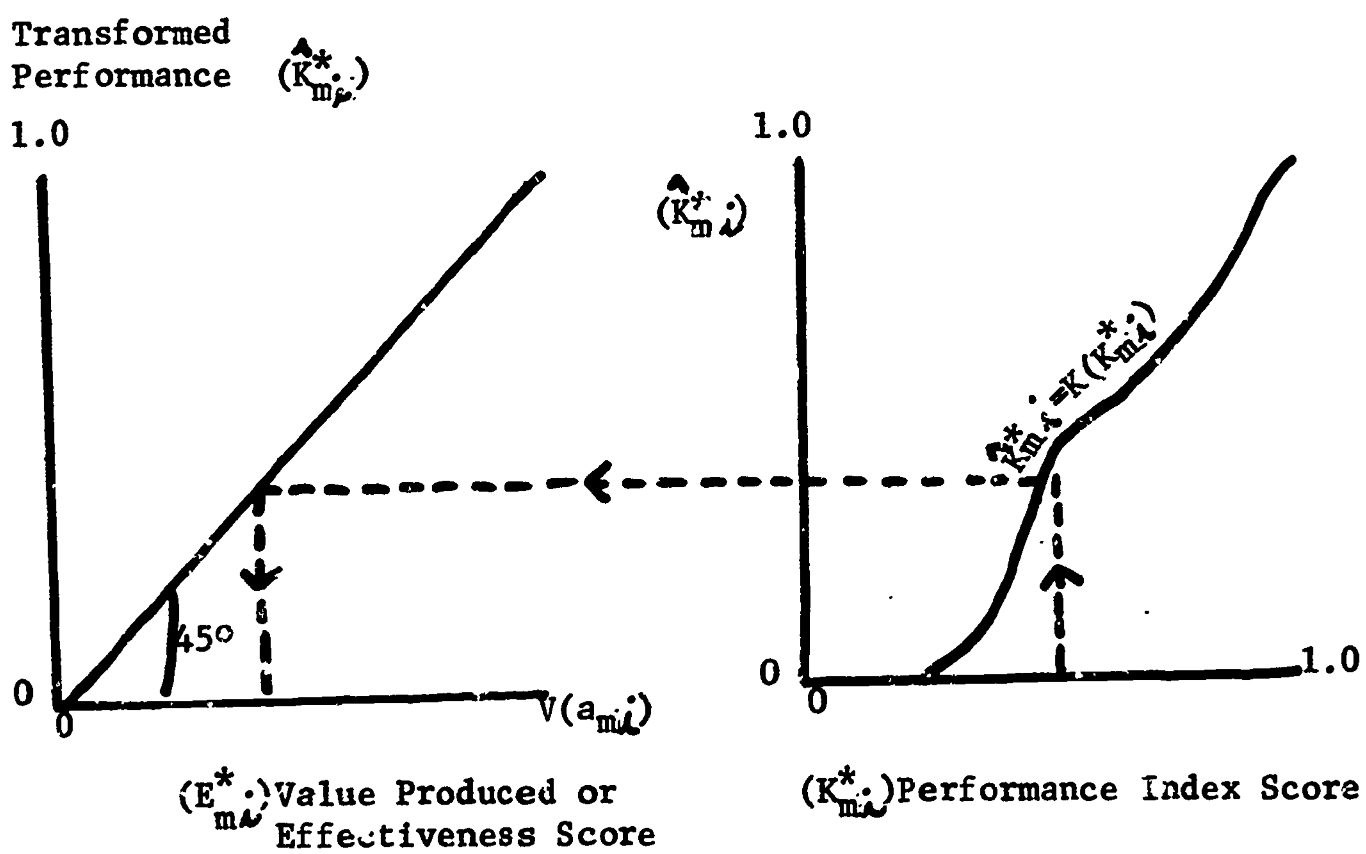

Figure 7. Transformation of Performance Index Scores into Effectiveness Scores

The right hand section of Figure 7 shows the relationship between the criterion index scores, K^*_{mi}, and the decision-maker's adjustments, $\hat{K}^*_{mi}$. The special case is where $\hat{K}^*_{mi} = K^*_{mi}$ over the complete range from 0 to 1.0. In general $\hat{K}^*_{mi} = k(K^*_{mi})$, where the function k denotes the perceptions that underlie the transformation.

The left hand section of Figure 7 shows the way $\hat{K}^*_{mi}$ is used to generate value produced or effectiveness. The reflection line joins the points $\{E^*_{mi} = 0 \ , \ \hat{K}^*_{mi} = 0\}$ and $\{E^*_{mi} = V(a_{mi}), \hat{K}^*_{mi} = 1\}$, and specifies that the change in effectiveness with respect to a unit change in performance is constant. The relationship is

$$E^*_{mi} = \hat{K}^*_{mi} \ V(a_{mi}) \quad ,$$

and the change in effectiveness for a small change in performance is

$$\frac{dE^*_{mi}}{d\hat{K}^*_{mi}} = V(a_{mi}) \ .$$

The differential of effectiveness, dE^*_{mi}, is equal to $d\hat{K}^*_{mi} \ V(a_{mi})$. The reflection line did not necessarily have to be drawn at 45° to the X-axis. If it had made a 30° angle with the X-axis then

$$\frac{dE^*_{mi}}{d\hat{K}^*_{mi}} = V(a_{mi})/0.5774 \ ,$$ since the tangent of 30° is 0.5774

and the equation describing the relationship between the variables would have been

$$E_{mi} = \hat{K}^*_{mi} \, 0.5774 \quad V(a_{mi}) \ .$$

The 45° reflection line adequately describes the way the variables relate to each other in this analysis.

Now that effectiveness has been defined as weighted performance, two simple ideas should be considered.

1. Are large effectiveness scores always preferred?

2. What is the maximum effectiveness score?

In order to conclude that the decision-maker prefers any larger E score to any smaller E score, several comments are necessary. First, the relative values assigned to the overall system objectives represent a set of targets for the decision-maker. If a unit of value is equally preferred, no matter what objective is being produced, the decision-maker clearly prefers a larger E to a smaller E in any case. If a unit of value on one objective is preferred to a unit of value on another objective then the assignment of values requires revision. It is, of course, possible to constrain the production of an overall objective in such a way that some production is preferred over other production. For example, the decision-maker could specify that overall objective O_i must be produced at some minimum level or better, i.e. $\sum_m \hat{K}^*_{mi} V(a_{mi}) \geq 0.62 \left[V(O_i)\right]$. This type of production constraint could have efficiency implications for the system. It would have the same effect on the system operations as a policy since a policy can inhibit functioning with respect to given criteria in selected instances.

The search for an optimal solution for this type of problem depends on such factors as the nature of the production function, the costs of production, performance, and values.

The maximum E score is the sum of the valuations assigned to the overall system objectives, i.e., $\sum_{i=A}^{R} V(O_i)$. This is readily seen by inspecting the E function:

$E^*_{mi} = \hat{K}^*_{mi} V(a_{mi})$, and observing that when $\hat{K}^*_{mi}$ is equal to 1.0 (the maximum value since $0 \leq \hat{K}^*_{mi} \leq 1.0$), $E^*_{mi} = V(a_{mi})$. Therefore, under conditions of perfect performance ($\hat{K}^*_{mi} = 1.0$), $\sum_m V(a_{mi}) = V(O_i)$, and over all objectives the maximum E is $\sum_{i=A}^{R} V(O_i)$.

In this situation, as in Case 4, it is within the scope of the argument to treat performance as a random variable. This procedure is now outlined.

The engineer provides the probability density of $K_{m\ell}$ as in earlier instances. In an a priori sense the distribution of $f_{m\ell}(K^*_{m\ell})$ is identical to $f_{m\ell}(K_{m\ell})$. Two transformations are required. The first allows $\hat{K}^*_{m\ell}$ scores to substitute for $K^*_{m\ell}$ scores. Since a simple multiplicative form has been used to relate E to its components, the second transformation is constant for all such relationships and the probability density of $E^*_{m\ell}$ can be inferred from $f_{m\ell}(\hat{K}^*_{m\ell})$. That is,

$$E^*_{m\ell} = \phi_{m\ell}(\hat{K}^*_{m\ell}, V(a_{m\ell}))$$

$$E^*_{m\ell} = \hat{K}^*_{m\ell} V(a_{m\ell}) .$$

Since $V(a_{m\ell})$ is a constant for all $\hat{K}^*_{m\ell}$, the expected value, $\bar{E}^*_{m\ell}$, is given by

$$\bar{E}^*_{m\ell} = \bar{V} = \int_{\hat{K}^*_{m\ell}(V(a_{m\ell}))=0}^{\hat{K}^*_{m\ell}(V(a_{m\ell}))=1} \hat{K}^*_{m\ell} V(a_{m\ell}) \; f_{m\ell}(\hat{K}^*_{m\ell}(V(a_{m\ell}))) \, d\hat{K}^*_{m\ell}(V(a_{m\ell}))$$

$$\bar{E}^*_{m\ell} = \bar{V} = V(a_{m\ell}) \int_{\hat{K}^*_{m\ell}=0}^{\hat{K}^*_{m\ell}=1} \hat{K}^*_{m\ell} f(\hat{K}^*_{m\ell}) \, d\hat{K}^*_{m\ell} .$$

A final set of relationships can be commented on prior to considering Case 8. It was seen that effectiveness is a function of performance and potential value. Performance, however, is in turn a function of cost and non-cost factors. In fact, the very foundation of cost-effectiveness is tied up in these relationships and it remains for Case 8 to put things in order.

Case 8

This situation represents an extension of Case 7 under a budgeting constraint. Here the decision-maker pursues a set of overall system objectives by means of selecting a group of activity-designs in an a priori framework. This is the first and only cost-effectiveness case.[42]

To arrive at the conclusion that Case 8 represents the only cost-effectiveness case, the previous analyses should have provided clues as to the necessary and sufficient conditions for cost-effectiveness analysis. Case 1 was not a cost-effectiveness situation because costs were not involved. In Case 2 it was observed that even costs were not sufficient since the decision-maker was interested in a single objective and he had no other alternative outlets for funds that could be saved due to economic considerations. Consequently, it is not until Case 8 that the analysis finds budgetary restrictions and multiple outlets competing for this budget. The necessary and sufficient conditions for cost-effectiveness analysis to be appropriate for a decision structure are:

1. More than one alternative outlet for the available resources.
2. Less available resources than the alternative outlets can use ideally. A budget constraint is not sufficient unless it forces

[42]This point was made earlier, but it warrants repetition at this time. Cost-effectiveness is considered by the author to be the general way to approach this problem. This is due to the general incommensurability and intangibility of benefits. In addition, if program evaluation for the purpose of improving allocations in the next period is desired (this comment anticipates the purpose of Case 9) then the relationship of value produced now to costs now is generally of primary importance. This does not preclude the possibility of specific exceptions necessitating some form of benefit-cost analysis.

the curtailment of at least one activity.[43] If an organization has enough resources to do everything it wants to do in the near future, then cost-effectiveness analysis in the present is not needed to support allocation decisions for the near future.

Case 8 borrows the structure and analysis of Case 7. To this it brings the implications of cost. The critical relationship in the analysis is between performance, cost, and non-cost factors. That is,

$$K^*_{mi} = k(C_{mi}, G_{mi})$$

where:

K^*_{mi} = The performance index score

C_{mi} = The estimated cost for activity m as a producer of O (this estimate is not treated as a random variable).

G_{mi} = The non-cost factors associated with the performance of activity m as a producer of O_i. While these could be viewed as a function of C_{mi}, they are assumed to be given and adequate in the analysis. They include the human factors, such as disposition toward the tasks, level of managerial knowhow, level of skills, and the technological factors.

Assume there are overall system objectives valued as $V(O_A)$, $V(O_B)$,..., $V(O_R)$. To interject some realism into the analysis assume that the production of O_A is specified by the decision-maker to be at least θ_A. The decision-maker has his engineers develop cost-effectiveness curves for each proposed activity. Figure 8 shows a hypothetical curve prepared by the engineer. This function indicates more than C_1 dollars must be

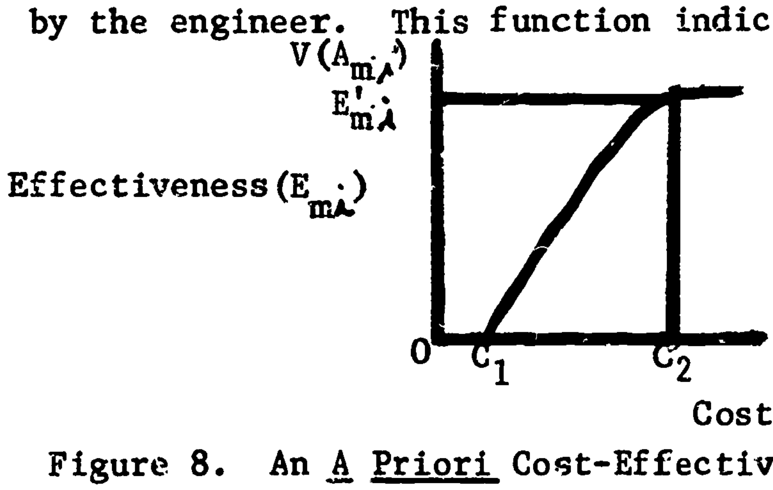

Figure 8. An A Priori Cost-Effectiveness Curve.

[43]For instance, a budget constraint of $1,000,000 would probably not restrict the vacation plans of a married couple.

spent before anything is produced. When C_2 dollars are spent the marginal productivity response becomes almost zero at the level of E'_{mi}. This implies that the G_{mi} factors are restricting further productivity. Implicit in the construction is a series of relationships. They are the relationships between

1. C_{mi}, K^*_{mi} (Given G_{mi}),
2. K^*_{mi}, $\hat{K}^*_{mi}$,

and 3. $\hat{K}^*_{mi}$, E^*_{mi}.

If the system had been in operation for a period, then evaluation could be conducted for the purpose of obtaining cost-effectiveness points. These points would reflect the productivity of the system <u>as it is</u>. Allocations for the next period could be based on these considerations.

The problem involves non-linear programming with the elements of the situation falling into three classes: 1) the functions relating effectiveness to cost, e.g., $E_{mi} = f_{mi}(C_{mi})$, 2) the specifications (constraints) telling how much of which objectives should be produced, e.g. $E_A \geq \theta_A$, and 3) the budget constraint, i.e., $\sum_m C^*_{mi} \leq B$. The programming problem would involve a numerical analysis of the functions. This could be done by taking the derivative of effectiveness with respect to cost at, for example, \$100 intervals for each proposed activity. This would generate a list of slopes which can be combined for all activities. Then the production inequalities (those specifying production must be at least θ_A) can be satisfied. Once this is done the remainder of the problem is a search for the maximum production for the unencumbered funds. This is not as simple as the procedure just described because the decision-maker cannot purchase the increment of effectiveness related to the expenditure of $100, in the interval $2,400 to $2,500, unless he has also agreed to purchase the first $2,400 of the activity's production.

Case 9

The final case considers the evaluation of Cases 7 and 8. It is the general problem faced by the decision-maker who has an ongoing system of activities and wants to evaluate current operations so as to prescribe subsequent action.

The evaluation of Case 7 (no constraint on resources) is similar to Cases 5 and 3 and is not repeated here. The one difference is that the system of Case 7 has multiple objectives and therefore one would encounte more of the same comparisons.

The evaluation of Case 8 leads to the central purpose of this dissertation which is to develop a generalized program evaluation model for ongoing educational systems. While the system being developed is capable of many types of evaluation, the principal thrust is to evaluate those aspects of the system necessary to improve the allocation of the next period budget.

The structure of the analysis leans heavily on the concepts and constructs of Cases 7 and 8. The overall system objectives and values provide the production target. What information is required in order to determine how well the system produced? In an overall sense it is the sum of the production (effectiveness) scores for the various activities. This total relative to the maximum score possible rates the system in terms of relative effectiveness. That is,

$$\text{REL }(E^*) = \frac{\sum_{i=A}^{R} \sum_{m} \hat{K}^*_{mi} V(a_{mi})}{\sum_{i=A}^{R} \sum_{m} V(a_{mi})}, \quad \hat{K}^*_{mi} = 1 \text{ in the denominator,}$$

$$= \frac{\sum_{i=A}^{R} \sum_{m} \hat{K}^*_{mi} V(a_{mi})}{\sum_{i=A}^{R} V(0_i)}.$$

The relative productivity of the system toward overall system objective $\mathring{A}$ is

$$\text{REL }(E^*_i) = \frac{\sum_{m} \hat{K}^*_{mi} V(a_{mi})}{V(0_i)}, \quad V(0_i) > 0.$$

These overall evaluations do not provide the basic information necessary to evaluate for the purpose of making future-period decisions. Presumably, decisions made in the present for the next period should incorporate the same kind of analvsis as was used in Case 8; that is, a systematic search over the alternative possibilities so as to arrive at a combination of activity levels which will lead to a better productivity.

This calls for an assessment of the cost-effectiveness relationship for each ongoing activity. The assumption is that activities will be carried forward although this is not a necessary assumption for the analysis. The reason for this assumption is to avoid the consideration of alternative activities in the present context. A cost-effectiveness curve is developed for each activity by borrowing the curve used to plan the activity in Case 7 and then presenting the relationship to the implementation staff.

Figure 9 shows a cost-effectiveness curve for activity a_{mi}. It represents a curve that has been revised from the a priori relationship presupposed by the analysis of Case 8. Several aspects of the relationship warrant attention. With regard to costs C^*_{mi} is the amount of

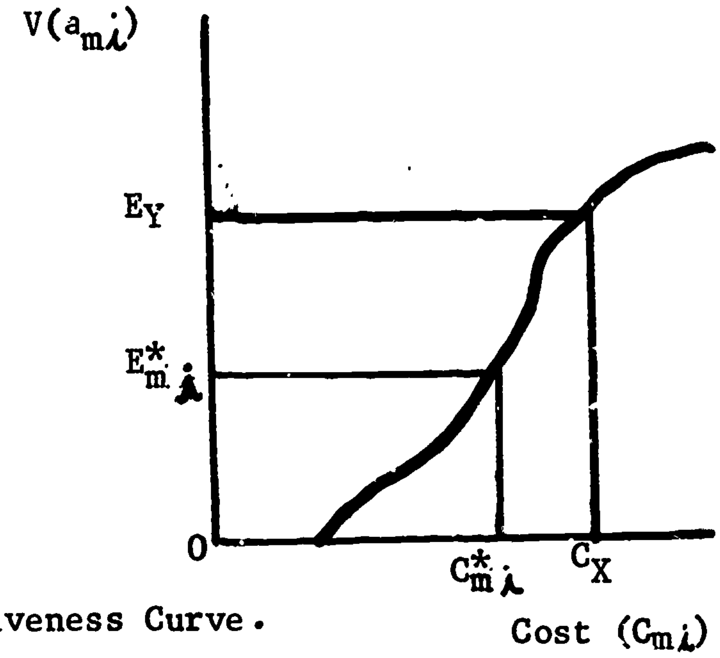

Figure 9. Revised Cost-Effectiveness Curve.

resources actually expended and C_{mi} the level allocated to the activity to pursue overall objective M.[44] If the activity were a developmental activity, then the expenditure of $C_X - C^*_{mi}$ additional dollars would allow productivity to rise to E_Y (assuming the adequacy of the revised $E_{mi} = f_{mi}(C_{mi})$. If the activity were, on the other hand, concerned with the maintainance of an ongoing activity, then it would require C_X dollars to produce at a level of E_Y. Since the purpose of this analysis is to evaluate ongoing educational systems, the developmental activity

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[44]Practically, $(C_{mi}-C^*_{mi})$ will probably be close to zero since administrators are reluctant to return unexpended resources for obvious reasons. The firm that can find ways to make administrators comfortable with returning resources that cannot be spent wisely will benefit substantially. This problem is probably more acute in public sector organizations.

problem is disregarded. This does not imply that schools do not engage in project type activities. Obviously, the methods developed here can be extended to the whole class of ad hoc activities, but the emphasis should relate to ongoing activities and programs.

An inspection of the cost-effectiveness curve such as the one in Figure 9 yields a point $\{C_m^*, E_m^*\}$ representing the level of productivity during the current year. It is intuitively obvious that the implementation staff has a reasonably good idea of how production would be increased if there were small changes in cost from the level of the current year's expenditures. They are less certain of the response for large changes from the present expenditure level. The engineer on the other hand has studied the production function and consequently is more aware of the process that relates the inputs and outputs than the implementation staff. Consequently, it would appear to be a good idea to have the engineer available for consultation (if not direct involvement) in the process of assessing what happens if costs are varied in light of the present period experience. The difficulty is that the responsibility for subsequent implementation and maintenance of the activity is remote from the responsibilities of the engineer. This means that those responsible for these evaluations will probably not involve the engineer.

At any rate, the implementation staff should prepare a schedule that lists expenditure levels above and below C_{m4}^* as well as the estimated responses in production associated with the changes from C_{m4}^*. These are analogous to the $\frac{dE_{m4}}{dC_{m4}}$ values generated in Case 8.

The same type of search process is instituted as in Case 8. There is, however, the problem of what will be referred to as human factors, H. If resources are to be taken away from one activity and given to another based on cost-effectiveness considerations, then the decision-maker is painfully aware of such human elements as loss of morale. While no attempt is made to study or measure H, it does figure into the decision process. In general, if

$$\frac{\left(+\Delta K_{mi(t+1)}\right)\left(V(a_{mi})_{(t+1)}\right)}{\Delta C_{nM(t+1)}} > \frac{\left(-\Delta K_{ni(t+1)}\right)\left(V(a_{ni})_{(t+1)}\right)}{\Delta C_{ni(t+1)} - H_{ni}}$$

then resources will be diverted from activity a_{ni} to activity a_{mi}. In this inequality the symbols are defined as

$\Delta K_{mi(t+1)}$ = the change in performance in year t+1 associated with the cost increment if it would be added to a_{mi}.

$V(a_{mi})_{(t+1)}$ = the decision-maker's assignment of potential value to activity a_{mi} as it would contribute to overall objective i.

$\Delta C_{ni(t+1)}$ = the increment of resources that is being considered for transfer from a_{ni} to a_{mi}.

H_{ni} = a dollar unit assessment of the human factors associated with the loss of $\Delta C_{ni(t+1)}$ dollars by the administrator of activity a_{ni} and the gain of these dollars by the administrator of activity a_{mi}.

B. Summary

In summary, Case 9 has drawn from the other cases in order to provide a general program evaluation model for ongoing school systems. Case 1 provided a starting point in terms of certainty equivalence and generated a criterion for selecting an activity aimed at one objective with no constraining factors. Case 2 instituted a cost-constraint and showed that the only result was the possible elimination of the preferred activity of Case 1 because it costs too much. Case 3 indicated that evaluation of Cases 1 and 2 was not essentially a statistical problem. It also stressed the purpose of evaluation as improvement of subsequent operations. Case 4 considered multiple activities aimed at the one overall objective. The need for a weighting of outcomes according to their worth to the decision-maker was indicated. The resulting criterion was a weighted performance called expected worth. Case 5 brought in costs and the results were similar to those of Case 2. The implication of a cost constraint was that some packages could be eliminated from consideration, but if the decision-maker had only a single objective there was not a problem of cost versus effectiveness.

The evaluation of Cases 4 and 5 in Case 6 was similar to Case 3. Again the emphasis was placed on evaluation for future improvement in operations. Case 7 introduced a set of overall system objectives and considered how to select a set of activities to produce the objectives. Productivity was defined as a function of performance and potential value. Case 8 provided a cost-effectiveness framework to decide among the proposed activities designed to produce the overall system objectives. It was seen that a decision-maker only has a cost-effectiveness problem when he pursues at least two objectives and has a level of resources that restricts at least some of the activities that could be conducted. Case 9 ties the cost-productivity relationships of the current year to the budgetary needs of the next year. The central feature of Case 9 is the cost-effectiveness function. It was indicated in Chapter I that educators seem to know very little about the processes that take the inputs of education and link them to educational productivity.

III. APPLYING THE MODEL TO A SCHOOL SUB-SYSTEM

This chapter uses the evaluative structure of Case 9 and applies it to the programs of a sub-system of an ongoing school system. There are two main reasons for applying this model to a school system sub-system. Since it is unrealistic to assume that existing school information systems are capable of providing relevant data to support managerial decisions with regard to the allocation of resources, the first priority is an assessment of the practicality of obtaining the data required by the model from school systems.[45] The second priority is also pragmatic and is a determination of the extent to which the type of analysis suggested by the model is useful to the school decision-maker.

Basically this chapter presents background information about the pilot school system and then considers the sequence of steps adopted to apply the model and provide data. The next chapter uses these data to generate and discuss model outputs.

A. Selection of the Pilot School Sub-System

The Radnor Township School District is located approximately

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[45]It should be pointed out that numerous efforts are under way to design management information systems for schools. Most of these plans start with a premise that since school decision-makers do not know what they want, the planners will design a flexible system that can relate "all possible data" in "all possible ways." One project, previously referred to started with a set of questions, structured from the school administrator's point of view, and proceeded to develop a PPBS for intermediate units and school districts in Pennsylvania. This, however, seems to be an exception to the prevailing "flexible design in the face of ignorance" approach.

twenty-five miles from the center of Philadelphia and is clearly suburban by virtually any socio-economic criterion. The school system operates a senior high, a junior high and four elementary schools. The pupil population is in excess of 4,200, with approximately 950 students in the senior high (grades 10-12). The 1967-68 proposed budget for the school district was slightly more than $3.8 million.

The major reason for selecting this school system for study was that it had a strong reputation for being progressive, especially with regard to self evaluation and improvement. The system is small and consequently the prospects of keeping data collection problems under control appeared to be good. Once an initial contact was made with Radnor administrators, a series of alternatives for possible study were considered. The health and physical education administrators seemed interested in the study and were very cooperative. In addition, health and physical education programs seemed to eliminate the problems associated with studying learning outcomes. While these problems should be treated in an overall school program evaluation effort, learning outcomes present a host of difficulties. In this limited study it was thought best to circumvent these problems. An additional advantage was that the student population, program staff, and records were housed in the same building. Finally, it was decided to restrict the effort to the health and physical education programs in the Senior High School for school year 1967-68.

The author identified three persons as being critical to an analysis of the operation of the sub-system: the Assistant Superintendent for Curriculum, who is ultimately responsible for planning and decision making in the area of health and physical education, the Physical Education Coordinator for the school system, who is also the

Chairman of the Physical Education Department in the Senior High School, and the Nursing Coordinator for the school system, who is also the School Nurse in the Senior High School. Both coordinators report to the Assistant Superintendent for their system-wide responsibilities, but at the same time are responsible to the Senior High School Principal for the high school programs. The coordinators participate in system-wide scheduling and budgeting processes while the Principal makes Senior High School budget decisions. Obviously, a great deal of cooperation and communication is required.

B. Application of the Model

The purpose of this section is to describe how the model was applied to a sub-system of a school system in order to evaluate the contribution of programs to the productivity of the system. It is important to maintain the focus of the analysis on evaluation as a means for improvement of ongoing systems as opposed to an optimization methodology.

A distinct preference for system-wide evaluation as an approach to improving schools is advanced by Burkhead. He contents himself with "analyzing relative costs and gains, not for an optimum allocation pattern" in his input-output study. This compromise is founded on the many technical difficulties and complex socio-economic interrelationships which inhibit attempts to control important variables.[46]

A similar point of view in terms of improving resource allocation in education is expounded in a study by Abt Associates. They indicate that the goal is optimal decisions "but optimization is much more difficult than evaluation, since it involves the generation of programs

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[46] Burkhead, Fox and Holland, op. cit., pp. 10-13.

whereas evaluation does not. Optimization is a sensitive complex problem, but if only evaluation can be carried out, this alone will be useful."[47]

The remaining portions of this chapter describe the implementation of the model as an evaluative structure. The resulting structure provides the linkage between Case 9 and the health and physical education activities of Radnor. A plan describing the sequence of activities required to implement the model is presented in Exhibit 3. Included with the implementation functions are several application steps as well as a set of steps describing the relationship between Case 9 and Case 8 for the next period. It is important for the analyst to familiarize himself with the activities and style of operation prior to undertaking the implementation of the model. The implementation steps are:

1. Define overall objectives.
2. Assign values to overall objectives.
3. Reconcile activities to overall objectives.
4. Distribute value to activities.
5. Define performance criterion for each activity.
6. Define cost criterion for each activity.

These steps permit the basic structure to exist but are incapable of generating evaluative outputs. In order to apply the model, two application steps are necessary to feed the relevant data through the structure:

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[47]Abt Associates, op. cit., p. 1.

1. Observe performance outcomes for each activity.

2. Observe cost for each activity.

The next section describes the familiarization efforts previously mentioned.

1. A prior step

A prior condition for evaluation is that activities are being conducted. Usually these activities are conducted under the headings of programs, the definition of a program being arbitrary. A program is defined, for purposes of this study, as a set of activities which are related. Often the logic of the relationship is administrative; that is, the activities are administered by one person and are grouped under a program label solely on this basis.

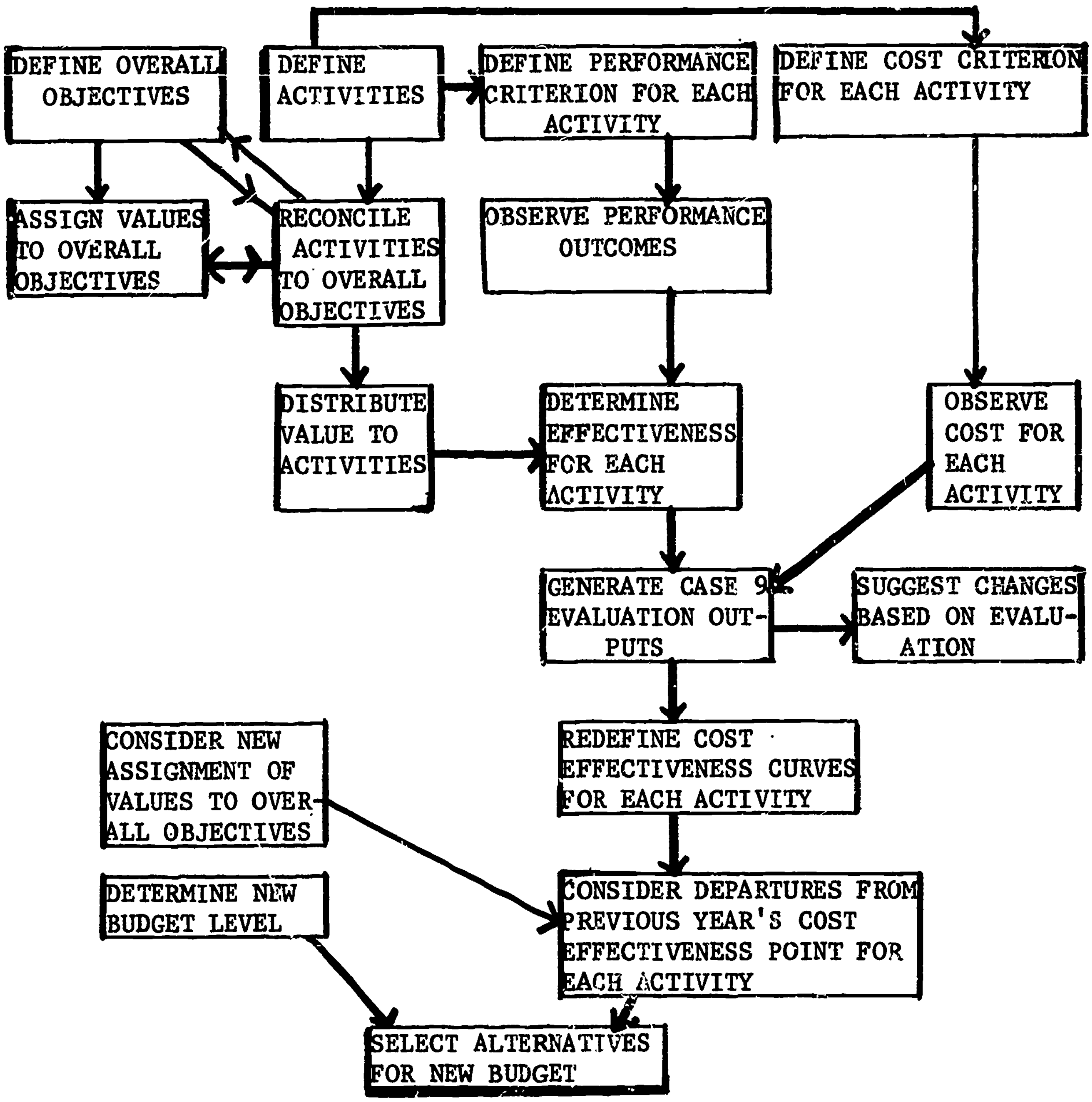
The activities at Radnor in the "health and physical education" domain were grouped under the descriptors that follow.[48] This structure was jointly agreed upon by the Assistant Superintendent for Curriculum and the author during an interview on February 23, 1968.

Health Services Programs	Physical Education Programs
1. Annual Screening	6. Physical Education
2. Physical Examination	7. Adapted Physical Education
3. Communicable and Infectious Disease	8. Health Education
4. Emergency	
5. Follow-up	

[48] Appendix B describes the eight programs as they operated in school-year 1967-68. The grouping of some activities in this structure is arbitrary and in some cases misleading. As the study progressed activities were shifted so as to provide a better description of school reality.

EXHIBIT 3

AN OUTLINE OF THE CASE 9 EVALUATION MODEL AND ITS RELATIONSHIP TO THE CASE 8 ALLOCATION MODEL



Once the author was able to derive an understanding of the nature of the programs, the first formal task-- defining overall health and physical education objectives-- was considered.

2. Overall system objectives

Just as firms produce to meet consumer needs (and thereby enjoy profits), school systems produce to meet pupil needs. A utility function could be postulated to express each pupil's need for various amounts of the types of services that the school produces, given the amount of each service he already possesses. The individual will have his utility maximized when the ratios of the marginal utilities for the respective goods are proportional to the amounts of the constraining element used. Ordinarily the prices of the commodities are related to the marginal utilities to determine if the consumer's position can be improved. In this instance, prices are not relevant. Since time would be a major factor limiting an individual's consumption of various amounts and combinations of educational commodities, it would function as a constraint.

A relationship for each pupil could result from viewing the pupil as a consumer of economic goods. The function U_1 describes individual 1's utility for the various educational services. There is a total of T time available. Individual 1 requires t_{a_1} of time to consume a unit of educational service X_a. The expression $\frac{\partial u_1}{\partial X_{a_1}}$ is the individual's marginal utility for a unit of X_a.

The function Z_1 is to be maximized subject to the constraint expression.

$$Z_1 = U_1(X_a, X_b, \ldots, X_n) + \lambda F\left[T_1 - (t_a X_a + t_b X_b + \ldots + t_n X_n)\right]$$

$$\frac{\partial Z}{\partial X_{a_1}} = \frac{\partial u_1}{\partial X_{a_1}} - \lambda \frac{\partial (F_1)}{\partial X_{a_1}} = \frac{\partial u_1}{\partial X_{a_1}} - \lambda t_{a_1} = 0$$

$$\frac{\partial Z}{\partial X_{b_1}} = \frac{\partial u_1}{\partial X_{b_1}} - \lambda \frac{\partial (F_1)}{\partial X_{b_1}} = \frac{\partial u_1}{\partial X_{b_1}} - \lambda t_{b_1} = 0$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$\frac{\partial Z}{\partial X_{n_1}} = \frac{\partial u_1}{\partial X_{n_1}} - \lambda \frac{\partial (F_1)}{\partial X_{n_1}} = \frac{\partial u_1}{\partial X_{n_1}} - \lambda t_{n_1} = 0$$

$$\lambda = \frac{\partial u_1}{\partial X_{a_1}} \Big/ t_{a_1} = \frac{\partial u_1}{\partial X_{b_1}} \Big/ t_{b_1} = \ldots = \frac{\partial u_1}{\partial X_{n_1}} \Big/ t_{n_1}$$

The conclusion is that the consumer (student) will maximize his utility when the marginal utility of the respective educational services is proportional to the incremental time across all services. From these relationships it follows that in order to have the school administration provide optimally for a pupil, it is necessary for him to know:

1. How much of each educational service the pupil "needs". This could be determined by estimating how much of the educational service he "has" and how much he "should have". The utilities could be assigned by a knowledgeable school counselor.
2. Once needs are assessed it is necessary to describe the function which relates the pupil's consumption of the educational service to the time it takes to affect this consumption. This would,for

example, be the learning curve in instances such as arithmetic and reading.

From this type of schedule the school administrator could sum over the pupil population and obtain estimates of how much of the various educational services should be produced and for whom. The present discussion is not an attempt to minimize the problems associated with a meaningful assessment of pupil needs. First, it is presumptuous to assume that the child knows what he needs or that he would necessarily select what is best for him, if it were offered. Allowing the parent to serve as a proxy consumer would probably give some limited improvement. One approach to the assessment of pupil needs would involve a survey or inventory of needs with the information interpreted by the decision-maker (and his expert advisors). This interpretive role is consistent with present school practice since it is implicitly part of the budget allocation process.

The approach used in this study assumed that the Assistant Superintendent for Curriculum has the responsibility for interpreting pupil needs or at least reviewing the interpretations of the two coordinators. A set of overall health and physical education objectives were developed. This was not an easy task. A study by Lawrence Downey indicates that educators faced with the job of trying to spell out the objectives of education were often in substantial disagreement. He cites instances of outputs such as 'unified view of self in the universe'.[49]

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[49]Lawrence W. Downey, The Task of Public Education, Midwest Administration Center (Chicago: The University of Chicago, 1960), p. 15.

Dyer, in discussing the problem of objectives in connection with how educators allocate resources says:

> The trouble is that in spite of all the hard thinking and earnest talk about educational goals and how to define them, the goals produced have been essentially nonfunctional -- and I mean even when they have come clothed in the so-called behavioral terms we so much admire. They have had little or no effect on the deals and deliberations that go on in faculties and school boards and boards of trustees and legislative chambers where the little and big decisions about education are being made. As you watch the educational enterprise going through its interminable routines, it is hard to avoid the impression that the whole affair is mostly a complicated ritual in which the vast majority of participants-pupils, teachers, administrators, policy makers - have never given a thought to the question why, in a fundamental sense, they are going through the motions they think of as education.[50]

The overall health and physical education objectives were defined by the Assistant Superintendent and the author during an interview on March 22, 1968. They were:

Symbol	Label	Description
O_A	Appraisal	Every child should have his health status appraised in many respects.
O_B	Follow-up	Possible faults, defects, etc. require follow-up.
O_C	Emergency	Health emergency situations should be provided for adequately.
O_D	Health Education	Health education is to be provided.
O_E	Physical Education	Physical Education is to be provided.

The author maintains that the purpose of overall objectives is to

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[50]Henry S. Dyer, "The Discovery and Development of Educational Goals," Proceedings of the 1966 Invitational Conference on Testing Problems, New York, October, 1966, (Princeton: The Educational Testing Service), p. 13.

provide a foundation on which it is practical to categorize specific, observable activities. Specificity occurs at the activity level, with each overall objective serving as a framework within which one is able to examine the various activities aimed toward the same general target area. The criterion of adequacy of these overall objectives is indeed pragmatic--i.e., the ease with which the activities to be evaluated can be distributed to the overall objectives by the decision-maker. In this study, the five overall health and physical education objectives were adequate. Initially, there was a sixth overall objective, "Communicable Disease", but the decision-maker merged it with "Emergency".

3. Overall system objective valuation

The need to assign values to objectives of differing importance is not perceived clearly in the educational administration. Recently, the Pennsylvania Study Commission tried to structure school system objectives. The approach involved a panel of educational and civic leaders and experts. There was reluctance to assign weights, as measures of importance, to the objectives generated on the grounds that "all ten were important goals of education and that none should be neglected".[51]

The need for weighting objectives is obvious (although politically it may not always be wise), since if they are not differentiated the implicit assumption is that they are of equal importance. Rankings may provide helpful information, but are not very useful in most decision

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[51] A Plan for Evaluating the Quality of Educational Programs in Pennsylvania. Vol. 1: Basic Program, A Report from the Educational Testing Service to the State Board of Education(June 30, 1965), p. 11.

situations, since questions arise such as -- "do I produce the objective ranked first and disregard the others, or..."

The method used in this study to weight objectives is referred to as the Churchman - Ackoff Objective Weighting Model. The reasons for selecting this approach were that the method is relatively simple and provides a measure of relative weights for the decision-maker. Also, most of the other valuation and scaling techniques require multiple judges, and in this study the emphasis is the single designated decision-maker who had the overall responsibility.

The method provides a mechanism for weighting multiple objectives on the basis of repeated comparisons and produces a set of internally consistent weights. It does this by allowing the rater to value and revalue when inconsistencies arise. The assumptions of the method are:

"1. For every outcome O_j, there corresponds a real non-negative number V_j, to be interpreted as a measure of the true importance of O_j.

2. If O_j is more important than O_k, then $V_j > V_k$ and if O_j and O_k are equally important, then $V_j = V_k$.

3. If V_j and V_k correspond to O_j and O_k respectively, then $V_j + V_k$ corresponds to the combined outcome O_j- and -O_k."[52]

The first statement postulates the existence of a value function. The second is that of transitivity and the third specifies additivity.

In allowing the Assistant Superintendent for Curriculum (the decision-maker) to apply this method to objectives, there were several

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[52] C. West Churchman, Russel L. Ackoff, and Leonard E. Arnoff, Introduction to Operations Research(New York:John Wiley & Sons, Inc.,1959), p. 140.

problems. The method is designed to force the rater to assess and reassess objectives singularly and in combination and, ideally, provides a set of weights with internal consistency. The decision-maker was briefed about the purposes of the method and given a written set of directions to serve as a guide during the interview. An unexpected problem arose due to the fact that the decision-maker felt that the objectives in some groupings[53] were of nearly equal importance. These perceptions restricted the nature of the comparisons he was able to make. For example, in a typical experiment, cited by Ackoff, et.al., the preliminary weights assigned were 1.00, 0.80, 0.50 and 0.30.[54] It is far easier to combine these quantities than a set of initial weights such as 1.10, 1.05, 1.00, and 0.90, yet this is the way some sets of activities were perceived by the decision-maker.

Value problems are discussed in greater detail later in the chapter since the present section related to the valuation of overall health and physical education objectives.

The values assigned were:[55]

Overall Objective (O_K)	$V(O_K)$
O_A	110

[53]This comment refers to the fact that program activities were grouped so that they could be valued in terms of potential contribution to the overall objectives they were designed to produce.

[54]Churchman, Ackoff, and Arnoff, op. cit., p. 139.

[55]Value assignments were made by the Assistant Superintendent for Curriculum during an interview conducted by the author on April 30,1968.

O_B	100
O_C	140
O_D	125
O_E	125
$\sum_{i=A}^{R} V(O_i)$	600

The critical assumption, given the internal consistency of the values to the decision-maker, is that the empirically derived values represent locations on a relative scale reflecting the preferences of the rater.[56] In a recent article, Robert Winkler discusses the reasonableness of the assumptions underlying the measurement of subjective probabilities

> Of course, the theory of personalistic probability and the underlying principles of coherence constitute a normative theory and do not claim to describe actual behavior. We would no more expect people to never violate the postulates of coherence than we would expect them to never violate the rules of logic or arithmetic [he cites Bruno de Finetti for this]. Presumably, the degree to which an assessor obeys the rules of coherence would depend on such variables as the familiarity of the assessor with the terminology of probability and statistics and his general competence in quantitative reasoning.[57]

The weights for the overall health and physical education objectives were obtained in April, 1968. As the study progressed there was some

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[56] In Wroe Alderson and Paul E. Green, Planning and Problem Solving In Marketing (Homewood, Illinois: Richard D. Irwin, Inc., 1964), P.152, and Churchman, Ackoff and Arnoff, op.cit., pp. 150-152, there are suggestions that the quantities derived from the Churchman - Ackoff method can be combined with subjective probabilities to arrive at expected value determinations.

[57] Robert L. Winkler, "The Quantification of Judgement: Some Methodological Suggestions", Journal of the American Statistical Association, Vol. 62, No. 320, (December, 1967), p. 1113.

uneasiness as to what these values represented. In March, 1969, it was decided to try to answer the question -- how internally consistent is <u>this</u> decision-maker in providing judgments for his overall health and physical education objectives? Since it was possible that his values could have changed substantially from the previous year, it was assumed that if he were consistent in 1969, it would be reasonable to assume that he was consistent in 1968. Accordingly, a test for internal consistency was designed.[58]

The primary objective of this section is to determine the extent to which the Assistant Superintendent for Curriculum is consistent in his assignment of values. The procedure consisted of presenting the 20 permutations of his five overall health and physical education objectives taken two at a time. The task was specified in the following manner: "Consider overall objectives A and B. Let A be valued at 1.0. How do you rate the value of B as a multiple of A?" An example was provided so that he was forced to think in a multiplicative sense rather than an additive sense.

Before analysis of the data could be conducted, it was necessary to define an aggregative statistic and to structure the problem mathematically. The logic and development of this procedure are given below.

There are unknown parameters V_A, V_B, ... , $0 < V_i < \infty$. A subject is asked to consider two of these parameters V_A and V_B and to express "the value of B as a multiple of the value of A, just as if the value of A was set at 1."

58The data were collected by the author during an interview with the Assistant Superintendent for Curriculum on May 12, 1969. These data are used later in this chapter to test the hypothesis of consistency.

The ratio V_B/V_A is denoted as X and the estimate of X is denoted x. The statistic x is a function of the subject's perceptions of V_A and V_B and is the quotient of the random variables v_B and v_A. These variables are assumed to be independently and lognormally distributed. The latter assumption means the logarithms of the variates are normal and the variate itself is skewed positively with all values greater than zero. Aitchison and Brown indicate that the lognormal distribution has been used as a model to describe quantitative psychological responses to stimuli.[59] The independence assumption refers to the independence of errors in the subject's perceptions about V_A.

If a variable p is lognormally distributed,[60] $\Lambda(\mu,\sigma^2)$, then $q = \ln p$ is normally distributed, $N(\mu,\sigma^2)$. The general form of a normal cumulative distribution function is

$$\Phi(p;\mu,\sigma^2) = \int_{-\infty}^{p} \phi(t;\mu,\sigma^2)\,dt$$

$$= \int_{-\infty}^{p} \frac{1}{t\sigma\sqrt{2\pi}} \exp\left\{-\frac{1}{2\sigma^2}(\ln t - \mu)^2\right\} dt,$$

(The t appears in the denominator of the integrand since $\frac{d(\ln t)}{dt} = 1/t$.)

and $$\frac{d\Phi(p;\mu,\sigma^2)}{dp} = \frac{1}{p\sigma\sqrt{2\pi}} \exp\left\{-\frac{1}{2\sigma^2}(\ln p - \mu)^2\right\}.$$

This expression is the lognormal probability density and is given in Aitchison and Brown.[61]

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[59] Aitchison J. and J. A. C. Brown, The Lognormal Distribution, (Cambridge: Cambridge University Press, 1966), pp. 66-67.

[60] The notation $\Lambda(\mu,\sigma^2)$ is conventional. The mean, for instance of the lognormal density is $e^{\mu + \sigma^2/2}$. This will be discussed in more detail in this section.

[61] Aitchison and J.A.C. Brown, op. cit., p. 8.

Aitchison and Brown give the results for the mean and variance[62] but it is worthwhile for us to derive the mean since the result is of considerable interest. The mean is defined as

$$E(p) = \int_{-\infty}^{\infty} p f(p)\,dp,$$

$$= \int_{0}^{\infty} p \frac{1}{\sigma p\sqrt{2\pi}} \exp\left\{-\frac{1}{2\sigma^2}(\ln p - \mu)^2\right\} dp.$$

Let $Z = \frac{\ln p - \mu}{\sigma\sqrt{2}}$; then $dZ = \frac{1}{\sigma\sqrt{2}} \cdot \frac{1}{p}\,dp$, $dp = \sigma\sqrt{2}\,p\,dZ$, and

$$E(p) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-Z^2} \sigma\sqrt{2}\,p\,dZ.$$

To eliminate p, let $\ln p = \sigma\sqrt{2}\,Z + \mu$; then $p = e^{\sigma\sqrt{2}\,Z + \mu}$, and

$$E(p) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-Z^2} e^{\sigma\sqrt{2}\,Z+\mu} dZ .$$

The next step is to complete the square in Z:

$$E(p) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\left[Z^2 - \sigma\sqrt{2}\,Z + \frac{1}{2}\sigma^2\right] + \mu + \sigma^2/2} dZ$$

$$= \frac{1}{\sqrt{\pi}} e^{\mu+\sigma^2/2} \int_{-\infty}^{\infty} e^{-(Z-\sigma/\sqrt{2})^2} dZ$$

Let $t = Z - \sigma^2/\sqrt{2}$; then $dt = dZ$, and

$$E(p) = \frac{1}{\sqrt{\pi}} e^{\mu+\sigma^2/2} \int_{-\infty}^{\infty} e^{-t^2} dt = \frac{1}{\sqrt{\pi}} e^{\mu+\sigma^2/2} \left[(2)\tfrac{1}{2}\sqrt{\pi}\right].$$

Finally, $E(p) = e^{\mu+\sigma^2/2}$ (denoted as α by Aitchison and Brown).

This result is interesting since it means the expected value of a Λ variate is a function of μ but is not equal to μ. The symbol μ denotes the expected value of the density of ln p.

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[62] Aitchison and Brown, loc. cit.

The variance of p is given as[63]

$\beta^2 = \alpha^2 \eta^2$, where $\eta^2 = e^{\sigma^2} - 1$.

Using these results for the distribution of ν_A and ν_B we have

$$\Lambda(\nu_A) = \frac{1}{\nu_A \sigma_A \sqrt{2\pi}} \exp\left\{-\frac{1}{2\sigma_A^2}(\ln \nu_A - \mu_A)^2\right\}$$

and

$$\Lambda(\nu_B) = \frac{1}{\nu_B \sigma_B \sqrt{2\pi}} \exp\left\{-\frac{1}{2\sigma_B^2}(\ln \nu_B - \mu_B)^2\right\}$$

The expected values are

$$\alpha_A = e^{\mu_A + \sigma_A^2/2}, \quad \alpha_B = e^{\mu_B + \sigma_B^2/2},$$

and variances are

$$\beta_A^2 = \alpha_A^2 \eta_A^2, \quad \beta_B^2 = \alpha_B^2 \eta_B^2 .$$

The need for a definition of an aggregative statistic that would test the hypothesis of consistency is apparent. Several alternative statistics were considered. The statistic R' was defined as

$$R' = \prod_{i=1}^{C_2^n} (S_i - 1)^2 ,$$

where $S_i = r_i r_i'$ with, for example $r_1 = \nu_B/\nu_A$, $r_1' = \nu_A/\nu_B$,

and $C_2^n = \frac{n!}{2!(n-2)!}$.

This statistic, R', would present enormous practical difficulty since any time a rater assigned a perfectly consistent pair of values to two objectives the R' would be 0.

The very nature of the lognormal distribution was helpful in defining the statistic actually used to test the hypothesis of consistency. Aitchison and Brown discuss the nature of lognormal distributions:

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[63] Ibid.

The two-parameter lognormal distribution possesses a number of interesting reproductive properties, most of which are immediate consequences of those for the normal distribution. Since the latter has additive reproductive properties it is to be expected, from the characteristic property of the logarithmic function $\log X_1 + \log X_2 = \log X_1 X_2$, that the lognormal distribution will have multiplicative reproductive properties.[64]

The actual statistic defined in this study to test the hypothesis of consistency takes advantage of the fundamental multiplicative nature of the lognormal distribution. The statistic R^* is defined as

$$R^* = \prod_{i=1}^{C_2^n} S_i, \text{ with } \ln R^* = \sum_{i=1}^{C_2^n} \ln S_i .$$

In order to apply the many results derived by Aitchison and Brown, the author assumed experimental independence. This assumption is based on having the rater estimate such quantities as x_1 and x_1' in random sequences. The importance of having the rater provide independent assessments is stressed by Torgerson in a discussion of subjective estimation of ratios.[65] At a later place in this section a more thorough treatment of statistical independence is provided.

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[64] Ibid., pp. 9-10.

[65] Torgerson, p. 104.

A central limit theorem is cited by Aitchison and Brown.

If $\{X_j\}$ is a sequence of independent, positive variates having the same probability distribution and such that $E\{\log X_j\} = \mu$ and $VAR\{\log X_j\} = \sigma^2$ both exist, then the product $\prod_{j=1}^{n} X_j$ is asymptotically distributed as $\Lambda(n\mu, n\sigma^2)$.[66]

Another general theorem states that if $\{X_j\}$ is a sequence of Λ-variates where X_j is $\Lambda(\mu_j, \sigma_j^2)$, $\{b_j\}$ is a sequence of constants and $c = e^a$ is a positive constant, then provided $\sum_j b_j \mu_j$ and $\sum_j b_j^2 \sigma_j^2$ both converge, the product $c\prod_j X_j^{b_j}$ is $\Lambda(a + \sum_j b_j \mu_j, \sum_j b_j^2 \sigma_j^2)$.[67]

While the constants c and b_j are not relevant to the problem, the theorem does provide that the product of lognormal variates is also lognormal with the new parameters μ and σ^2 equal to the sums of the respective means and variances. Since $\ln(1/X) = -\ln X$ the distribution of $x_1 = \mathcal{N}_B/\mathcal{N}_A$ is $\Lambda(x_1) = \Lambda(\mu_B - \mu_A, \sigma_A^2 + \sigma_B^2)$,

and the distribution of $x_1' = \mathcal{N}_A/\mathcal{N}_B$ is

$$\Lambda(x_1') = \Lambda(\mu_A - \mu_B, \sigma_A^2 + \sigma_B^2).$$

This distribution of $S_1 = x_1 x_1'$ is, by virtue of the general theorem just cited, also a Λ-variate. It is defined by

$$\Lambda(S_1) = \Lambda(\mu_B - \mu_A + \mu_A - \mu_B, 2\sigma_A^2 + 2\sigma_B^2)$$
$$= \Lambda(0, 2\sigma_A^2 + 2\sigma_B^2).$$

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[66] Ibid., p. 13.

[67] Ibid., p. 11.

The density of S_1 on the assumption that $\sigma_A^2 = \sigma_B^2 = \sigma^2$ is

$$\Lambda(S_1) = \frac{1}{S_1 2\sigma\sqrt{2\pi}} \exp\left\{-\frac{1}{8\sigma^2}(\ln S_1 - 0)^2\right\}.$$

The next step defines the probability density of R*, where $R^* = \prod_{i=1}^{C_2^n} S_i$.

$$\Lambda(R^*) = \Lambda(C_2^n\,(0), 4C_2^n\,\sigma^2);$$

$$= \Lambda(0,\ 4C_2^n\,\sigma^2),$$

and
$$\Lambda(R^*) = \frac{1}{R^* 2\sigma\sqrt{2\pi C_2^n}} \exp\left\{-\frac{1}{8\sigma^2 C_2^n}\ (\ln R^* - 0)^2\right\}.$$

It has been established that the probability density of R* is $\Lambda(0, 4C_2^n\,\sigma^2)$. The statistic R* is a product of S_i values. When the rater is perfectly consistent for a pair of ratings the S_i is 1.0. Departures from 1.0 are taken as evidence supporting the hypothesis of inconsistency.

Since we know that the probability distribution of lnR* is normal, $\phi\,(0, 4C_2^n\,\sigma^2)$, it is convenient to treat R* in logarithmic form. Under the condition that VAR(lnR*) is known, the test for the hypothesis of consistency is structured as the standard normal deviate

$$Z = \frac{\ln R^* - 0}{2\sigma\sqrt{C_2^n}}.$$

The variance of lnR* was found to be $4\sigma^2 C_2^n$ but is in terms of the standard deviation of the logarithms of any of the original variables, such as σ_A. We want the maximum likelihood estimator of $4\sigma^2 C_2^n$ in order to calculate the t-statistic from the sample evidence obtained during the interview of May 12, 1969.

While the statistic R* is a product, the statistic lnR* is a sum and a correction factor is required to adjust for the fact that lnR* is not an arithmetic mean. The arithmetic mean of lnR* is

$$\overline{\ln R^*} = \frac{\ln S_1 + \ln S_2 + \cdots + \ln S_{C_2^n}}{C_2^n}$$. But ln R* is C_2^n times $\overline{\ln R^*}$.

In terms of the variance of these two terms we would obtain a relationship based on the fact that the variance of a constant multiplied by a variable is the square of the constant multiplied by the variance of the variable, i.e.

$$(C_2^n)^2 \, \mathrm{VAR}\left(\sum_{i=1}^{C_2^n} \ln S_i\right) = \mathrm{VAR}\left(\sum_{i=1}^{C_2^n} \ln S_i / C_2^n\right) .$$

Now we can structure the variance estimator of lnR*.

$$\mathrm{VAR}(\ln R^*) = (C_2^n)^2 \mathrm{VAR}(\overline{\ln R^*}),$$

and $$\widehat{\mathrm{VAR}}(\ln R^*) = (C_2^n)^2 \frac{C_2^n}{C_2^n - 1}\left[\sum_{i=1}^{C_2^n} \frac{(\ln S_i)^2}{C_2^n} - \left(\frac{\sum_{i=1}^{C_2^n} \ln S_i}{C_2^n}\right)^2\right];$$

$$= (C_2^n)^2 \left[\frac{\sum_{i=1}^{C_2^n} (\ln S_i)^2}{C_2^n - 1} - \frac{1}{C_2^n (C_2^n - 1)} \left(\sum_{i=1}^{C_2^n} \ln S_i\right)^2\right]$$

The t-statistic is

$$t = \frac{\ln R^* - 0}{\sqrt{\frac{C_2^n}{C_2^n - 1}\left[\sum_{i=1}^{C_2^n} (\ln S_i)^2 - \frac{1}{C_2^n}\left(\sum_{i=1}^{C_2^n} \ln S_i\right)^2\right]}},$$

with $C_2^n - 1$ degrees of freedom.

Two sets of data were obtained from the Radnor decision-maker in order to test the hypothesis of consistency. Each of the sets was made up of the C_2^n pairs of comparisons. The actual comparisons were presented in random order with one restriction--the permutations comprising a given combination were not presented in adjacent order to the decision-maker.

The data were:

Set #1

Combination	x_i or x_i'	$\ln x_i$ or $\ln x_i'$	$\ln x_i + \ln x_i'$	$(\ln x_i + \ln x_i')^2$
A/B	1.1	0.0953	-0.1279	0.01635841
B/A	0.8	-0.2232		
A/C	0.6	-0.5108	-0.1743	0.03038049
C/A	1.4	0.3365		
A/D	1.0	0.0000	0.0000	0.00000000
D/A	1.0	0.0000		
A/E	1.1	0.0953	-0.0101	0.00010201
E/A	0.9	-0.1054		
B/C	0.5	-0.6932	-0.0626	0.00391876
C/B	1.7	0.6306		
B/D	1.1	0.0954	-0.1279	0.01635841
D/B	0.8	-0.2232		
B/E	1.0	0.0000	-0.1054	0.01110916
E/B	0.9	-0.1054		
C/D	1.4	0.3365	-0.3567	0.12723489
D/C	0.5	-0.6932		
C/E	1.7	0.5306	0.1739	0.03024121
E/C	0.7	-0.3567		
D/E	0.9	-0.1054	0.0769	0.00591361
E/D	1.2	0.1823		

In order to test the composite hypothesis that the values represent a consistent set of preferences against the alternative of inconsistency, the t-statistic was calculated:

$$t = \frac{\ln R^* - 0}{\sqrt{\frac{C_2^n}{C_2^n - 1}\left[\sum_{i=1}^{C_2^n}(\ln S_i)^2 - \frac{1}{C_2^n}\left(\sum_{i=1}^{C_2^n}\ln S_i\right)^2\right]}}$$

$$t = \frac{-0.7141 \quad -0}{\sqrt{10/9\left[0.24161695 - \frac{1}{10}\quad(-0.7141)^2\right]}}$$

$$= \frac{-0.7141}{0.4602}$$

$$= -1.55$$

A second trial similar to the first set of ratings was also obtained and these data were subjected to the same test.

Set #2

Combination	x_i or x_i'	$\ln x_i$ or $\ln x_i'$	$\ln x_i + \ln x_i'$	$(\ln x_i + \ln x_i')^2$
A/B	1.0	0.000	-0.1054	0.01110916
B/A	0.9	-0.1054		
A/C	0.6	-0.5108	-0.1053	0.01108809
C/A	1.5	0.4055		
A/D	1.2	0.1823	0.0769	0.00591361
D/A	0.9	-0.1054		
A/E	1.2	0.1823	0.1823	0.03323329
E/A	1.0	0.0000		

Combination	x_i or x_i'	$\ln x_i$ or $\ln x_i'$	$\ln x_i + \ln x_i'$	$(\ln x_i + \ln x_i')^2$
B/C	0.6	-0.5108	0.0198	0.00039204
C/B	1.7	0.5306		
B/D	1.1	0.0953	0.1906	0.03632836
D/B	1.1	0.0953		
B/E	0.9	-0.1054	-0.2108	0.04443664
E/B	0.9	-0.1054		
C/D	1.7	0.5306	0.1739	0.03024121
D/C	0.7	-0.3567		
C/E	1.6	0.4700	0.2468	0.06091024
E/C	0.8	-0.2232		
D/E	0.8	-0.2232	-0.1279	0.01635841
E/D	1.1	0.0953		

$$t = \frac{0.3409}{\sqrt{10/9\left[0.25001105 - \frac{1}{10}(0.3409)^2\right]}}$$

$$= \frac{0.3409}{0.527}$$

$$= 0.65$$

The original purpose for structuring R* was to investigate the consistency of the values assigned by the Assistant Superintendent for Curriculum to the overall health and physical education objectives. The test for consistency was based on the assumption of independence of combinations within an individual sample. This assumption should be explored in more depth since the results cited from Aitchison and Brown explicitly require experimental independence.

The model implied in the use of the statistic $\ln R^*$ to test the hypothesis of consistency of assigned values is now examined. For elements A and B the value responses may be expressed as

$$V_{A:B} = \mu_{A:B} + e_{A:B} ,$$

and $V_{B:A} = \mu_{B:A} + e_{B:A}$; where $\mu_{B:A} = \frac{1}{\mu_{A:B}}$. The error terms $e_{A:B}$ and $e_{B:A}$ are random disturbances and are assumed to be distributed $\sim N(0,\sigma^2)$. The product variable, $V_{A:B} V_{B:A}$, is

$$1 + e_{B:A}\mu_{A:B} + e_{A:B}\mu_{B:A} + e_{A:B}e_{B:A} .$$

The mathematical expectation of the product variable is

$$1 + E(e_{A:B} e_{B:A})$$

since the middle terms have expected values of zero. If the expectation of the error covariance elements is assumed to be zero, implying a normal density of the error product, then the argument focuses on the relationship between $V_{A:B} V_{B:A}$ and subsequent products, for example $V_{A:C} V_{C:A}$.

Some references to the scaling and measurement literature are appropriate. Torgerson's suggestions,[68] including randomization of stimuli, were incorporated into the procedures used to assess the preferences of the Assistant Superintendent for Curriculum.

Guilford, in commenting on an article treating the problem of experimental independence, indicates that the investigators recommend that the observer should be allowed to maintain confidence that he is

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[68] Torgerson, p. 104.

observing and not guessing. Guilford concludes that the advice is sound and necessary for assuming independence.[69]

Luce, on the other hand, takes a different position with respect to response dependences. He indicates that writers generally persist in making the assumption of independence in spite of contrary evidence. While Luce acknowledges that no one has formulated response dependent models he argues for such developments in order to justify current practice.[70]

The task at hand is to consider the actual experiment to gain insight into the inherent problem of dependency. Earlier we had defined

$$R^* = \prod_{i=1}^{C_2^n} S_i \; ,$$

$$S_i = \psi_i \psi_i' \; ; \quad \text{where, for example,} \quad \psi_1 = N_B / N_A \; , \quad \psi_1' = N_A / N_B \; .$$

If the various product elements, e.g. $\psi_1 \psi_1'$, were independent then we would expect their errors to randomly distribute about their exp...ed values. The mathematical expectation of R* under the null hypothesis of consistency and the assumption of independence was zero.

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[69] J. P. Guilford, Psychometric Methods, 2nd edit., (New York: Mc Graw-Hill Book Company, Inc., 1954), p. 323.
The article discussed by Guilford is:
V. L. Senders and A. Sowards, "Analysis of Response Sequences in the Setting of a Psychological Experiment," American Journal of Psychology, Vol. 65, (1952).

[70] R. Duncan Luce, "Detection and Recognition," R. Duncan Luce, Robert R. Bush, and Eugene Galanter, Editors, Mathematical Psychology, (New York: John Wiley & Sons, Inc., 1963), p. 106.

Consequently, the test for the hypothesis of independence would involve a consideration of the deviations from $E(\ln R^*)$.

An ideal treatment of the problem would involve many values of $\ln R^*$. The deviations from $E(\ln R^*)$ would be tested for goodness of fit with the normal curve.

In a more limited context the hypothesis

$$H_0 : E(\ln R^*) = 0$$

could be tested.

In summary, there does not appear to be an adequate method to test the hypothesis of independence.

We can, however, examine the respective combinations of values across sample trials. Here the hypothesis of no combinations by trial interaction can be tested.[71] The null hypothesis is

$$H_0 : E(\ln t_{i1} + \ln t'_{i1}) = E(\ln t_{i2} + \ln t'_{i2}) ;$$

where the i subscript refers to the combination, and 1 and 2 to trials.

The test procedure is taken from Morrison and is the standard test for the significance of the difference between two random variables

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[71] A complete investigation into questions concerning population profiles is provided by Morrison. The method of "profile analysis" is extended to the multivariate case.
Donald F. Morrison, Multivariate Statistical Methods, (Mc Graw-Hill Book Company, 1967), pp. 141-148, 186-197.

from dependent samples.[72] The test statistic under H_0 is distributed as Student's t with $n-1$ degrees of freedom. The statistic is

$$t = \frac{\bar{d}\sqrt{n}}{S_d} \; ; \quad d_i = \ln t_{i1} + \ln t'_{i1} - \ln t_{i2} - \ln t'_{i2}$$
$$\bar{d} = \Sigma d_i / n$$
$$S_d = \left[\frac{n}{n-1}\left[VAR(d)\right]\right]^{1/2}$$

Combination (i)	Trial #1 $\ln t_{i1} + \ln t'_{i1}$	Trial #2 $\ln t_{i2} + \ln t'_{i2}$	d_i	d_i^2
AB : BA	-0.1279	-0.1054	-0.0225	0.0005
AC : CA	-0.1743	-0.1053	-0.0690	0.0048
AD : DA	0.0000	0.0769	-0.0769	0.0059
AE : EA	-0.0101	0.1823	-0.1924	0.0370
BC : CB	-0.0626	0.0198	-0.0824	0.0068
BD : DB	-0.1279	0.1906	-0.3185	0.1014
BE : EB	-0.1054	-0.2108	0.1054	0.0111
CD : DC	-0.3567	0.1739	-0.5306	0.2815
CE : EC	0.1739	0.2468	-0.0729	0.0053
DE : ED	0.0769	-0.1279	0.2048	0.0419
			-1.0550	0.4962

$\bar{d} = -1.0550/10 = -0.1055$ $\qquad S_d = \sqrt{\frac{0.4962}{9} - \frac{1.1130}{(10)(9)}} = 0.21$

$\Sigma d^2 = 0.4962$

$(\Sigma d)^2 = 1.1130$ $\qquad t = -0.1055\sqrt{10}/0.21 = -1.58$

There is a fair amount of evidence to indicate that the hypothesis of no combination by trial interaction is dubious. This means that the responses for the various combinations appear to have interacted across sample trials.

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[72] Morrison, pp. 133-134.

4. System activities and overall objectives

Activities were studied by the Assistant Superintendent for Curriculum and the author and related to the five overall health and physical education objectives during an interview on April 30, 1968. This step was the most critical step in the sequence since it provided the basic linkage for the entire network. Activities are the fundamental elements of the system since values, performance scores, and costs are all related at the activity level.

The eight programs previously listed were denoted $P_1, P_2, \ldots, P_m, \ldots, P_8$. Activity J, of program m, aimed at overall objective ℓ was denoted $a_{mJ}O_{\ell}$.

Table 1 lists the 48 activities, by program, with a brief description of each activity.

5. System activity valuation

Once the Assistant Supeiintendent for Curriculum had assigned a scale of educational value to overall objectives, he was able to relate health and physical education activities to these overall objectives. The author was then able to distribute the productivity potentials to the various health and physical education activities. Since activities were designed to contribute to specific overall objectives, they derived their potential for production from those overall objectives. Therefore, activities were not valued relative to other activities in their program. Within a given program the relatives can be on different scales until they are anchored by the unit of value assigned to the overall objectives.

TABLE 1

PROGRAM ACTIVITY RECONCILED TO OVERALL OBJECTIVES, BY PROGRAM, WITH BRIEF DESCRIPTION

Program (P_m)	Program Activity (a_{mJ}) Reconciled to (O_J)	Brief Description
Annual Screening	a_{11} O_A	vision appraisal
	a_{12} O_A	hearing appraisal
	a_{13} O_A	height-weight appraisal
	a_{14} O_B	discuss problems with pupil
	a_{14} O_B	discuss problems and health education topics with pupil
	a_{15} O_B	refer to parents
	a_{16} O_B	refer to teachers (other than physical education teachers)
	a_{17} O_B	refer to physical education teachers
Physical Examination	a_{21} O_A	reflex appraisal
	a_{22} O_A	speech appraisal
	a_{23} O_A	posture-orthopedic appraisal
	a_{24} O_A	heart and blood pressure appraisal
	a_{25} O_A	other appraisal
	a_{26} O_B	refer to parents
	a_{27} O_B	refer to teachers (other than physical education teachers)
	a_{28} O_B	refer to physical education teachers
	a_{29} O_B	discuss problems with pupil
	a_{29} O_D	discuss problems and health education topics with pupil

TABLE 1 - Continued

Program	Program Activity Reconciled	Brief Description
Communicable and Infectious Disease	a_{32} 0_D	education spillover
	a_{33} 0_A	detect venereal disease
	a_{34} 0_A	detect tuberculosis
	a_{35} 0_B	refer to parents
	a_{36} 0_B	refer to teachers (other than physical education teachers)
	a_{37} 0_B	refer to physical education teacher
NOTE: a_{31} was transferred into another program		
Emergency	a_{41} 0_C	care for serious injury
	a_{42} 0_C	care for less serious injury
	a_{43} 0_C	care for illness
	a_{44} 0_B	refer serious injury
	a_{45} 0_B	refer less serious injury
	a_{46} 0_B	refer illness
Follow-up	a_{51} 0_B	determine referral disposition when necessary
Health Education	a_{61} 0_D	"the pupil should accept responsibility for his own health"
	a_{62} 0_D	the health curriculum
Physical Education	a_{71} 0_E	every child should participate
	a_{72} 0_E	physical fitness
	a_{73} 0_E	physical confidence
	a_{74} 0_E	the program should present a wide variety of games and skills

TABLE 1-Continued

Program	Program Activity Reconciled	Brief Description
Physical Education	a_{75} 0_D	proper attitudes
	a_{76} 0_D	prepare for lifetime sports
Adapted Physical Education	a_{81} 0_A	posture orthopedic appraisal
	a_{82} 0_A	physical improvement
	a_{83} 0_A	proper attitudes toward physical problems
	a_{84} 0_E	children with physical problems should participate more

Distribution of value to activities was accomplished by a simple procedure. Activities were grouped by overall objective and then sorted into sub-groups of five, six, and, in one instance, seven. For example, twelve activities from five programs contributed to overall objective O_A (Appraisal). They were divided into two sets (one containing six activities, the other containing seven). The extra activity was "posture and orthopedic," which served as a numeraire.

During the course of the interview of April 30, 1968 certain factors became apparent. First, the superintendent seemed to have a set of values "internalized." In addition it was evident that he was not trying to rationalize the existence of the Radnor programs. He made numerous comments, such as "I am sure my teachers would put this number one, but my priorities are different." He agreed that the values obtained should be reassessed "in about a month" so as to indicate areas requiring obvious adjustment.

Table 2 gives values assigned at the final interview a month later. The final values were obtained by showing the preliminary values to the superintendent and discussing possible inconsistencies and implications with him.

Once the final valuations for the activities were obtained, they were used to distribute the potential value of the respective overall health and physical education objectives. This was done by summing the final valuation scores for each overall objective's activities and deriving relative shares. Then the relative shares were multiplied by the total potential value for the relevant overall objective to yield standardized values. The maximum production possible for $a_{mJ}O_i^*$ was obtained by:

TABLE 2

STANDARDIZED VALUES FOR PROGRAM ACTIVITIES, BY OVERALL OBJECTIVE

Program Activity reconciled to: Appraisal ($a_{mJ}O_A$)	Final Valuation ($b_{mJ}O_A$)	Relative Share $\left(\frac{b_{mJ}O_A}{\sum b_{mJ}O_A}\right)$	Standardized Value $\left(\frac{b_{mJ}O_A}{\sum b_{mJ}O_A}\right)[V(O_A)]$
a_{11}	115	0.09465	10.4
a_{12}	115	0.09465	10.4
a_{24}	115	0.09465	10.4
a_{25}	115	0.09465	10.4
a_{13}	105	0.08642	9.5
a_{21}	105	0.08642	9.5
a_{22}	105	0.08642	9.5
a_{23}	100	0.082304	9.1
a_{81}	100	0.082304	9.1
a_{33}	80	0.06584	7.2
a_{34}	80	0.06584	7.2
a_{91}	80	0.06584	7.2
	1215	0.999988	109.9

TABLE 2-Continued

Program Activity reconciled to: Follow-Up	Final Valuation	Relative Share	Standardized Value
a_{44}	250	0.10965	11.0
a_{35}	150	0.06579	6.6
a_{15}	150	0.06579	6.6
a_{26}	150	0.06579	6.6
a_{37}	125	0.05482	5.5
a_{17}	125	0.05482	5.5
a_{27}	125	0.05482	5.5
a_{45}	125	0.05482	5.5
a_{46}	125	0.05482	5.5
a_{14}	125	0.05482	5.5
a_{29}	125	0.05482	5.5
a_{28}	125	0.05482	5.5
a_{36}	120	0.05263	5.3
a_{16}	120	0.05263	5.3
a_{51}	120	0.05263	5.3
a_{82}	110	0.04824	4.8
a_{92}	110	0.04824	4.8
	2280	0.99995	100.3

Program Activity reconciled to: Emergency	Final Valuation	Relative Share	Standardized Value
a_{41}	200	0.47059	65.9
a_{42}	125	0.29412	41.2
a_{43}	100	0.23529	32.9
	425	1.00000	140.0

TABLE 2-Continued

Program Activity reconciled to: Health Education	Final Valuation	Relative Share	Standardized Value
a_{14}	125	0.13158	16.4
a_{29}	125	0.13158	16.4
a_{61}	120	0.12632	15.8
a_{62}	120	0.12632	15.8
a_{75}	120	0.12632	15.8
a_{76}	120	0.12632	15.8
a_{83}	120	0.12632	15.8
a_{32}	100	0.10526	13.2
	950	1.00002	125.0

Program Activity reconciled to: Physical Education	Final Valuation	Relative Share	Standardized Value
a_{72}	100	0.23256	29.1
a_{73}	90	0.20930	26.2
a_{71}	85	0.19767	24.7
a_{74}	80	0.18605	23.3
a_{84}	75	0.17442	21.8
	430	1.00000	125.1

$$V(a_{mJ}O_i) = \left[\frac{b_{mJ}O_i}{\sum\limits_{\text{All } J\, O_i} b_{mJ}O_i}\right] \cdot \left[V(O_i)\right],$$

where: $b_{mJ}O_i$ = the final valuation reflecting the relative potential of J^{th} activity in any program producing O_i.

6. Performance Criteria

Performance criteria are critical because they determine the extent to which the respective activities have done what they were designed to do. Chapter II referred to performance criteria in several ways. First there is the criterion itself, which prescribes what is to be observed, under what circumstances, etc. It is important to involve the decision-maker as much as possible in the process by which these criteria are selected. A second step in this operation is to develop the performance index $K_{mJ}O_i$. This defines performance over its range (in this study the range is 0 to 1.0) and indicates exactly what has to be observed in order to assign an actual performance score, $K^*_{mJ}O_i$. Generally, $K^*_{mJ}O_i$ is a percentage or a rating of some kind. It is very likely that the superintendent, on learning that 90% of the children had their eyes examined, might say "yes, but 10% were not examined." He may feel that $K^*_{mJ}O_i$ does not merit $0.9\left[V(a_{mJ}O_i)\right]$. To account for the possibility that the decision-maker might want to adjust performance, provision is made so that he might transform $K^*_{mJ}O_i$ into $\hat{K}^*_{mJ}O_i$.

Before commenting on the nature of the performance criteria and performance outcomes at Radnor, it is apprppriate to discuss some other aspects of performance criteria. In 1955 Alderson and Sessions, a marketing-management consulting corporation, devoted some space in their house organ to the problem of determining organizational effectiveness. They suggested a "figure of merit" as a measure of performance. This type of measure should meet two, sometimes competing, criteria. First, it should be acceptable to executives who are responsible for the system activities. Situations which they feel are preferred should obtain a higher merit score. The second criterion was that the index should be clearly defined and measurable.[73]

The suggestion of using subjective appraisals when objective criteria are not available is often made in the literature. The Abt Associates study comments on the necessity for subjective measures in allocating resources in education:

> ...Both costs and effectiveness theoretically can be measured, but there are many practical difficulties. At least costs can roughly be estimated in advance on the basis of budget allocations. The prediction of effectiveness is much more difficult. Yet without some such prediction, however crude or subjective, there is no rational basis for deciding between one educational improvement program and another.[74]

Hitch and McKean, in the classic study of economics applied to nuclear defense considerations, point out that better subjective appraisals of both output and performance could be obtained by more meaningful grouping of activities.[75]

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[73]Alderson and Sessions, Inc., "Systems and Models in Operations Research," Cost and Profit Outlook, Vol. VIII, No. 1, (Philadelphia: January, 1955), pp. 3-4.

[74]Abt Associates, ibid., p. 2.

[75] Charles J. Hitch and Roland N, McKean, The Economics of Defense In the Nuclear Age, (Cambridge: Harvard University Press, 1967), p. 61.

Both objective and subjective criteria were used to assess the extent to which activities were produced in the Radnor case study. In some cases it was possible to observe performance or use counts as outcomes, while in other instances it was necessary for the author to elicit subjective assessments. In all, there were three interviews in which the author derived performance estimates from the Nursing and Physical Education Coordinators. These interviews were held in May of 1968. Some of these judgments were based on data collected from pupil records and questionnaires. Appendix C considers the nature of each activity, the performance criterion used, the source of data, and any qualifying remarks by the Radnor participants. In quite a few instances the decision-maker qualified the subjective or objective rating assigned to a criterion. This amounted to the transformation of $K^*_{mJ}O_{\cdot i}$ to $\hat{K}^*_{mJ}O_{\cdot i}$. The first page of Appendix C discusses the method used to explain this transformation to the Assistant Superintendent.

It should be emphasized that "performance" is not a comment on Radnor School District personnel, but is a quantitative rating assigned to an aspect of a program. In given instances, human performance can be of the highest caliber but the level of program resources may not be adequate to do the job.

Table 3 presents the values of $K^*_{mJ}O_{\cdot i}$ and $\hat{K}^*_{mJ}O_{\cdot i}$. It is of interest to note that in four instances the Assistant Superintendent elevated the $K^*_{mJ}O_{\cdot i}$ score and in six instances he saw the need to lower $K^*_{mJ}O_{\cdot i}$. These changes were made during an interview on May 16, 1968. A word of criticism about the study methodology is in order. While the criteria $K_{mJ}O_{\cdot i}$ were developed before outcomes $K^*_{mJ}O_{\cdot i}$ were obtained, the transformation of $K^*_{mJ}O_{\cdot i}$ into $\hat{K}^*_{mJ}O_{\cdot i}$ should also be done before the outcomes are

TABLE 3

ACTIVITY PERFORMANCE OUTCOMES $K^*_{mJ}O_i$ AND ADJUSTED SCORES $\hat{K}^*_{mJ}O_i$

ACTIVITY	$K^*_{mJ}O_i$	$\hat{K}^*_{mJ}O_i$	ACTIVITY	$K^*_{mJ}O_i$	$\hat{K}^*_{mJ}O_i$
$a_{11}\ O_A$	0.97	0.97	$a_{36}\ O_B$	1.00	1.00
$a_{12}\ O_A$	0.91	0.91	$a_{37}\ O_B$	1.00	1.00
$a_{13}\ O_A$	0.98	0.98	$a_{41}\ O_C$	1.00	1.00
$a_{14}\ O_B$	0.75	0.75	$a_{42}\ O_C$	1.00	0.95
$a_{14}\ O_D$	0.50	0.50	$a_{43}\ O_C$	1.00	0.90
$a_{15}\ O_B$	0.20	0.75	$a_{44}\ O_B$	1.00	1.00
$a_{16}\ O_B$	0.80	0.80	$a_{45}\ O_B$	1.00	1.00
$a_{17}\ O_B$	0.40	0.40	$a_{46}\ O_B$	1.00	1.00
$a_{21}\ O_A$	0.90	0.90	$a_{51}\ O_B$	0.80	0.95
$a_{22}\ O_A$	0.90	0.90	$a_{61}\ O_D$	0.75	0.75
$a_{23}\ O_A$	0.90	0.90	$a_{62}\ O_D$	Not Rated	0.40
$a_{24}\ O_A$	0.91	0.91	$a_{71}\ O_E$	0.99	0.99
$a_{25}\ O_A$	0.91	0.91	$a_{72}\ O_E$	0.90	0.80
$a_{26}\ O_B$	0.17	0.45	$a_{73}\ O_E$	0.80	0.80
$a_{27}\ O_B$	1.00	1.00	$a_{74}\ O_E$	1.00	0.85
$a_{28}\ O_B$	0.45	0.45	$a_{75}\ O_D$	0.96	0.96
$a_{29}\ O_B$	1.00	0.80	$a_{76}\ O_D$	0.70	0.55
$a_{29}\ O_D$	1.00	0.80	$a_{81}\ O_A$	1.00	1.00
$a_{32}\ O_D$	0.25	0.50	$a_{82}\ O_B$	0.40	0.40
$a_{33}\ O_A$	0.30	0.30	$a_{83}\ O_D$	0.90	0.90
$a_{34}\ O_A$	0.95	0.95	$a_{84}\ O_E$	0.75	0.75
$a_{35}\ O_B$	1.00	1.00	$a_{91}\ O_A$	Not Rated	1.00
			$a_{92}\ O_B$	Not Rated	0.00

TABLE 4

ADJUSTED PERFORMANCE SCORES $\hat{K}^*_{mJ}O_\ell$ BY PROGRAM AND OVERALL

HEALTH AND PHYSICAL EDUCATION OBJECTIVE

	OVERALL OBJECTIVES				
Program	Appraisal (O_A)	Follow-Up (O_B)	Emergency (O_C)	Health Education (O_D)	Physical Education (O_E)
Annual Screening (P_1)	11=0.97 12=0.91 13=0.98	14=0.75 15=0.75 16=0.80 17=0.40		14=0.50	
Physical Examination (P_2)	21=0.90 22=0.90 23=0.90 24=0.91 25=0.91	26=0.45 27=1.00 28=0.45 29=0.80		29=0.80	
Communicable & Infectious Disease (P_3)	33=0.30 34=0.95	35=1.00 36=1.00 37=1.00 44=1.00	41=1.00	32=0.50	
Emergency (P_4)		45=1.00 46=1.00	42=0.95 43=0.90		
Follow-Up		51=0.95			
Health Education (P_6)				61=0.75 62=0.40	
Physical Education (P_7)				75=0.96 76=0.65	71=0.99 72=0.80 73=0.80 74=0.85
Adapted Physical Education (P_8)	81=1.00	82=0.40		83=0.90	84=0.75
Dental (P_x)	91=0.00	92=0.00			

observed. This type of after-the-fact adjustment is not desirable since it gives a decision-maker the option to "make his system look good".

Table 4 displays the values of $\hat{K}^*_{mJ} O_{\ell}$ by program and overall health and physical education objective.

7. Activity costs

Costs in the case study were defined as "out of pocket" variable costs -- i.e. variable costs spent from the school budget. The rationale for considering only expenditures chargeable to the school budget is as follows. If the decision-maker could get volunteers to work at no cost to his school system, this could affect outputs. But it is entirely reasonable to regard a decision-maker as rational when he endeavors to provide gains for his operation "at no cost". From a societal point of view, he is suboptomizing since the same volunteers could perhaps produce more at a hospital. The main point is that the present effort is not attempting to assess the "real costs" of health and physical education or anything remotely related to this. Here the emphasis is on the school administrator as a rational manager.

Jesse Burkhead draws the same conclusion when discussing Theodore Schultz's efforts aimed at evaluating investment in education in terms of a full range of benefits and costs to all segments of society. Burkhead says:

> A comprehensive cost-benefit approach is necessary for arriving at judgments as to whether we have, as a nation over - or under invested in secondary or college education. However, for the resource decisions that face a specific school board, it is necessary to look at only the benefits that accrue to the community, neglecting those that spill over to other areas, and to look only at the resource costs that are within the control of the board.[76]

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[76] Burkhead, Fox and Holland, op. cit., p. 8.

The author expected that cost data could not be separated at the program activity level. Also, it was anticipated that sufficient information would be available so that estimates of 1967-68 expenditures by program could be derived. Both expectations proved to be reasonable.

There were several accounts which contained relevant cost data. These accounts were structured according to specifications which have been standardized in Pennsylvania school districts by the Pennsylvania Department of Public Instruction.

1. Instruction 0200

This includes salaries and supplies which relate to instruction. The Senior High School is denoted by 0222 with a budgeted amount of $436,097. Only a small proportion of this amount was separated for health and physical education salaries. Salary figures were aggregated at the program level in order to obscure the salaries of individuals. The four personnel involved in the administration and instruction of the physical education programs were paid a total of $36,800 in 1967-68. Excluded in the total were the athletic program and School Doctor salaries.

2. Health Service 0400

This includes salaries of nurses, doctors, dentists, and a dental hygienist . In addition, supplies and expenses are included. The total amount budgeted in 1967-68 was $63,975. Only a small segment of this can be tied to the Senior High School health programs.

3. Procedures

Cost Data were collected from the two major accounts. These expenditures were listed in the following manner:

Description	Vendor	Amount ($)	Date
dixie cups	Pontiac Co.	48.10	12 Sept.67

In the case of the health service programs, the Nursing Coordinator assigned the various expenditures to the program which generated a need for the expenditure. Since many of the expenses were district wide they were pro rated on the basis of school population (unless more specific information was available). The total public school enrollment was taken as 4388 and the Senior High School figure was set at 950. For example, the pro rata share of across the board supplies for the Senior High School was 950/4388 = 0.22.

The physical education expense items were listed in the same fashion as the health expenditures. In this case the Physical Education Coordinator was able to match dollars to programs since the account for the Senior High School was kept separately.

The notion of amortizing equipment expenditures was discarded since the amount of money involved was small (less than $2,000 for all programs, spent on equipment during 1967-68) and the level of funds available for these purchases each year is somewhat uniform.

In order to allocate the salaries to the various programs a time-study form was completed by the two Coordinators. The Nursing Coordinator distributed her time as follows:

Program	Percentage
Annual Screening	30
Physical Examination	5
Communicable and Infectious Disease	5
Emergency and Illness	33
Follow-up	2
Other	25
	100

Some of the estimates, for example, the Physical Examination and Follow-up Programs, were figured on the number of school days required to staff the program. These estimates were based on 200 school days.

The Physical Coordinator split her time as follows:

Program	Percentage
Physical Education	70
Adapted Physical Education	25
Other	5
	100

In addition, she allocated 70 percent of the time of her three teachers to Physical Education and 30 percent to Adapted Physical Education.

The School Doctor's time allocation was based on discussions with the Coordinators. Table 5 shows the total allocation of expenses and salaries to the various programs. As was mentioned previously, the data have been pooled.

A few words should be said about the cost data. Due to the many problems associated with deriving the preceeding figures they should be viewed with caution. In Chapter VI recommendations are made concerning future ways to handle program expenditures and overhead costs.

Some notation was defined so that subsequent analysis could be facilitated. The total of expenditures for program m is

$$C^*_m = \sum_J C^*_{mJ} O_i,$$

and the expenditure associated with the production of overall objective $\dot{i}$ over all programs is

$$C^*_i = \sum_{m=1}^{8} \sum_{\text{All } J \ O_i} C^*_{mJ} O_i .$$

TABLE 5

SALARIES AND EXPENSES, BY PROGRAM

Program	Total($)	Expenses($)	Salaries($)
Annual Screening	2,961	261	2,700
Physical Examination	3,385	13	3,372
Communicable and Infectious Disease	913	98	815
Emergency	3,595	625	2,970
Follow-up	180	--	180
Health Education	3,000	*	*
Physical Education	27,259	1,499	27,760
Adapted Physical Education	11,825	206	11,619
TOTAL	53,118	2,702	47,416

* The $3000 Figure for Health Education is based on a proportion of a science teacher's salary and an estimate of cost of materials.

The total expenditure level for all programs is

$$C^* = \sum_{m=1}^{8} C^*_m = \sum_{m=1}^{8} \sum_{J} C^*_{mJ} O_i$$

or

$$C^* = \sum_{i=A}^{R} C^*_i = \sum_{i=A}^{R} \sum_{m=1}^{8} \sum_{All\ J\ O_i} C^*_{mJ} O_i$$

C. Summary of Chapter III

This chapter has examined how the model was applied to gather data in Radnor during school year 1967-68. In all, there were seven steps required. A prior step, study of the activities and programs at Radnor, was essential as a point of departure. Then five overall health and physical education objectives were devised and valued relative to each other. The next operation consisted of relating the health and physical education activities to the overall objectives. This anchoring process allowed the overall values to be distributed to the activities once the importance of the activities to each other (along production lines) was determined. Then performance outcomes and costs were obtained, the latter at the program level.

There are several assumptions implicit in the way the data suggested by the model were derived and later manipulated. These assumptions are:

1. The decision-maker has perfect knowledge of pupil needs and their importance to individuals. It is also assumed that this knowledge is reflected by the set of values attached to the overall objectives.
2. The values assigned represent an internally consistent set of relative scores.

3. An appropriate definition of system output is value produced by the system.

4. System activities are noninteracting.

5. Production and costs are tied to the annual budget cycle.

6. Efficiency for school systems is a desirable goal, and providing resource allocation procedures that try to foster production is a preferred way to accomplish this.

In the next chapter the author uses school year 1967-68 information, collected at Radnor during the period February to May of 1968, to generate outputs from the model.

IV. MODEL OUTPUTS AND PRESENT YEAR EVALUATION

This chapter utilizes data derived from the Radnor case study. Basically, evaluation outputs are of two types. A first kind attempts to satisfy the natural curiosity of administrators to find out how well their system did at the termination of the school year. Generally, these evaluations are at a higher level of aggregation, i.e. the program level and the overall objective level. The second kind of evaluation is not designed to satisfy curiosity, but, rather, to present detail on cost-effectiveness relationships of activities. This flow of information represents one of the basic inputs for the budgeting process.

In Chapter III it was stated that costs were not retrievable from the Radnor accounting system at the activity level. This meant the cost-effectiveness data obtained from school year 1967-68 was at the program level.

Tables 2 and 3 provided $V(a_{mJ}O_{\ell})$ and $\hat{K}^*_{mJ}O_{\ell}$ values respectively. They are combined by multiplying each performance score by the maximum value attainable to form productivity or effectiveness outputs. The resulting products are the elements of Table 6 and are the basic inputs for much of the treatment in this chapter. The logic of the evaluations presented in this chapter is basically a systematic movement from the most general outputs down to those at the activity level.

Listed next is a description of the outputs directed toward answering the question - "How well did the system perform in 1967-68?".

output	description
1a.	Overall system effectiveness, by overall objective.

outputs	description
1b.	Overall system effectiveness, by program.
1c,	Overall relative system effectiveness, by overall objective.
1d.	Overall relative system effectiveness, by program.
2a.	Overall objective effectiveness, by program.
2b.	Overall objective relative effectiveness, by program.
3a.	Overall objective effectiveness, by activity.
3b.	Program effectiveness, by activity.
3c.	Overall objective relative effectiveness, by activity.
3d.	Program relative effectiveness, by activity.
4a.	Overall system effectiveness-cost ratio.
4b.	Program effectiveness-cost ratios.
4c.	The Elasticity of Cost-Effectiveness.
5a.	The 1967-68 cost-effectiveness point, by program.

Outputs grouped in sets 1 and 2 were aimed at providing assistance to the decision-maker in evaluating 1967-68 performance. Group 3 was primarily detail provided for those operating the programs. Detail of this nature is presented in Appendix D. It is interesting to note that the concept of "relative effectiveness" at the activity level reduces to the performance score, $\hat{K}^*_{mJ}O_{i}$, since

$$E^*_{mJ}O_{i} = (\hat{K}^*_{mJ}O_{i})\left[V(a_{mJ}O_{i})\right] ,$$

and

$$REL(E^*_{mJ}O_{i}) = (\hat{K}^*_{mJ}O_{i}) \left[V(a_{mJ}O_{i})\right] / V(a_{mJ}O_{i}).$$

A. Overall System Effectiveness, by Overall Objective and Program

Overall system effectiveness is synonymous with overall system productivity and is the sum of the production elements across the system; that is,

$$E^* = \sum_{m=1}^{8} \sum_{J} (\hat{K}^*_{mJ}O_{i}) \left[V(a_{mJ}O_{i})\right] = 486.1,$$

TABLE 6

VALUE PRODUCED BY ACTIVITY, PROGRAM AND OVERALL OBJECTIVE

	Annual Screening		Physical Examination		Communicable and Infectious Disease		Emergency	
O_A	α_{11}	10.1	α_{21}	8.6	α_{34}	6.8		
	α_{12}	9.5	α_{22}	8.6	α_{33}	0.0		
	α_{13}	9.3	α_{23}	8.2				
			α_{24}	9.5				
			α_{25}	9.5				
		28.9		44.4		6.8		
O_B	α_{14}	4.1	α_{26}	3.0	α_{35}	6.6	α_{44}	11.0
	α_{15}	3.3	α_{27}	5.5	α_{36}	5.3	α_{45}	5.5
	α_{16}	4.2	α_{28}	2.5	α_{37}	5.5	α_{46}	5.5
	α_{17}	2.2	α_{29}	4.4				
		13.8		15.4		17.4		22.0
O_C							α_{41}	65.9
							α_{42}	39.1
							α_{43}	29.6
								134.6
O_D	α_{14}	8.2	α_{29}	13.1	α_{32}	6.6		
		8.2		13.1		6.6		
O_E		50.9		72.9		30.8		156.6

Follow-up	Health Education	Physical Education	Adapted Physical Education	Other	Total
			a_{81} 9.1	91 0.0	
			9.1	0.0	89.2
a_{51} 5.0			a_{82} 1.9	a_{92} 0.0	
5.0			1.9	0.0	75.5
					134.6
	a_{61} 11.8	a_{75} 15.2	a_{83} 14.2		
	a_{62} 6.3	a_{76} 8.7			
	18.1	23.9	14.2		84.1
		a_{71} 24.5	a_{84} 16.4		
		a_{72} 23.3			
		a_{73} 21.0			
		a_{74} 17.5			
		86.3	16.4		102.7
5.0	18.1	110.2	41.6	0.0	486.1

or, alternatively,

$$E^* = \sum_{i=A}^{R} \sum_{m=1}^{8} \sum_{\text{All } J\ O_i} (K^*_{mJ} O_i) \left[V(a_{mJ} O_i) \right] = 486.1.$$

When looking at programs, the first type of E^* formulation is preferable but when examining the productions of overall objectives the alternative expression is more meaningful. The contribution of production of overall objectives to E^* is shown in Table 7. Also presented in this table is relative productivity, REL(E^*).

Effectiveness figures, E^*_m, did not convey any particular meaning to the decision-maker, due to the fact that he had no standard by which to relate the findings. Two types of standards could have been utilized. The first and most natural way to compare E^*_is would be to compute the comparable figure for 1966-67. In Radnor's case, this was not possible since 1967-68 was the first year this kind of data were collected. A means of comparison would be to express the actual production figures relative to what productivity would have been assuming perfect performance. These relative effectiveness values were computed to provide evaluative information to the Assistant Superintendent about the productivity of the overall health and physical education objectives.

The Emergency Objective, O_C, was produced at nearly perfect levels of performance. Health Eduction, O_E, as an overall system objective, had the largest deficiencies in terms of relative effectiveness. Overall relative effectiveness was at the 0.81 level, indicating plenty of possibilities for increasing productivity.

Table 8 examines the productivity of programs in a similar vein. The Emergency Program, as was expected, was the best on any productivity

TABLE 7

SYSTEM EFFECTIVENESS AND RELATIVE EFFECTIVENESS, BY OVERALL OBJECTIVE

OVERALL OBJECTIVE	EFFECTIVENESS	MAXIMUM PRODUCTION POSSIBLE	RELATIVE EFFECTIVENESS
O_M	$E_i^* = \sum_{m=1}^{8} \sum_{\text{All } J\ O_i} (\hat{K}^*_{mJ} O_i) \left[V(a_{mJ} O_i)\right]$	$V(O_i)$	$REL(E_i^*) = \sum_{m=1}^{8} \sum_{\text{All } J\ O_i} (\hat{K}^*_{mJ} O_i) \left[V(a_{mJ} O_i)\right] / V(O_i)$
O_A	89.2	109.9	0.81
O_B	75.5	100.3	0.75
O_C	134.6	140.0	0.96
O_D	84.1	125.0	0.82
O_E	102.7	125.1	0.82
Total or Average	486.1	600.3	0.81

TABLE 8

PROGRAM EFFECTIVENESS AND RELATIVE EFFECTIVENESS

PROGRAM	EFFECTIVENESS	MAXIMUM PRODUCTION POSSIBLE	RELATIVE EFFECTIVENESS
P_m	$E_m^* = \sum_J (\hat{K}_{mJ}^* O_i) [V(a_{mJ} O_i)]$	$\sum_J V(a_{mJ} O_i)$	$REL(E_m^*) = \sum_J (\hat{K}_{mJ}^* O_i) [V(a_{mJ} O_i)] / \sum_J V(a_{mJ} O_i)$
P_1	50.0	69.6	0.73
P_2	72.9	88.4	0.82
P_3	30.8	45.0	0.68
P_4	156.6	162.0	0.97
P_5	5.0	5.3	0.94
P_6	18.1	31.6	0.57
P_7	110.2	134.9	0.82
P_8	41.6	51.5	0.81
P_x	0.0	12.0	0.00
Total or Average	486.1	600.3	0.81

criterion. It so happens that this program was the only producer of the overall objective of the same name. The Health Education Program, P_6, exhibited a poorer production record than the overall objective of the same name, indicating that health education activities incorporated into other programs were producing at an average level of relative effectiveness greater than the level in program P_6 itself (0.57). This also pointed out the need for someone in the Radnor system to coordinate the health education efforts.[77]

Some of the problems in programs such as Annual Screening (P_1) and Communicable and Infectious Disease (P_3) could easily have been resolved. Some of the lower scores in P_1 resulted from the follow-up procedures. For instance, the nurse was using expert judgment and receiving a low performance criterion score. Subsequent iterations of this model should be based on a more thorough discussion of criteria at several levels so as to be more realistic. As was pointed out earlier, detailed output by activity was less meaningful for the decision-maker in this study. These data are given in Appendix D.

B. Overall Objective Effectiveness by Program

A cross classification showing the production and overall objectives allowed the decision-maker to see which programs were directed toward which overall objectives and the relative effectiveness of these endeavors. Table 9 shows the distributions.

While the relative productivity of Appraisal (O_A) was 0.81, it is clear that the Communicable and Infectious Disease Program (P_3) was a low contributor.

[77] The Assistant Superintendent for Curriculum had indicated that this was planned for school year 1969-70.

TABLE 9

EFFECTIVENESS AND RELATIVE EFFECTIVENESS BY OVERALL OBJECTIVE AND PROGRAM

PROGRAM (P_m)	A		B		C		D		E	
	$E^*_m O_A$	REL($E^*_m O_A$)	$E^*_m O_B$	REL($E^*_m O_B$)	$E^*_m O_C$	REL($E^*_m O_C$)	$E^*_m O_D$	REL($E^*_m O_D$)	$E^*_m O_E$	REL($E^*_m O_E$)
P_1	28.9	0.96	13.8	0.60	-	-	8.2	0.50	-	-
P_2	44.4	0.91	15.4	0.67	-	-	13.1	0.80	-	-
P_3	6.8	0.47	17.4	1.00	-	-	6.6	0.50	-	-
P_4	-	-	22.0	1.00	134.6	0.96	-	-	-	-
P_5	-	-	5.0	0.94	-	-	-	-	-	-
P_6	-	-	-	-	-	-	18.1	0.57	-	-
P_7	-	-	-	-	-	-	23.9	0.76	86.3	0.83
P_8	9,1	1.00	1.9	0.40	-	-	14.2	0.90	16.4	0.75
Total or Average	89.2	0.81	75.5	0.75	134.6	0.96	84.1	0.67	102.7	0.82

An inspection of Appendix D would indicate that certain appraisal activities in P_3 had low performance ratings. This was due to the judgment that venereal disease was not a problem for the Radnor school population, and, therefore, activities directed at this problem were minimal. Therefore, unless the dimensions of the problem change, there seems to be little reason to consider activity changes with regard to this aspect of O_A.

The overall objective, Follow-Up (O_B), was produced in six of the eight programs. Actually, the one activity in the Follow-Up Program (P_5) is a residual activity. Problems with follow-up appeared to be more critical in programs P_1, P_2 and P_8. The Annual Screening Program (P_1) and the Physical Examination Program (P_2) actually performed a great deal better than the scores indicated. This is based on a realization that record-keeping for purposes of running programs such as these could not be expected to meet criteria for systematic record keeping. It was concluded that the amount of effort required to modernize the health record system would not be worth the effort. One suggestion, however, was that more care should be exercised by physicians when completing forms for pupils, and clear recommendations should be set forth when the doctors have something to specify about the care of the pupils.

In P_8(the Adapted Physical Education Program) the follow-up was rated low due to a lack of information. The author suggested that if the program was worth doing, the benefits of the program should have been demonstrated.[78]

Comment on the Emergency Objective (O_C) has been given previously.

While Health Education as an overall objective (O_D) was produced in six programs, only the activities in the Adapted Physical Education Program (P_8) received a high score (0.90). The Assistant Superintendent indicated that someone would soon be brought in to assume coordination and development of these activities. One way to approach this problem would be to devise a "health education test" to determine how deficient the Radnor students actually are in health education. It is conceivable that children who are bombarded by many sources of information may know a great deal more than is generally supposed. At least a survey of this nature would throw light on the Health Education needs of the Radnor student population.

Relative productivity of the Physical Education Overall Objective was at level 0.82. Discussions with the Physical Education Coordinator indicated that this was not a bad score, especially in view of the activities involved. More will be said about this when costs are introduced.

As was indicated before, the decision-maker in most circumstances should not be overly interested in detailed evaluation for activities.

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[78]This program was mandated by the State beginning with school year 1967-68. While Radnor did have some ongoing activities, there was some skepticism as to the merits of the program relative to those of other programs. The Radnor staff did generally want to give the program a trial, but it is interesting that the State can mandate a set of activities such as these when in a particular setting a minimal nutrition level would be much more relevant.

In this vein it should be emphasized that no statistic has intrinsic worth. The utility or worth of a statistic is derived from two factors: 1) the importance of the question it is designed to answer, and 2) the extent to which it answers the question. The statistics generated in this chapter are descriptive and are primarily of value in the specific Radnor context. The statistics that relate productivity to cost tend to have more general interest since the dollar is the frame of reference.

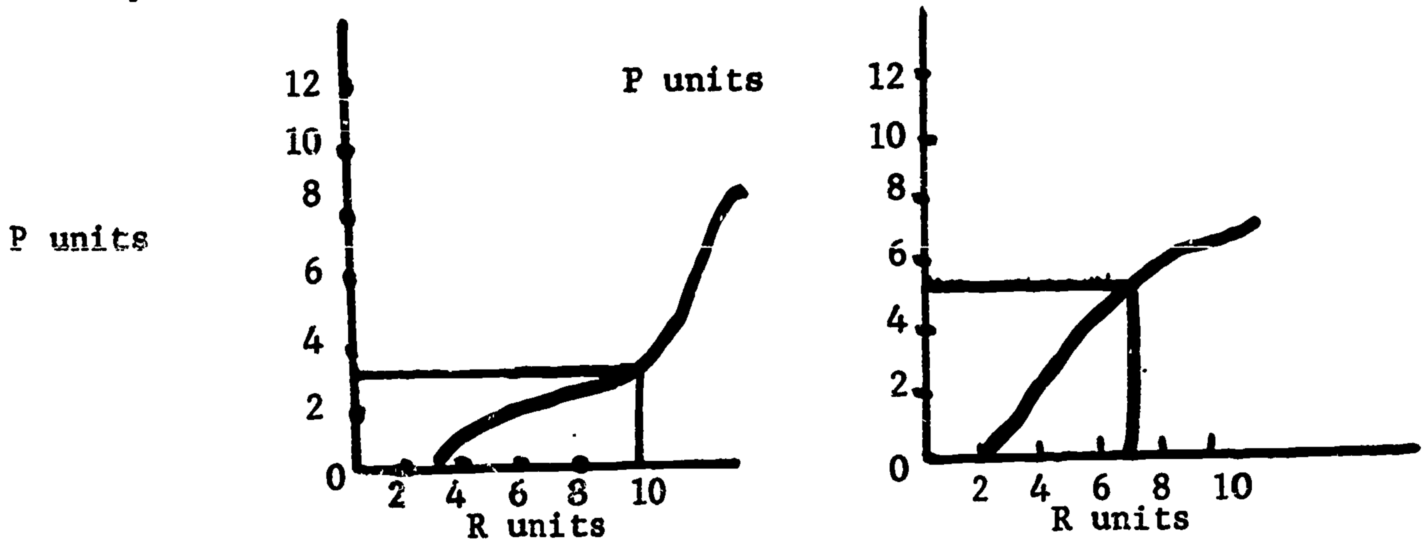
C. Cost-Effectiveness Evaluation

This section considers cost and effectiveness with the framework remaining ex post. Three types of outputs are considered here. First to be considered are some overall comparisons pertaining to programs. Then a measure called The Elasticity of Cost-Effectiveness is defined and some values are discussed. Lastly, the 1967-68 cost-effectiveness point is worked out by program.

The effectiveness-cost average per $1,000 for the Radnor health and physical education programs was 9.2 in 1967-68. That is

$$E^{*}/C^{*} \times \$1000 = \frac{486.1}{\$53,118} \times \$1000 = 9.2 .$$

Table 10 shows the same ratios by programs. Here the ratio is defined as $E^{*}_{m}/C^{*}_{m} \times \$1000$. It is evident from an inspection of Table 10 that programs differed widely in amounts of production per unit of cost they produced during 1967-68. Production per dollar was highest in the Emergency Program (P_4) and lowest in the two physical education programs (P_7 and P_8). It is important to stress that these figures can only be put in perspective by examining the respective effectiveness-cost curves. For example, consider the curves of Figures 10a and 10b. The left hand situation represents a case where the decision-maker has spent 10 units of resources for a production of 3 (P units), while the right hand sketch



Figures 10a and 10b Cost-Effectiveness Curves

indicates a production of 5 (P units) for 7 resource units. The respective ratios are $\frac{3}{10}$ and $\frac{5}{7}$. It is clear that the decision to spend at particular levels in the future, ceteris paribus, depends on the incremental relationships between effectiveness and cost, and not the present-year ratios.[79] Therefore, Table 10 was not helpful with regard to 1968-69, but did give the superintendent a feeling for "where the system was".

One way to evaluate past performance is to look at the system "with and without" the particular element being evaluated. This notion is suggested many times in the literature, especially in the literature of water resource development.[80] This is as close to marginal analysis as

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[79] This statement holds for ongoing program activities, but as was pointed out in discussions of Cases 8 and 9, project-type activities must be considered with regard to the remaining developmental costs and not merely incremental differences from the status quo. If the situation rests on a consideration of the activity before anything has been developed, then the full developmental cost is relevant when assessing project-type activities.

[80] For example, Otto Eckstein, Water Resource Development, (Cambridge: Harvard University Press, 1965), pp. 51-52.

can be expected when dealing with discrete activities and programs. The resulting comparisons resemble the elasticity measures that are abundant in economics. The Elasticity of Cost-Effectiveness is defined as

$$(E/C)_m = \frac{E_m^*/E^*-E_m^*}{C_m^*/C^*-C_m^*} ,$$

where

$$E_m^* = \sum_J (\hat{K}_{mJ}^* O_i)(V(a_{mJ} O_i)) ,$$

$$E^* = \sum_{m=1}^{8} \sum_J (\hat{K}_{mJ}^* O_i)(V(a_{mJ} O_i)) ,$$

$$C_m^* = \sum_J C_{mJ}^* O_i ,$$

and

$$C^* = \sum_{m=1}^{8} \sum_J C_{mJ}^* O_i .$$

For convenience let

$$E_m^* = \Delta E,$$

$$E^* = E,$$

$$C_m^* = \Delta C,$$

and

$$C^* = C.$$

The Elasticity of Cost-Effectiveness is defined as

$$(E/C)_m = \frac{\Delta E / E-\Delta E}{\Delta C / C-\Delta C} \quad ; \quad \begin{matrix} \Delta E < E \\ \Delta C < C \end{matrix}$$

$$= \frac{\Delta E(C-\Delta C)}{\Delta C(E-\Delta E)}$$

$$= \frac{C\Delta E - \Delta C\Delta E}{E\Delta C - \Delta C\Delta E} .$$

Other elasticity measures, such as the Elasticity of Demand, assume that the factor $\Delta C \Delta E$ is of extremely small magnitude and drop it from consideration. In the present context, however, it is the very essence of the problem that $\Delta C \Delta E$ cannot be taken as inconsequential. If the expression is separated differently, the results are more meaningful:

$$(E/C)_m = \frac{\Delta E(C-\Delta C)}{\Delta C(E-\Delta E)} = \frac{\Delta E}{\Delta C} \cdot \frac{C-\Delta C}{E-\Delta E} .$$

Now the multiplication is reversed and

$$(E/C)_m = \frac{\frac{\Delta E}{\Delta C}}{\frac{E-\Delta E}{C-\Delta C}} \gtreqless 1; \qquad \begin{matrix} C > \Delta C > 0 \\ E > \Delta E > 0 \end{matrix} .$$

The numerator is the ratio of the effectiveness to the cost of the element being evaluated and the denominator is the ratio of the rest of the system's effectiveness to its cost. When the ratio of the ratios is unity, the program being evaluated does not alter the average effectiveness-cost ratio for the system. A ratio less than 1.0 reflects the evaluation of a program producing at a lower rate per dollar than the average of the other programs comprising the system. If the ratio is greater than 1.0, then this indicates that a program is being evaluated which has a higher rate of productivity per unit of input than the average of the remaining system programs.

Table 11 shows the results of the calculation of the Elasticity of Cost-Effectiveness. This measure is also useful in Chapter V as a means of examining the implications of various controlled changes. The wide disparity among the elasticity values indicates that program production gains could be realized by careful consideration of cost-effectiveness criteria. The two physical education programs (P_7 and P_8) were conspic-

TABLE 10

COST, EFFECTIVENESS AND EFFECTIVENESS-COST, BY PROGRAM

Program	Cost ($)	Effectiveness	Effectiveness / Cost ($1,000)
P_m	C^*_m	E^*_m	E^*_m / C^*_m x$1000
P_1	2,961	50.9	17.2
P_2	3,385	72.9	21.5
P_3	913	30.8	33.7
P_4	3,595	156.6	43.6
P_5	180	5.0	*
P_6	3,000	18.1	6.0
P_7	27,259	110.2	4.0
P_8	11,825	41.6	3.5
Total or Average	$53,118	486.1	9.2

TABLE 11

THE ELASTICITY OF COST-EFFECTIVENESS, BY PROGRAM

Program P_m	Elasticity of Cost-Effectiveness $(E/C)_m$
P_1	1.98
P_2	2.59
P_3	3.87
P_4	6.55
P_5	3.06
P_6	0.65
P_7	0.28
P_8	0.33

uous when their production contributions per unit of input were compared to those of the remainder of the system.

The last evaluative data from school year 1967-68 are the cost and effectiveness figures from Table 10. Ordinarily, if expenditures were available at the activity level, there would be one effectiveness-cost point $\{C^*_{mJ}O_i^{:}, E^*_{mJ}O_i^{:}\}$ for each activity. The eight points taken from Table 10 are, in general, $\{C^*_m, E^*_m\}$. In the next chapter other points in the neighborhood of $\{C^*_m, E^*_m\}$ are found and an attempt is made to sketch that portion of the effectiveness-cost curve so that insights for budget allocations can be found.

Before entering Chapter V, it is appropriate to consider a basic assumption employed throughout the last part of Chapter IV. The assumption is that effectiveness per dollar of cost is a suitable measure of efficiency. This is not an attempt to argue that it is the best measure, but that several factors substantiate its reasonableness as a measure for school system evaluation. First, it must be conceded that school inputs are often associated with intangible and incommensurable outcomes. Second, the basis of micro-economic analysis is marginal comparison. On the production side this is usually a measure of cost per physical unit produced. The effectiveness concept used in this dissertation resulted from an attempt to cope with the problems of intangible and incommensurable outputs and, at the same time, allow system alternatives to be considered. The major and most vulnerable assumption deals with the underlying concept of educational value. Its vulnerability, however, rests with the measurement techniques and not with the conceptualization. When more adequate values can be generated from the decision-maker's preference function, better economic comparisons can be realized. The next chapter considers the subsequent period allocation problems and the sensitivity of model outputs to changes in the decision-maker's value function.

V COST-EFFECTIVENESS ALLOCATIONS FOR 1968-1969

Earlier in this study it was advocated that the purpose of evaluation is to provide bases for improvement. This chapter deals with the transition from evaluating school system behavior, after the completion of the school year to immediate considerations for the next year.[81] The logic underlying these procedures is found in the relationship between Cases 8 and 9 of Chapter II. Case 9 developed the basis for evaluating ongoing school systems, and Case 9 outputs, based on year t evaluation, are those that are required as input elements for Case 8 allocations in year t+1.

The plan of this chapter is to present data relevant to the effectiveness-cost curves for each program. A listing of incremental relationships between effectiveness and cost for segments of effectiveness-cost curves is assembled and analyzed under three budget strategies: 1) the best allocation strategy, 2) the suboptimization strategy, and 3) the "make-everybody-happy" strategy. The implications of these strategies are then discussed and sensitivity analysis is utilized to explore outcome implications for selected modifications of the decision-maker's value structure.[82]

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[81] Realistically school budgets are not prepared by a single decision at the end of the school year. This does not lessen the need for improvements in the allocation process. It does imply that barometers (performance) measures) are needed to predict the $\hat{K}^{*}_{mJ}O^{*}_{*}$ values for the end of school yeart.

[82] Sensitivity analysis has been suggested as a way to consider the responses of models to variations in assumptions and parameter values. By this means, feedback can be obtained as to the appropriateness of applying the model to systems with parameter values other than those studied. Some of the authors suggesting this type of analysis are:

Hamburg, op.cit., p. 14.

Teichroew, Daniel, An Introduction To Management Science, (New York: John Wiley & Sons, Inc., 1964), pp. 259-260.

A. Effectiveness-Cost Data For Programs

The Nursing Coordinator and the Physical Education Coordinator were interviewed so that effectiveness-cost information could be obtained. The Assistant Superintendent was interviewed for information relevant to the Health Education Program. The data shown below indicate the type of information that was presented to the respondents in order to help them with their estimates.

Communicable & Infectious Disease	Maximum Production	Production	%
Detect venereal disease	7.2	2.2	30
Detect tuberculosis	7.2	6.8	95
Follow-up to parents	6.6	6.6	100
to teachers	5.3	5.3	100
to phys. ed.	5.5	5.5	100
Health education spill-over	13.2	6.6	50
Overall average performance			73

In addition to the information on the activities in the program, the respondent was shown a graph like the one in Figure 11. The graph showed the data corresponding to the program's effectiveness-cost point from 1967-68. Then the graph was discussed and the respondent was told that she (he) would be asked some questions about how average performance would change as a result of changes in costs. The term "average performance" was used since it seemed to convey more meaning to the respondents

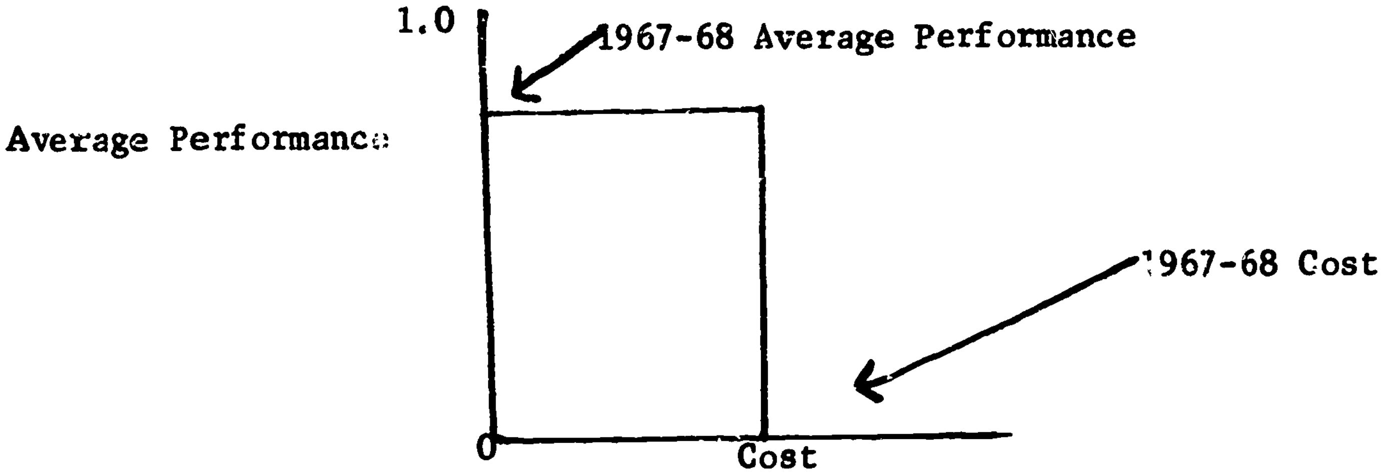

Figure 11. Basis for Effectiveness-Cost Discussions

than terms such as "production," "productivity," or"effectiveness." The respondent was asked, as an opening question, "what would happen to average performance in Program m if you were to have an additional $1000 available? Whatever the response, a series of follow-up questions were asked such as "and why would performance go up?", or "what would improve that allows performance to rise?", etc. The procedure was continued by discussing the addition of $2000, etc. Cuts in program resource levels were also treated in the same manner.

The estimates that resulted from the interviews with the three Radnor respondents are found in Appendix E. All things considered, the respondents seemed comfortable in the neighborhood of the 1967-68 effectiveness-cost point and less comfortable as the discussion moved along the cost-axis in either direction. Generally, there was a "crisis feeling" about the present level of resources. That is, respondents were very willing to discuss additions to the expenditure level, but reductions tended to elicit a rigid response. This pattern was probably due to one or both of the following reasons:

1. Administrators generally tend to feel that they can't get along with less resources.
2. The Radnor respondents felt that programs were operating at levels of return where small reductions in expenditures would be accompanied by large decrements of effectiveness.

B. Incremental Effectiveness-Cost Data

The relationships and estimates of Appendix E were separated into their components. Discussion has been focused on relative effectiveness or average performance but these outputs have to be put into absolute terms. Table 12 shows the incremental relationships ranked in order of gain per $1,000.

These estimates were translated into the framework of Case 8. In general, the decision-maker will add resources to the program as long as the additions continue to promise the best productivity per dollar. It is important to bear in mind that the human costs should be considered. When a decision-maker is overly bound to cost-effectiveness recommendations and therefore is not discriminating about when to initiate program changes, apparent gains can be swamped by ignoring human costs(H_m).

TABLE 12

EFFECTIVENESS-COST ESTIMATES, RANKED IN ORDER OF GAIN PER THOUSAND DOLLARS

Program and Increment (Decrement)	Magnitude of Estimated Gain(Loss)	Estimated Cost Associated with Estimated Gain (Loss)	Estimated Gain (Loss) per 1000 Dollars
1-2*	8.4	1.0	8.4
6-2	7.0	1.5	4.7
7-1	4.0	1.0	4.0
1-1	3.5	1.0	3.5
4-1	3.2	1.0	3.2
7-2*	2.7	1.0	2.7
3-1	0.9	0.5	1.8
8-3*	5.2	3.0	1.7
7-3	4.0	3.0	1.4
7-4*	2.7	2.0	1.4
2-1	0.9	1.0	0.9
2-2*	0.9	1.0	0.9
2-3*	0.9	1.0	0.9
3-2	0.4	0.5	0.8
8-2	1.5	2.0	0.8
6-1	0.3	0.5	0.6
8-1	0.5	1.0	0.5
8	(5.7)	1.0	(5.7)
7	(9.4)	1.0	(9.4)
7	(10.8)	1.0	(10.8)
7	(13.5)	1.0	(13.5)
4	(8.1)	0.5	(16.2)
2	(28.3)	1.0	(28.3)
3	(19.4)	0.5	(38.8)
4	(51.8)	0.5	(103.6)

NOTE: In some instances the increment stands alone and in others the increment is related to a prior increment. To incorporate this into the analysis the increments are numbered. For example 7-1 is the first increment for program 7. An asterisk indicates dependence on a prior increment.

Before examining budget strategies, some prior observations should be emphasized. Human nature would seem to dictate that when an administrator is asked what would happen if his accustomed level of resources were reduced, he would respond that the operation <u>must</u> suffer drastically. This seems to be borne out by the large estimated losses in productivity associated with small reductions from 1967-68 level of expenditures. Also, the coordinators indicated that most of the programs were near a leveling-off part of the effectiveness-cost curve, since gains associated with increased resource levels were far less than the program average without the incremental expenditure.

The data also suggested that the present allocation (1967-68) was to some extent inconsistent with the superintendent's preferences. This would appear to be the price he must pay for insisting that some overall objective, $O_{\cdot}$, must be produced at level $(\hat{K}^{*}_{mJ} O_{i}^{\cdot})$ $[V(a_{mJ} O_{i}^{\cdot})] \geq \theta_{i}^{\cdot}$. A policy or state-mandated program could impose this type of production constraint.

Two sketches showing the relationship between productivity and cost are given in Figure 12. The left hand diagram describes the relationship between total productivity and cost, while the right hand diagram indicates the relationship between marginal productivity and cost, with both curves assuming an underlying diminishing marginal productivity. The total production curve rises to its maximum when cost is C_2, with marginal production at C_2 being equal to zero. If production continues, the implication drawn from the marginal product curve is that of a lesser output at $C > C_2$ than at C_2.

An ongoing program may be near its maximum but it is difficult to tell if it has passed a maximum in cost-effectiveness analysis. All that can be observed is that the marginal productivity of proposed incremental expenditures is small and decreasing. Generally a zero increase in effectiveness associated with a proposed increment of cost suggests that

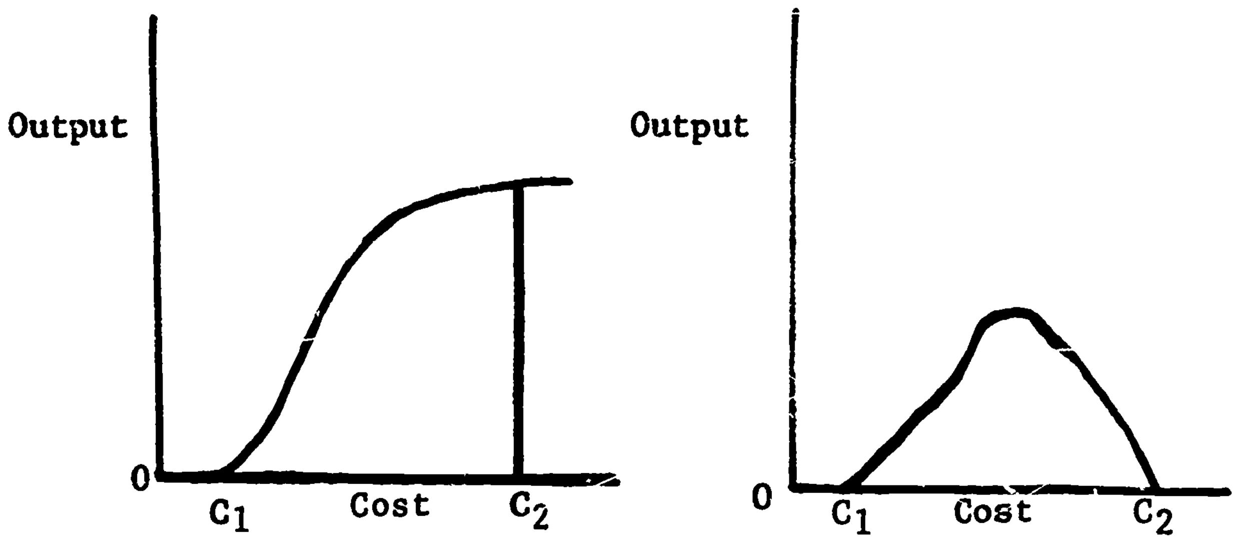

Figure 12. Cost-Productivity Relationships

expansion of the effort be discontinued.

In cost terms, the marginal cost curve intersects the average cost curve at the latter's minimum. This is no more than a warning point. Under idealized pure competition conditions the firm will produce past the point of minimum average costs as long as the marginal cost is less than the unit revenue.[83] With regard to school systems, the value of a unit of output must have the same meaning to the consumer as the producer if an optimal arrangement is to be obtained. There are practical deterrents to this since even dollars have different subjective values to different people as well as to the same person under different circumstances. The "second best" way to make these comparisons would be to strive for equality of educational value per unit of cost across the

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[83]Sidney Weintraub, Intermediate Price Theory, (Philadelphia: Chilton Books, 1964), pp. 45-48.

various outputs produced by the educational system. At worst, this would yield an optimal productivity within the educational enterprise, given a particular set of values.

C. Budget Strategies

A budget is a plan showing how much money is intended for allocation to the programs of a system. This study does not attempt to allocate the 1968-69 Radnor health and physical education budget, which would be presumptuous for many reasons. The present section does make a supposition about the budget level, and, given the particular budget level, the implications of various budget strategies are explored. Data of Table 12 are utilized as the three budget strategies are considered. These strategies are:

1. The B(best) strategy asks the decision-maker to allocate a $6,000 increase to programs by finding the increment promising the best return per dollar from the remaining available alternatives at any given point in the allocation sequence.

2. The S(suboptimization) strategy asks the decision-maker to allocate an undetermined sum to the best available return per dollar in each program. This guarantees that every program will have a budgeted amount greater than its 1967-68 expenditure level.

3. The H(happy) strategy asks the decision-maker to allocate as much as is requested by each program, irrespective of return per dollar.

Each resulting allocation is assessed in terms of three criteria:

1. The overall system relative effectiveness

2. The overall system effectiveness-cost ratio

3. The Elasticity of Cost-Effectiveness

1. A $6000 Increase for Strategy B

To apply the mandates of strategy B the decision-maker examines the estimated gain per $1000 rankings in Table 12. He will select those increments that promise the highest payoffs as long as they do not exceed

$6000. He does not care which particular programs receive the $6000 increase from the 1967-68 expenditure level.

According to this strategy, the preferred allocation would be to select increments 1-1 and 1-2*(for para-professional assistance in the Annual Screening Program), 6-2 (for a part-time health education coordinator in the Health Education program, bearing in mind that this increment can be purchased without prior increment, 6-1), 7-1 (for equipment in the Physical Education Program), and 4-1 (for para-professional help in the Emergency Program). Those increments would expend $5,500 and therefore he cannot afford 7-2*. If 7-2* is so discrete that it cannot be broken into $500 package then he must select 3-1 or decide to leave $500 unexpended. The assumption is that 3-1 is selected (for classroom education on communicable and infectious diseases).

The overall health and physical education system's relative effectiveness rises from 0.81 in 1967-68 to 0.86 under strategy B. The effectiveness-cost ratio, however, would drop from 9.2 per $1000 in 1967-68 to 8.8. If spending $6000 in the best possible way lowers the average efficiency then the marginal efficiency is below the average efficiency for the 1967-68 version of the system. The results are consistent with the assessment that the system has passed the point of minimum average cost per unit. Under strategy B the $6000 was allocated to Programs 1, 3,4, 6 and 7. If the $(E/C)_m$ scores are compared to those of 1967-68 it is apparent that the intended distribution would lower the scores relative to 1967-68 for <u>all programs receiving additional money</u>. The one incremental exception is the equipment purchase for the Physical Education Program. This also suggests that the programs not receiving increases would rise in relative efficiency with respect to the dollar gainers. Elasticity of Cost-Effectiveness scores are found in Table 13 and lend substance to this contention.[84]

2. Strategy S

The suboptimization strategy asks the decision-maker to select the best increment from each program. He seeks efficiency, but only within programs, one at a time. A strategy such as this does gain in one respect since each program will participate in spending the budgetary increase.

TABLE 13

ELASTICITY OF COST-EFFECTIVENESS FOR 1967-68 AND STRATEGIES B AND S AND H, WITH SOME SUMMARY MEASURES

Program P_m	(E^*/C^*) 1967-68	$(E/C)_m$ Strategy B	$(E/C)_m$ Strategy S	$(E/C)_m$ Strategy H
P_1	1.98	1.51	1.64	1.87
P_2	2.59	2.70	2.26	1.76
P_3	3.87	2.75	2.99	2.51
P_4	6.55	5.29	5.75	6.48
P_5	3.06	3.19	3.46	3.91
P_6	0.64	0.62	0.68	0.69
P_7	0.28	0.32	0.38	0.37
P_8	0.33	0.35	0.29	0.32
REL(E)	0.81	0.87	0.88	0.90
E*/C*($000)	9.3	8.8	8.1	7.2

Although relative effectiveness for the health and physical education programs, overall, rises slightly to 0.88, the productivity per $1000 falls sharply to 8.1. Table 13 reveals the elasticity values for strategy B and comparable data from 1967-68,

84 Elasticity calculations are shown in Appendix F.

In the instance of strategy S, two programs exhibit lower scores than strategy B and six show higher scores. This is due to the $5000 intended for the Adapted Physical Education Program (P_8). An expenditure of $5000 in that manner would be so inferior (in economic terms) that other programs would end up "looking good" in a relative sense. The key figure is the overall production per $1000, which indicates the price that must be paid in order to suboptimize.[85]

3. Strategy H

The strategy suggesting that the decision-maker should give to the programs whatever they need is poor in general and is disastrous when marginal productivity is less than average productivity.

Overall relative effectiveness climbs to 0.90 but the rate of productivity per $1000 falls to 7.2 from 9.2 in 1967-68. The elasticity figures in Table 13 behave as would be expected. Programs receiving hypothetical allocations, above the $6000 allocated under strategy B, suffer according to the elasticity measure.

4. The Three Strategies

The three strategies, when compared, show what happens when economic considerations are ignored. The critical measure from an economic viewpoint is the overall ratio of production to cost. It seems that personnel administering programs, if they are not asked to consider economic criteria, will tend to examine overall relative effectiveness alone and not strive for a balance between effectiveness and cost.

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[85] The Follow-up Program (P_5) was not changed, yet its elasticity score rises as more money is put into the system for other programs.

The next section examines the sensitivity of model outputs to changes in the decision-maker's value structure.

D. Sensitivity Analysis

This section deals with some changes in the preferences of the decision-maker. The purpose is to determine the response of selected output measures to changes in the value structure which was used. It is apparent that changes in preferences could transform inefficient programs into efficient producers and vice-versa. Two value structure changes were studied.

1. The Emergency Objective (O_C) was nearly perfect in terms of relative effectiveness and appeared to be high in effectiveness per dollar. The parameter $V(O_C)$ was tripled to study the influence of a substantial magnification of the importance of an overall objective which reflected high system performance.

2. The Physical Education Objective (O_E) was a little above average in relative effectiveness but was low in efficiency according to elasticity measures. The parameter $V(O_E)$ was tripled to study the influence of a substantial magnification of the importance of an overall objective which reflected average system performance.

Each of the newly generated value systems were examined in terms of:

1. Overall system relative effectiveness
2. Overall system effectiveness-cost ratio
3. The elasticity of cost-effectiveness
4. The allocation of $6000 under strategy B.
   a. The resulting overall system relative effectiveness
   b. The resulting overall system effectiveness-cost ratio
   c. The resulting elasticity of cost-effectiveness values, if necessary

1. Tripling $V(O_C)$

When the overall objective O_C is tripled in value, the contributions of all activities related to O_C are magnified. The resulting value structure is presented next, along with the 1967-68 base value set.

O_i	$V(O_i) \mid 3\ (V(O_C))$	1967-68
O_A	109.9	109.9
O_B	100.3	100.3
O_C	420.0	140.0
O_D	125.0	125.0
O_E	125.1	125.1
TOTAL	880.3	600.3

The procedure involved a distribution of the revised total value to the system activities. The distribution structure provided in Chapter III (Table 2) was carried over to this situation. In this instance three activities were involved since only they contributed to O_C. These activities were in the Emergency Program, (P_4), although this program also has three additional follow-up activities that were not involved in the value modification. The resulting productivity potentials, by program, were:

P_m	$\sum_{i=A}^{R} V(a_{mJ}O_i)$
P_1	69.6
P_2	88.4
P_3	45.0
P_4	442.0
P_5	5.3
P_6	31.6
P_7	134.9
P_8	51.5
P_x	12.0
TOTAL	880.3

Although performance scores were carried over from the 1967-68 case study, the value produced in P_4 changed, even though production scores for the other programs were held constant.

P_m	E_m
P_1	50.9
P_2	72.9
P_3	30.8
P_4	425.9
P_5	5.0
P_6	18.1
P_7	114.1
P_8	41.6
TOTAL	760.3

The overall system relative effectiveness rises to 0.86 from 0.81 in school year 1967-68, solely as a result of the change in value structure. The ratio of production per $1000 rises to 14.3, but this is largely a function of the arbitrary value change. A standard such as 14.3 would be very useful, however, in assessing the effects of system changes given the new value structure.

The Elasticity of Cost-Effectiveness is useful even though the 1967-68 context has been altered, since the ratio is interpreted apart from any particular school context. The resulting elasticity outcomes were:

P_m	$(E/C)_m$	$(E/C)_m$ (1967-68)
P_1	1.22	1.98
P_2	1.56	2.59
P_3	2.41	3.87
P_4	17.54	6.55
P_5	1.95	3.06
P_6	0.41	0.64
P_7	0.17	0.28
P_8	0.20	0.33

These elasticities were based on the 1967-68 program expenditures. The 1967-68 elasticities are shown on the right as a basis for comparison. The elasticity shift is in the direction of P_4 and, of course, away from all other programs.

On the assumption that the revised value structure with $3[V(O_C)]$ was the appropriate set of values and the decision-maker was faced with the allocation problem treated earlier in this chapter, the budget strategies can be re-examined.

First the decision-maker considered how he would allocate the $6000 increase over the 1967-68 expenditure level by applying the mandates of strategy B. Then he needed a revision of Table 12 that reflected the same performance-cost relationships but embraced the preference shift. Table 14 provides these revised values. It is interesting that the only realignment among the increments was that 4-1 jumped from sixth to first place. And were the hypothetical conditions imposed upon the decision-maker, the same purchases would have been made. Overall system relative effectiveness was elevated to the 0.90 level. Productivity per $1000 for the entire system of health and physical education programs would have been 13.5 as compared to 14.3 for school year 1967-68 (given the revised values for O_C).

This indicated that a rise in the valuation of a well-produced objective is not sufficient to elevate the overall system efficiency scores unless there is adequate opportunity for expenditure in the highly valued area. Since $REL(E_C)$ was already at the 0.97 level there was little room for expenditure on the activities contributing to O_C. The elasticity calculations are omitted in this instance since they convey little additional information.

TABLE 14

EFFECTIVENESS-COST ESTIMATES, RANKED IN ORDER OF GAIN PER THOUSAND DOLLARS:

$3[V(O_C)]$ CASE

Program and Increment (Decrement)	Magnitude of Estimated Gain(Loss)	Estimated Cost Associated With Estimated Gain (Loss)	Estimated Gain(Loss) per 1000 Dollars
4-1	8.8	1.0	8.8
1-2*	8.4	1.0	8.4
6-2	7.0	1.5	4.7
7-1	4.0	1.0	4.0
1-1	3.5	1.0	3.5
7-2*	2.7	1.0	2.7
3-1	0.9	0.5	1.8
8-3*	5.2	3.0	1.7
7-3	4.0	3.0	1.4
7-4*	2.7	2.0	1.4
2-1	0.9	1.0	0.9
2-2*	0.9	1.0	0.9
2-3*	0.9	1.0	0.9
32-	0.4	0.5	0.8
8-2	1.5	2.0	0.8
6-1	0.3	0.5	0.6
8-1	0.5	3.0	0.5
8	(5.7)	1.0	(5.7)
7	(9.4)	1.0	(9.4)
7	(10.8)	1.0	(10.8)
7	(13.5)	1.0	(13.5)
2	(28.3)	1.0	(28.3)
3	(19.4)	0.5	(38.8)
4	(22.1)	0.5	(44.2)
4	(141.4)	0.5	(282.8)

NOTE: In some instances the increment stands alone and in others the increment is related to a prior increment. To incorporate this into the analysis the increments are numbered. For example, 7-1 is the first increment for program 7. An asterisk indicates dependence on a prior increment.

2. Tripling $V(O_E)$

The procedures of this section are identical to those of the previous section. Here $V(O_C)$ was restored to its 1967-68 level and $V(O_E)$ was magnified threefold. The resulting preference function is given below and is accompanied by the 1967-68 values for purposes of comparison.

O_i	$V(O_i) \mid 3[V(O_E)]$	1967-68
O_A	109.9	109.9
O_B	100.3	100.3
O_C	140.0	140.0
O_D	125.0	125.0
O_E	375.3	125.1
TOTAL	850.5	600.3

When the new aggregate value total was distributed among programs the division was:

P_m	$\sum_{i=A}^{R} V(a_{mJ} O_i)$
P_1	69.6
P_2	88.4
P_3	45.0
P_4	162.0
P_5	5.3
P_6	31.6
P_7	341.5
P_8	95.1
P_x	12.0
TOTAL	850.5

The 1967-68 performance scores were applied to the revised value structure emphasizing O_E. The resulting productivity scores for programs were:

P_m	E_m
P_1	50.9
P_2	72.9
P_3	30.8
P_4	156.6
P_5	5.0
P_6	18.1
P_7	291.0
P_8	74.2
TOTAL	700.5

Overall system relative effectiveness rose to 0.82 compared to the 0.81 of 1967-68 when values were undistorted. This slight increase in overall relative effectiveness meant that the productivity-cost relationships in the two physical education programs were a little better than the system average. The ratio of production per $1000 was 13.2 and, as was pointed out earlier, has little interpretive value in isolation since it is largely a function of the magnitude of the values. This ratio would be useful as a basis for comparing contemplated alternative actions given this particular frame of reference, i.e. assignment of values.

The resulting elasticity measures were:

P_m	$(E/C)_m$	$(E/C)_m$ [1967-68]
P_1	1.33	1.22
P_2	1.71	1.56
P_3	2.62	2.41
P_4	3.97	17.54
P_5	2.11	1.95
P_6	0.44	0.41
P_7	0.67	0.17
P_8	0.41	0.20

A comparison of the two sets of elasticity figures showed that the increase in valuation caused a favorable shift toward programs P_7 and P_8, which were oriented toward O_E, while programs not producing O_E declined substantially.

This provided an opportunity to test the conclusion drawn from the case in which O_C was tripled. In that instance it was concluded that not only would an objective have to be magnified in value to influence allocations substantially, but also there would have to be available opportunities for expenditures in the over-values domain. In order to assess this, a new allocation of the $6000 was considered by constructing a new table similar to Tables 12 and 14. Table 15 lists these estimates based on the relative performance-cost curves used earlier.

When increments were ranked according to the values reflecting the shift toward O_E, the higher rankings contained a great deal of P_7, the Physical Education Program. The Adapted Physical Education Program, (P_8), needed more than the push it received from tripling O_E. But it should be pointed out that only one activity of the four in P_8 was influenced by the revaluation. The new allocation based on strategy B would be $2000 to P_7, $2000 to P_1, and $1500 to P_6. The total of $5500 fell short of the $6000 available but not many alternatives were available. Increment 3-1 was far down the list as a result of the change in valuation and the next two increments in line being too costly. A compromise decision was made to allocate only $5500.

The resulting overall health and physical education relative effectiveness score was 0.86, as opposed to 0.82 prior to the allocation of the $5500. The overall effectiveness per $1000 fell slightly to 12.6, versus 13.2 prior to the allocation. This indicates that the $5500 did not help average system efficiency.

TABLE 15

EFFECTIVENESS-COST ESTIMATES, RANKED IN ORDER OF GAIN PER THOUSAND DOLLARS:

$3[V(O_E)]$ CASE

Program and Increment (Decrement)	Magnitude of Estimated Gain (Loss)	Estimated Cost Associated with Estimated Gain (Loss)	Estimated Gain(Loss) Per 1000 Dollars
7-1	10.2	1.0	10.2
1-2*	8.4	1.0	8.4
7-2*	6.8	1.0	6.8
6-2	7.0	1.5	4.7
1-1	3.5	1.0	3.5
7-3	10.2	3.0	3.4
7-4	6.8	2.0	3.4
4-1	3.2	1.0	3.2
8-3*	9.5	3.0	3.2
3-1	0.9	0.5	1.8
8-2	2.8	2.0	1.4
8-1	1.0	1.0	1.0
2-1	0.9	1.0	0.9
2-2*	0.9	1.0	0.9
2-3*	0.9	1.0	0.9
3-2	0.4	0.5	0.8
6-1	0.3	0.5	0.6
8	(10.5)	1.0	(10.5)
4	(8.1)	0.5	(16.2)
7	(23.9)	1.0	(23.9)
7	(27.3)	1.0	(27.3)
2	(28.3)	1.0	(28.3)
7	(34.2)	1.0	(34.2)
3	(19.4)	0.5	(38.8)
4	(51.8)	0.5	(103.6)

NOTE: In some instances the increment stands alone and in others the increment is related to a prior increment. To incorporate this into the analysis the increments are numbered. For example, 7-1 is the first increment for program 7. An asterisk indicates dependence on a prior increment.

The resulting Elasticity of Cost-Effectiveness data were compared to the system prior to the $5500 allocation and the system under the 1967-68 preference function(i.e. prior to changing $V(O_E)$. These comparisons were:

P_m	$(E/C)_m$ (After $5500)	$(E/C)_m$ (Before $5500)	$(E/C)_m$ (1967-68)
P_1	1.04	1.33	1.98
P_2	1.84	1.71	2.59
P_3	2.83	0.63	3.87
P_4	4.27	3.97	6.55
P_5	2.28	2.11	3.06
P_6	0.44	0.44	0.65
P_7	0.72	0.67	0.28
P_8	0.46	0.41	0.33

In all instances, programs that did not receive part of the $5500 allocation ($P_2$, P_3, P_4, P_5, P_8) showed increased elasticity outputs relative to the new value set (i.e. $3[V(O_E)]$). Programs 6 and 7 stayed roughly the same, indicating that the proposed increments would keep them close to their previous efficiency levels. Program 1 would suffer in terms of efficiency according to the allocation proposal. This is due, in part, to the fact that its products were devalued as a result of the increased valuation of production. Also the 11.9 gain would cost $2000, this is a 6.0 rate of gain per $1000 and is far below the average 12.6 figure for all programs.

Perhaps the most interesting observation involved the Physical Education Program, P_7. Even with the tripling of potential value for most of its activities, the program is unable to absorb an increase in expenditure level in an efficient manner. It is true that $(E/C)_7$ rose to 0.72 from 0.28. But if the 0.72 is weighed against all other programs lumped together, the resulting comparison is 0.72 to 1.40 (which is the reciprocal of 0.72).

3. Sensitivity Analysis Conclusions

The conclusions that can be drawn from the sensitivity analysis are:

A. When an overall objective is overvalued (undervalued) relative to other overall objectives, it will affect relative productivity for the system as a whole but will not affect relative productivity for activities. The direction in which the system's overall relative productivity is pushed depends on the performance of the activities that are overvalued in relation to the average level of relative productivity for the system.

B. When an overall objective is overvalued (undervalued) relative to other overall objectives, it will affect efficiency for the system as a whole. This is due to the fact that efficiency is a function of production and cost. Changes in preferences cause changes in the values assigned to the outcomes produced by the activities. This, in turn, changes the aggregate value produced by the system and consequently efficiency is influenced. The analogy in the private sector would be an increase in price per unit of a given product altering efficiency relationships since it would then be efficient to produce more of the product, ceteris paribus.[86]

C. In order for a shift in valuation for an overall objective to influence the potential for allocating resources to the programs producing that overall objective, there must be opportunity in these programs. Opportunity is restricted when the programs producing the overall objective are producing at very high levels of relative productivity and/or when the available outlets will produce at low levels of productivity per unit of input.

D. Changes in the value structure are not sufficient to change the allocation pattern. Changes must be considered along with the resulting changes in output potential and the nature of the many production-cost relationships across the entirety of the system. When the relevant information has been supplied by each of the data files, the resulting allocation should be an improvement by virtue of being able to provide more educational production for the consumers of school services.

E. Summary

This chapter has taken the evaluation data of Chapter IV and used

[86] The "ceteris paribus" is more acceptable if the price increase is based on an increase in consumer demand and not an arbitrary price increase by the producer. A price rise in response to a real increase in consumer demand should represent increased profit for the producer. If, however, the price rise is arbitrarily administered by the producer, there may be a corresponding response in consumer demand. Whether or not the producer gains depends on the nature of the consumer response.

it as a basis for entry into the problem of improving next year's allocation. By using evaluation of the present state of the system as a baseline there is a presupposition that the decision-maker needs to have a clear idea of where he is before he can proceed to where he wants to go. This feeling permeates the entire study and is best evidenced by the relationship between effectiveness and cost. In order to make projections of cost-effectiveness it is helpful to know where you presently are. In the absence of this information the situation degenerates to an a priori decision structure ignorant of the system's immediate experiences.

The section on budget strategies demonstrated the practical implications to school administrators of alternative allocation strategies.

The sensitivity analysis indicated that values are important in evaluating systems of educational programs but other factors such as cost and performance are also important.

The last chapter provides a summary of the study, a set of recommendations to the Radnor Superintendent, and some suggestions for research related to this study.

VI SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This dissertation has focused on the problem of evaluation of the programs of ongoing school systems. A theory, specifying general relationships among the variables required for evaluation, was developed. In addition, the necessary and sufficient conditions for appropriate application of cost-effectiveness analysis were specified. The model suggested that four basic information files were essential to this type of analysis. These information files include 1) a set of valued overall objectives which serve as a standardizing parameter set against which evaluations are made, 2) a fundamental structure relating system activities to the overall objectives, 3) a set of performance criteria and a performance outcome for each criterion which determines the extent to which the activity produced what it was designed to produce, and 4) a set of activity expenditures.

Based on these concepts a program evaluation model was applied to a sub-system of a school system. This case study commented on the problems encountered in obtaining data for the information files required by the model to produce outputs for program evaluation based on educational and economic criteria.

The remainder of this chapter discusses 1) the application of the model at Radnor, with some recommendations for Radnor, 2) a general set of recommendations and conclusions, and 3) suggestions for further research.

A test of the feasibility of obtaining the type of data required by the model was provided by the health and physical education programs in the Senior High School of the Radnor Township School System. This was not without many practical problems. Three sets of recommendations were made to the Assistant Superintendent for Curriculum (the decision-maker in the study, who is now Superintendent of Schools at Radnor).

1. Much of the evaluative output of Chapter IV has more interpretive value in relative rather than absolute contexts. It is possible to assess the relative productivity of the 1967-68 health and physical education systems with respect to each overall objective. It is also possible to assess relative productivity by program and activity within program. Clear standards are missing, however, since estimated or intended production from the previous period was not available. The first recommendation was to perform a 1968-69 iteration of the model, <u>if it would provide a satisfactory payoff</u> in terms of questions that remained unanswered from the 1967-68 study.

2. In considering the 1968-69 allocation problems based on 1967-68 evaluations and effectiveness-cost estimates, another recommendation seemed in order. Sometimes activities are conducted even though there are more efficient alternatives elsewhere in the system. For instance, it may be preferred, with regard to economic criteria, to give a particular child an additional hour of social studies per week rather than an hour of music instruction. Yet a policy may exist which dictates that each child will receive two hours of music instruction per week. Under these circumstances the cost of music instruction to that child would be what he was unable to gain had he been given the social studies work. In this context it was recommended that

spending at levels higher than 1967-68 would possibly conflict with economic criteria given the stability of preferences, performances, and costs.[87]

3. The next recommendation was based on the possible utility of a 1968-69 iteration for the health and physical education programs. It appeared from the analysis of budget strategies and 1968-69 budget possibilities that most of the questions were answered in this sub-system. It was recommended that this type of systematic analysis be tried in other sectors of the Radnor School System. Should this recommendation be adopted, the accounting and budgeting systems would require modifications so that intended and actual costs could be associated with activities. Also mentioned was the idea of pupil-need assessment. With detailed information about pupil needs it would be possible to direct activities to individual pupil needs. This would allow the school system to plan individual "prescriptions" so that each child could receive a program more relevant to his needs.

The suggested expanded application of the model is for school year 1969-70, so that adequate preparation can be made prior to the start of the school year.

Broader implications for using this type of analysis derive from

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[87]This is a suboptimization comment relative to one education system since alternatives outside this sub-system were not considered. It is possible, although not highly likely in the author's opinion, that the best returns per dollar spent are found in the health and physical education sub-system. Only a broader set of objectives, value assignments, and performance and cost outcomes can provide answers such as those generated by the model in this study.

some problems encountered at Radnor. The principal problem is that explicit statements of objectives generally are not made in school systems. While some methods that can be directed toward defining objectives do exist, a rationale which permits school administrators to see the need for this does not appear to exist. The criteria for assessing methods for structuring objectives should be pragmatic. Do school administrators use them to structure objectives? Are the objectives generated useful in directing the system's activities? Would they be willing to use these methods even if they do not currently?

Once these objectives are thought through, measurement problems arise. The measurement of subjective values is difficult for two reasons. First, measurement procedures need to be simple yet provide outputs of at least interval-scale quality. An appropriate level of compromise needs to be established so that more useful measures can be developed. The second factor inhibiting the measurement of subjective values is that people are usually uncomfortable about sharing their values with others and often are afraid that explicitness will constrain them in the future. This is due in part to their unfamiliarity with "mathematical procedures" such as those used in this dissertation.

Before this type of analysis can be used in other parts of school systems, there is a need for good performance criteria. Cognitive outcome criteria have been especially troublesome since it is difficult to avoid the problems of standardized testing. One way to approach this is to try for greater understanding of the relationships that link cost and performance, and performance and production of preferred outcomes. Increasing the quantity and quality of the communications between the decision-maker and those who engineer and operate his programs, probably would be helpful. Another source of assistance could come about by better communication between quantitative researchers and those with less quantitative sophistication. This can provide a basis for improved measurement of critical variables.

There are several other problems that invite future research. The measurement of subjective values is an area that should provide opportunity for much inquiry.

Community values and preferences could be assessed to first find out what is wanted by generating value profiles and then determining the program mix that will produce the best allocation for each profile. This type of analysis, if handled properly, could foster a greater understanding of the community by school administrators and vice-versa.

While statistical problems were treated in Chapter II, they were largely ignored in the application of the model to the Radnor school system. Future efforts embracing this approach should consider the distributions of the performance variables. This would introduce prior and posterior distributions and would constitute a natural lead-in to Bayesian evaluation and allocation models.

The concept of the "value of sample information"[88] as something to be considered prior to sampling, could be extended to the "value of a research proposal" or the value of an experimental design. With a carefully developed analysis it would be possible to weigh alternative proposals for a given school system by considering the expected contribution to the value structure.

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[88] Schlaifer, Robert, Probability and Statistics for Business Decisions (New York: McGraw-Hill Book Company, Inc. 1959), pp.443-456.

There is no doubt that the chief executive of a school system needs better ways to gather, process, and summarize information necessary for his budgetary decisions. One can visualize the superintendent of a large urban school system seated in front of a computer console late in the evening. He enters estimates of a preference structure, representing a vociferous critic group, into the keyboard. He also enters a budget constraint and instructs the computer to allocate the new budget to programs in accord with the critic group's preference structure. He waits for a real-time response from the computer. A great deal of developmental effort remains before this can become an operational reality.

APPENDIX A

The Eckstein-McKean Ratio Argument with Implications for Cost-Effectiveness

The use of the ratio of benefits to costs has been criticized on several grounds. The leading antagonist of the ratio is Roland McKean and the principal advocate is Otto Eckstein. Almost all arguments on this subject in the literature focus on the criterion (ratio or otherwise) as a means of ranking projects for future investment.

The reason the controversy is important is that most practical applications of the methodologies embodying economic criteria use ratios as the criterion. This is a natural consequence of the intangible, incommensurable nature of public sector benefits. McKean makes the following criticisms of the ratio approach:[89]

1. The ratio is undesirable because it might be misinterpreted by uncritical analysts.
2. The ratio should not be used to compare "dissimilar" investments.
3. The ratio can be treacherous because it doesn't reflect the absolute magnitude of gains and costs.

The first point is reasonable but it presupposes that benefit-cost ratios are misleading in all cases. The author suggests that when the ratio is utilized we should take extra care to caution users as to the potential dangers.

The second comment by McKean is taken from the context of a dialogue with Eckstein. The latter has suggested that the ratio is appropriate for selecting preferred alternatives from projects that are "similar" in

[89] McKean, op. cit., p. 110.

terms of capital intensity (turnover in McKean's terms) and risk. McKean agrees that the ratio is appropriate in this type of situation but raises the question why not use the present value of net benefits since in this case both criteria will point to the same selections.[90] Before answering this question we can look at a part of Eckstein's argument.

Eckstein presents an analogy which considers a supermarket investment and a hydroelectric project investment. He shows that the benefit-cost ratio and the rate of return criteria give drastically different results and that each criterion tells little about the relative merits of the alternatives. This is because the supermarket represents a high risk venture whose success hinges on the chances that the location will assure profitability; while the hydroelectric proposition represents a large fixed investment over a long period of time and has a relatively known demand and minimal risk. In this latter case the rate of return criterion is sound but, in general, the criterion should be adapted to the nature of the alternatives.[91]

Now we want to return to McKean's question which asked why use the ratio if we have "similar" projects. The response is simple - often we face a situation where we are unable to assign dollar values to incommensurable and intangible benefits and consequently are unable to obtain a net benefit determination. In 1965 the United Nations Research Institute for Social Development and Office of Social Affairs held a one week conference on Cost-Benefit Analysis of Social Projects. Norman Scott, in

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[90] Ibid.

[91] Otto Eckstein, Water Resource Development (Cambridge: Harvard University Press, 1965), p. 54-55.

summarizing the discussions related to benefit-cost ratios, said:[92]

> This argument in favor of maximizing a ratio was defended on the grounds that social benefits and costs cannot be reduced to the same units on a national scale nor, frequently, at the project level.

McKean's third criticism related to the very nature of ratios in that they conceal absolute magnitudes. One remedy is to indicate the absolute magnitude of numerator and denominator. But McKean himself provides another solution in another section of his writing. He indicates that benefit-cost ratios can be used to rank alternatives for a given budget. In such cases the analyst must be careful to exclude investment costs not relating to the given budget.[93]

The problem is that on one hand the ratio is dangerous on logical grounds but on the other hand it offers a way to express relationships when dealing with intangibles and incommensurables. In terms of cost-effectiveness analysis, ratios must be utilized. The reasons for this are the same reasons that give rise to the need for cost-effectiveness as an analytical tool. A final compromise is in order. When an analyst decides in favor of a ratio criterion he should be sure that 1) the absolute magnitude of the numerator and denominator are indicated, and 2) the same budget constrains the comparisons or, if different budgets are used, the emphasis is uniform with regard to the nature of the investment.

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[92] Cost-Benefit Analysis of Social Projects, Report of a meeting of experts held in Rennes, France, 27 September-2 October 1965, United Nations Research Institute for Social Development, Report No.7, p. 5.

[93] McKean, op. cit., p. 114.

APPENDIX B

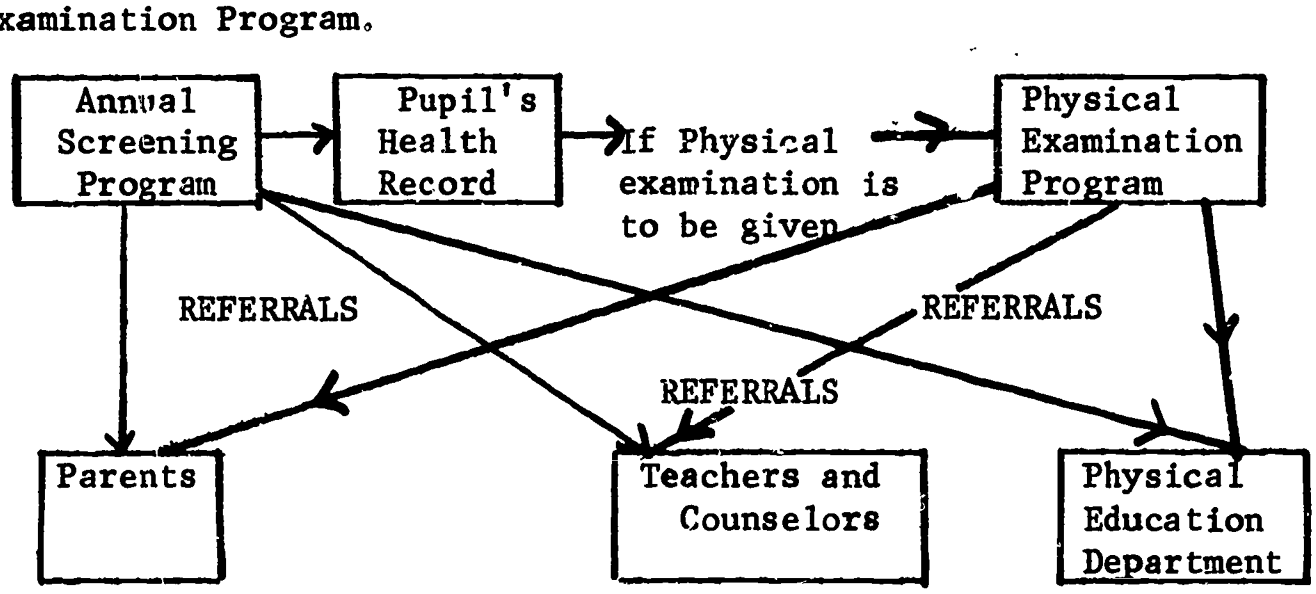
DESCRIPTION OF RADNOR HEALTH AND PHYSICAL EDUCATION PROGRAMS IN THE SENIOR HIGH SCHOOL

1. Annual Screening Program

The target population is all Senior High School students. Ideally, the timing is as early as possible in the school year since the information is required for the Physical Examination Program (for 11th grade students only) and for follow-up reasons.

Each pupil is weighed and measured for height. Vision is tested and if there is uncertainty the child is retested in a few days. Hearing is tested for all 11th grade pupils as part of the physical examination, for new pupils who are not accompanied by adequate health records and for those pupils with records of hearing difficulty. The "Pupil Health Record" is updated and the nurse confers with the child and discusses problems and health practices. Pupils are referred to an appropriate agency when necessary.

The following chart describes the flow of information and shows the interrelationship of the Annnual Screening Program to the Physical Examination Program.



2. Physical Examination Program

The target population is all 11th grade pupils and new students who are not accompanied by adequate health records. The examination is given as early as possible in the school year to facilitate follow-up. In many cases private physicians conduct the physical examination and forward the results to the School Nurse by the first day of the school year.

Each student has previously (unless he was examined by a private doctor prior to the beginning of the school year) been through the Annual Screening Program. Consequently, he has had vision, hearing, height, and weight checked. The child is checked for postural deviations, orthopedic defects, cardiac defects, etc. by the School Doctor. The "Pupil Health Record" is updated and the School Nurse discusses problems and health practices with the child. Students are referred to an appropriate agency when necessary. The chart describing the flow of information in connection with the Annual Screening Program is also appropriate here.

3. Communicable and Infectious Disease Program

The target population for this program is variable. With respect to communicable diseases, the program aims at all pupils. The tuberculosis screening activity is offered to 11th grade students. Actually, the State of Pennsylvania mandates a screening program for 1st and 9th grade children. The 11th grade children in 1967-68, however, had not been screened for tuberculosis in the 9th grade since the mandate went into effect this year (piror to this 11th graders were tested). Consequently, this year's 11th graders and the 1968-69 11th grade pupils will be screened for tuberculosis in this program as well as the state-mandated student population.

Each child is given the Tine Test under direction of the School Doctor. Positive reactors are referred to Delaware County Tuberculosis and Health Society Mobile X-ray Unit in the spring of the school year. In terms of other diseases teachers send pupils to the nurse and the nurse, after examination, recommends exclusion and medical care when appropriate.

4. Emergency Program

This program has a target population of all Senior High School students.

The Emergency Call System provides a nurse at all times during the school day. This functions through the school secretary. In the event the nurse is not available a qualified back-up person is designated. Free ambulance service is available through the Radnor Police and Fire Departments. The school nurse must accompany the child to the hospital since no physician attends the ambulance. The family doctor is contacted as soon as possible.

In instances of less serious emergency the nurse administers first aid. The nurse must evaluate the complaint and the symptoms observed. An estimate is made of the need for immediate or deferred medical care. In doubtful situations the family doctor or parent is consulted. Students are not sent home without the knowledge of the parent, an emergency person listed in the nurse's files, or the family doctor, or, in rare cases, the school principal. Transportation is generally provided by the parent.

Notations are made on the "Pupil Health Record" concerning all accidents and serious conditions.

5. Follow-Up Program

This program has a target population of selected students who have been referred. Since referral is a normal consequence of the Annual Screening Program, the Physical Examination Program, the Communicable Disease Program, and the Emergency Program, there is little left to be called "follow-up".

The Follow-Up Program consists of those follow-up activities not otherwise classified. This amounts to the activities performed by the nurse to obtain a final disposition for each student referred. This is usually done by telephone and personal contact with pupils but, in rare instances, the nurse could make a hom visit. Also, the Home and School Visitor may, in rare instances, make a home visit on behalf of the nurse.

6. Health Education

The target group for this program is all Senior High School children. As was mentioned earlier there are certain health education spillovers deriving from some of the other programs (e.g. Physical Examination Program).

A series of 17 Health Instructional Units were prepared on a pilot basis for 1967-68.[94] The classroom health education program was conducted in science, social studies and physical education. In addition, the nurse provides resource materials to the teachers.

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[94] Guidelines For Curriculum Development in Health Education, Interim working manuscript prepared for Commonwealth of Pennsylvania, Department of Public Instruction, Bureau of General and Academic Education (November, 1967).

The Radnor Health Coordinator participated in the preparation of these pilot materials.

7. Physical Education

This program has a target population of all Senior High School students. In fact, one of the program objectives is 100 per cent participation where this is meant to include each student on whatever basis he can participate.

The program is designed so that there are three physical education periods per week for 10th and 11th grade students and two periods per week for seniors. There are games, sports, and activities. The sexes are segregated. A detailed curriculum of instruction governs the classroom activities. For example, in the 10th grade the instructional emphasis is placed on game fundamentals while in the later grades the emphasis is on scoring, rules and strategies.

There is also a first-aid course given in the physical education curriculum.

Varsity sports were not included as part of this study. Intra-mural activities operated on a very limited basis in 1967-68.

8. Adapted Physical Education

This program aims at pupils with postural and orthopedic defects and pupils with other physical deficiencies impairing normal physical participation in the Physical Education Program.

This program supplements the regular Physical Education Program. Children are screened visually and then by photographic grid to select those with the greatest need for a special program. Those selected for the program are specially rostered.

The program features special exercises and routines which are individualized to the needs of the child. Post-screening is also conducted at the end of the year.

APPENDIX C

THE PERFORMANCE CRITERIA

The general procedure to determine performance outcome scores was to 1) agree to a criterion, 2) determine how scores would be obtained, 3) obtain the outcome score, $K^{*}_{mJ}O^{\bullet}_{\lambda}$, and 4) permit the decision-maker to modify the outcome score yielding $\hat{K}^{*}_{mJ}O^{\bullet}_{\lambda}$.

The method used to allow the decision-maker the opportunity to change the raw score was to show him a sketch (see below and to discuss the problem with him in the following way:

> If we look at the diagram (Figure 13) we notice that the vertical axis represents value produced and the horizontal axis talks about performance. The line bisecting the angle is called K=V. This means that 80% performance is entitled to 80% of the value and 35% of the performance received 35% of the value. If you feel that the line K=V should be changed to reflect something else you can do so. For instance, if you feel that a performance score of 80% is poor for a particular activity, you could have it produce a 70% value or, for that matter, any value you want. If you do change these relationships we will discuss their implications for your activities.

The remainder of this appendix provides a brief discussion for each performance criterion within a program.

1. Performance in the Annual Screening Program

Vision appraisal ($a_{11}\ O_A$)

This objective was tested by an objective criterion. The total number of pupils to be tested was 934 and the total actually tested was 905.

$$K^{*}_{11}O_A = \frac{905}{934} = 0.97$$

The program specifications indicate that all Senior High School students should be tested annually. A few of the 29 "not tested" were actually tested during the second half of the previous school year. The cut-off date for the purpose of analysis was arbitrarily set at 31 March 1967

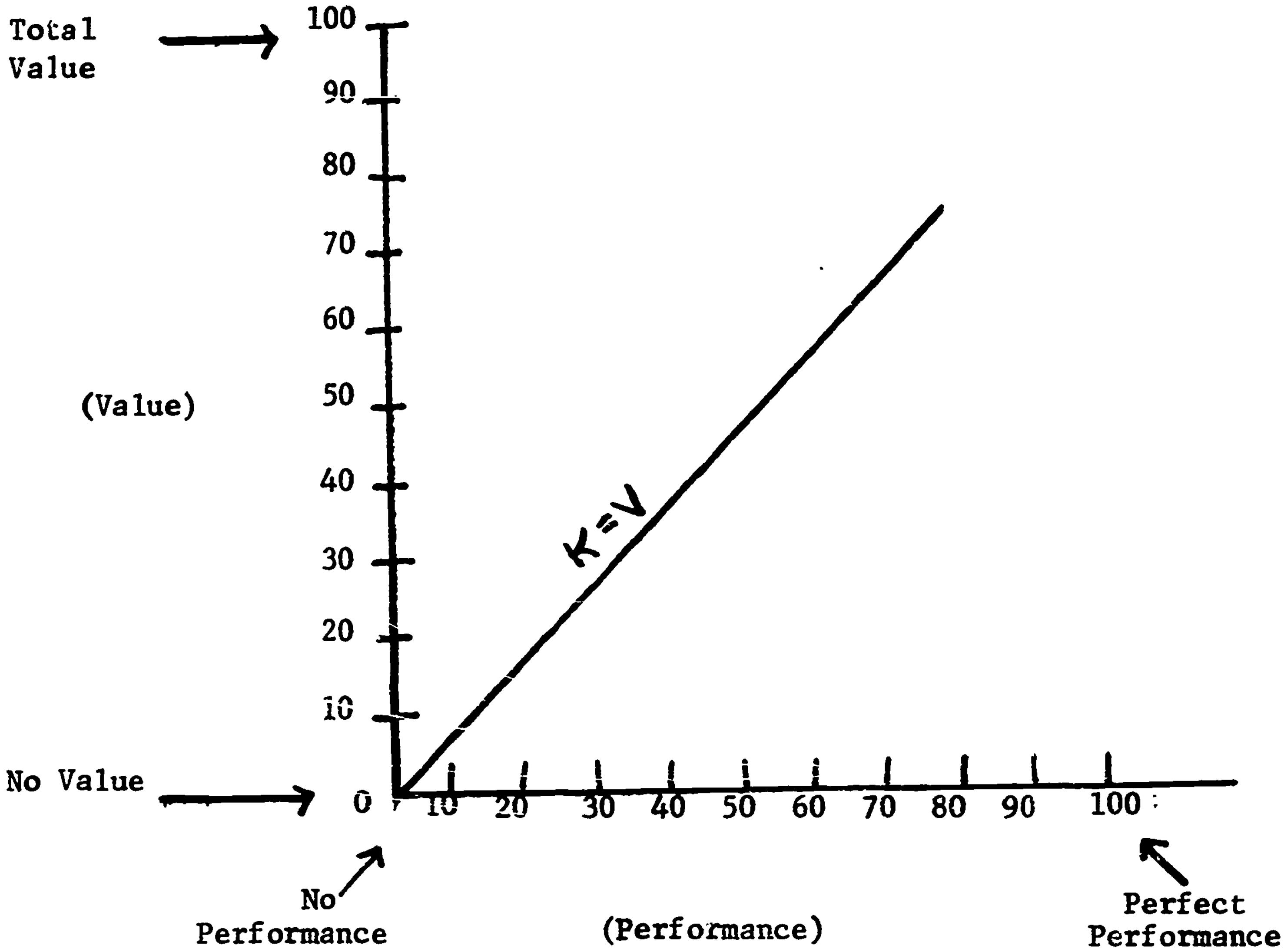

Figure 13. Value-Performance Discussion Graph

(this comment applies to a_{12} and a_{13} equally).

This Assistant Superintendent was presented with these data and a graph relating value to performance. Given the option of modifying $K^*_{11}O_A$ he chose to permit this to equal $\hat{K}^*_{11}O_A$.

Hearing appraisal ($a_{12}O_A$)

Hearing performance was assessed objectively. The hearing appraisal function was to be done for all 11th grade pupils, those transferring to Radnor with inadequate hearing records, and those with prior hearing problems. The total to be tested was 378 and the actual number tested was 343.

$$K^*_{12}O_A = \frac{343}{378} - 0.91$$

The decision-maker accepted $\hat{K}^*_{12}O_A = K^*_{12}O_A$

Height-weight appraisal ($a_{13}O_A$)

This objective was also assessed by an objective standard. The total to be tested was 934 with 918 tested.

$$K^*_{13}O_A = \frac{918}{934} = 0.98 \quad \text{and } \hat{K}^*_{13}O_A = K^*_{13}O_A.$$

Discussion with Student for follow-up ($a_{14}O_B$)

The pupil-nurse discussions in this program have two basic objectives. They are aimed at follow-up $a_{14}O_B$ and health education $a_{14}O_D$. These objectives were both assessed subjectively by means of a semi-structured interview with the Nursing Coordinator. The format for this interview is described as follows:

"1. One of the ideas built into the Annual Screening Program (we will treat the Physical Examination apart from this) is the discussing of problems with the student with respect to follow-up . I will show you a scale and we will see if you can tell me the extent to which you feel the objective is presently (school year 1967-68) being met with a mind toward follow-up. We can discuss the scale to help you decide."

The value she assigned to $a_{14}O_B$ was 0.75 and the value for $a_{14}O_D$ was 0.50. There were some qualifying remarks,

This is difficult to estimate. If I had more time in the school year I think I could do a more effective job. Too much time is needed for paper work that can be done by a paraprofessional.

The values for $a_{14}O_B$ and $a_{14}O_D$ were unchanged by the superintendent from the subjectivity assigned values. Figure 14 is a copy of the diagram

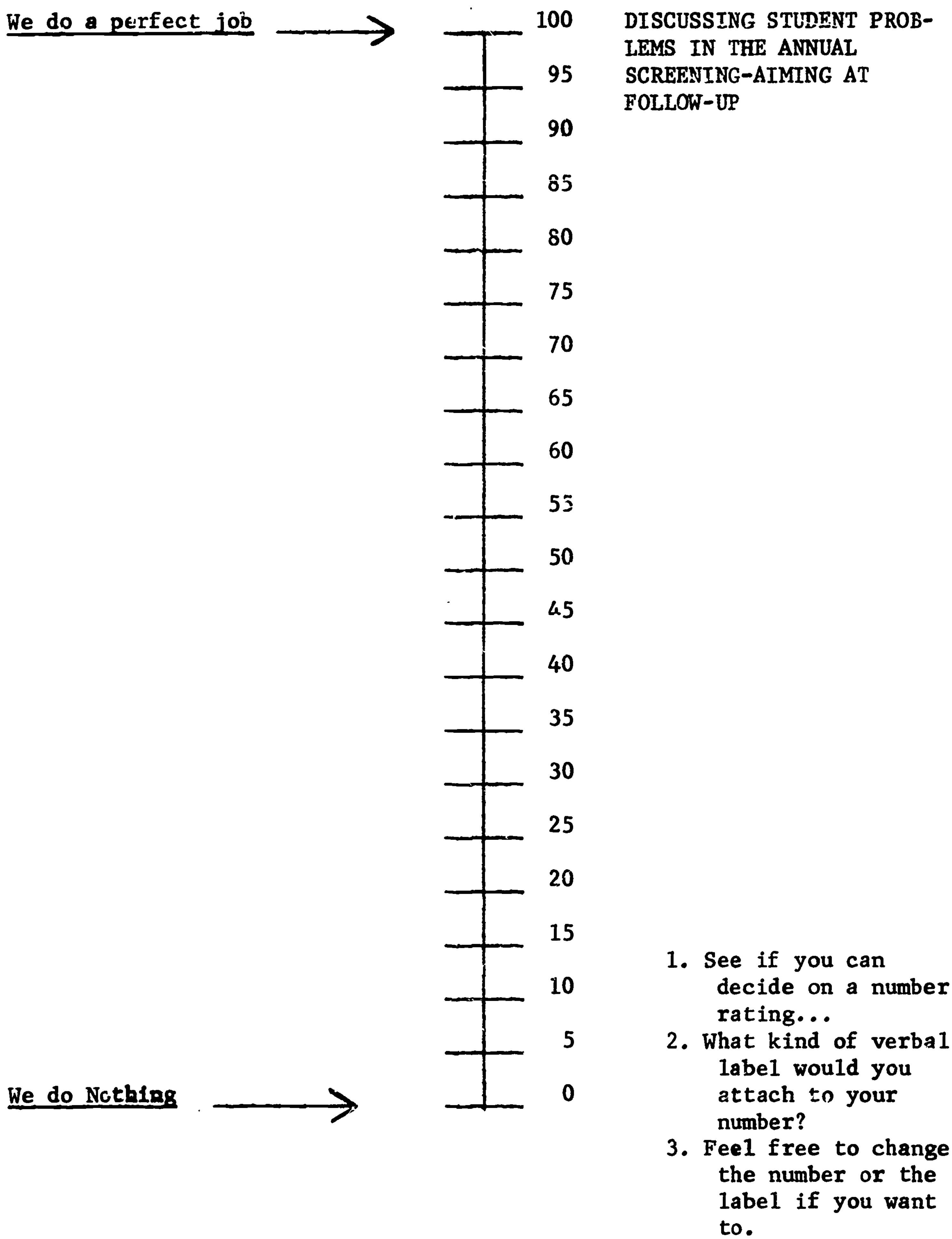

Figure 14. Typical Scale Presented to Discuss Performance Estimation

presented for this type of situation.

Referral of defects to parents $(a_{15}0_C)$

This objective was assessed by an objective criterion. The total to be referred was 221 with 45 being referred, $K^*_{15}0_B = \frac{45}{221} = 0.20$.

There are several factors to be mentioned in connection with this statistic. Of the 60 defects for vision and hearing, 40 were referred. Of the 159 defects for height-weight imbalances, 4 were referred (two other defects were found as a spillover from this screening). This was a case of the Author and the Nursing Coordinator using different criteria. In addition, the 159 height-weight defects were based on a chart depicting average relationships with overweight and underweight ranges. This does not consider body structure. The nurse would not have had 159 defects by her more expert criteria. In addition, there are many defects of which the nurse knows the parents are aware yet which the records may not indicate. She also may know when a student is on a special diet. Based on this information the Superintendent set $\hat{K}^*_{15}0_C = 0.75$.

Referral of defects to teachers $(a_{16}0_B)$

This is restricted to referral of defects to teachers other than physical education teachers. It was evaluated subjectively by the Nursing Coordinator in the semi-structured interview, and $K^*_{16}0_B = 0.80$. Some qualifying remarks by the Coordinator were:

> I tell them in the grade-level meetings. If a child is really bad I go direct to the teachers.

$\hat{K}^*_{16}0_B$ was taken equal to $K^*_{16}0_B$.

Referral of defects to physical education teachers($a_{17}O_B$)

This performance was assessed subjectively by means of a semi-structured interview with the Physical Education Coordinator. The following data were also presented to help form a judgment.

> To help you make a more informed judgment I can tell you that as a result of the Annual Screening during 1967-68 there were 37 vision and 6 hearing defects referred to parents. There were 159 height-weight defects but only 4 of these were referred.

Based on these data and other inputs the value assigned was $K^{*}_{17}O_B = 0.40$. Some remarks qualified this rating.

> We need specific written notifications since I can't always attend the grade-level meetings. The present method is not adequate. Also we need quicker referral with cases pertaining to postural deviation.

The decision-maker let $\hat{K}^{*}_{17}O_B = K^{*}_{17}O_B$.

2. Performance in the Physical Examination Program.

Reflex appraisal ($a_{21}O_A$)

This objective was assessed by an objective criterion. There is one problem connected with the objective measures for the Physical Examination Program. The Physical Examination is aimed at all 11th grade students and those transferring to Radnor without adequate physical examination data. The State of Pennsylvania allows for the examination of pupils by the private physician in cases where this is preferred by the parents. Those students not examined by the private doctor are examined during the school year by the school doctors. The reporting forms which both private and school doctors use are based on what can be called an "inference system". If the child is adequate or normal with respect to a given physical criterion the doctor leaves the space blank. Only where abnormality is manifest does the doctor make a mark or comment. When someone reads the form it is possible to see a child's name and nothing else but the doctor's signature (sometimes not even the date). Therefore, the "inference" is that the child is checked for all defect possibilities during the examination. The total to be tested was 308 of which 277 were tested. $K^*_{21}O_A = \frac{277}{308} = 0.90$.

The Superintendent let $\hat{K}^*_{21}O_A = K^*_{21}O_A$.

Speech appraisal ($a_{22}O_A$)

This was also checked objectively. The total to be tested was 308 of which 277 were tested. $K^*_{22}O_A = \frac{277}{308} = 0.90$ and $\hat{K}^*_{22}O_A = K^*_{22}O_A$.

Posture and orthopedic appraisal($a_{23}O_A$)

This performance was assessed objectively with the total to be examined at 308 and the actual number of students tested at 277.

$K^*_{23}O_A = \frac{277}{308} = 0.90$, $\hat{K}^*_{23}O_A = K^*_{23}O_A$.

Heart and blood pressure appraisal($a_{24}O_A$)

This objective was assessed by objective standards. The number of pupils to be tested was 308 and the actual number tested was 280.

$K^*_{24}O_A = \frac{280}{308} = 0.91$, $\hat{K}^*_{24}O_A = K^*_{24}O_A$.

Other appraisal($a_{25}O_A$)

The criterion here was that if the examination was given "other things" were checked. $K^*_{25}O_A = 0.91$, $\hat{K}^*_{25}O_A = K^*_{25}O_A$.

Referral of defects to parents ($a_{26}O_B$)

This performance was checked objectively. In all there were 24 defects to be referred (some pupils had more than one defect). Four were actually referred. $K^*_{26}O_B = \frac{4}{24} = 0.17$.

The problem here is that the nurse's judgment as to what should be referred is superior to that resulting from a records check. In addition, parents often know of these problems and the nurse knows that they know. The decision-maker set $\hat{K}^*_{26}0_B = 0.45$.

Referral of defects to teachers($a_{27}0_B$)

This objective relates to referral of defects to teachers other than physical education teachers. It was evaluated subjectively by the Nursing Coordinator. $K^*_{27}0_B = 1.00$.

Some remarks qualified the rating.

> I also tell the teachers about these in the grade-level meetings but I only refer serious defects - not minor details. If a child had athlete's feet I wouldn't tell his math teacher.

The decision-maker concurred with $\hat{K}^*_{27}0_B = K^*_{27}0_B$.

Referral of defects to physical education teachers($a_{28}0_B$)

This objective was assessed subjectively by the Physical Education Coordinator. The following data were also presented to assist her judgment. "These figures represent the 24 defects referred to parents as a result of the Physical Examination. Included also are two defects that turned up as a result of the Annual Screening Program. There were 5 reflex, 13 posture and orthopedic, 1 heart and blood pressure, and 7 other defects." The criterion was assessed at $K^*_{28}0_B = 0.45$ with the comment:

> This is a little better [a reference to the referrals from the Annual Screening Program].

The decision-maker allowed $\hat{K}^*_{28}0_B = K^*_{28}0_B$.

Discussion of problems with student aiming at follow-up and education ($a_{29}0B$), ($a_{29}0_D$)

This effort is aimed at follow-up $a_{29}0_B$ and health education $a_{29}0_D$. The method of appraisal was a subjective rating obtained from the semi-structured interview, $K^*_{29}0_B = 1.00$, $K^*_{29}0_D = 1.00$.

The decision-maker, however, felt that the resources available for these efforts did not allow such a high performance and made the following adjustments: $\hat{K}^*_{29}O_B = 0.80$, $\hat{K}^*_{29}O_D = 0.80$.

3. <u>Performance in the Communicable and Infectious Disease Program</u>

This program operates at a more substantial level in the elementary schools, since pupil needs are greater there.

<u>Health education spillovers($a_{32}O_D$)</u>

Spillover benefits derive from pupil discussions with the nurse, in tuberculosis testing activities, and from literature readily available in the nurse's office. The objective was evaluated subjectively by the Nursing Coordinator during the semi-structured interview.

$K^*_{32}O_D = 0.25$.

She had several qualifying remarks:

> We don't get too much in the way of communicable or even infectious diseases in the high school. I do supply resource materials to the teachers but if you mean does the school do what it can - no. There should be a specific health curriculum with a qualified teacher. Our effort is spotty.

The Superintendent felt that the low rating was more a comment on the performance of the health education curriculum than the health education spillovers resulting from limited activities in the area of communicable and infectious diseases. Therefore the criterion was raised so that $\hat{K}^*_{32}O_D = 0.50$.

<u>Veneral disease appraisal($a_{33}O_A$)</u>

The evaluation of this objective is tricky. There is no specific activity directed toward this. On the other hand there does not appear to be a need to have an activity. The performance however was rated at 0.30 since there are spillovers deriving from educational efforts aimed at detection awareness in the classroom. Also, the nurse pointed out that the school doctor or private doctor would come across veneral disease cases if the condition was present.

Tuberculosis appraisal($a_{34}0_A$)

This activity was aimed at 11th grade pupils during 1967-68. The activity is temporary and will only run in the Senior High School for one more year due to a change initiated by the State of Pennsylvania. It was at the initiative of the Nursing Coordinator that this group was tested, since the State's change would have allowed the 11th graders in 1967-68 and 1968-69 to slip by untested.

There were 325 pupils tested but only 308 eligible according to the numbering system used in this study. The decision-maker set $\hat{K}^*_{34}0_A = 0.95$.

Referrals of veneral disease and tuberculosis($a_{35}0_B$),($a_{36}0_B$),($a_{37}0_B$)

This is referral to parents $a_{35}0_B$, teachers other than physical education teachers $a_{36}0_B$, and physical education teachers $a_{37}0_B$. Interestingly enough, there were no defects found and the performance ratings assigned were all at 1.00. The utility of these ratings is questionable.

4. Performance in the Emergency Program

Care for serious injury ($a_{41}0_C$)

This activity was assessed subjectively by the Nursing Coordinator during the semi-structured interview. $K^*_{41}0_C = 1.00$.

The qualifying remark was, "We handle them all."

The decision-maker concurred with $\hat{K}^*_{41}0_C = 1.00$

Care for less serious injury($a_{24}0_C$)

The Nursing Coordinator's subjective assessment was also used to evaluate this performance. $K^*_{42}0_C = 1.00$. The decision-maker felt that this was somewhat high and set $\hat{K}^*_{42}0_C = 0.95$.

Care for illness($a_{43}0_C$)

This was also assessed subjectively by the Nursing Coordinator during the semi-structured interview. $K^*_{43}0_C = 1.00$. The decision-maker adjusted this value to $\hat{K}^*_{43}0_C = 0.90$.

Referral and Follow-up of injuries and illness ($a_{44}0_B$),($a_{45}0_B$),($a_{46}0_B$)

The referrals of serious injury $a_{44}0_B$, less serious injury $a_{45}0_B$, and illness $a_{46}0_B$ were rated by the Nursing Coordinator during the semi-structured interview. These were all rated 1.00 and the Assistant Superintendent agreed.

5. Performance in the Follow-up Program

Each program has some type of follow-up built into it. One activity which seemed to remain apart was the determination of the status of each student who was referred, with special emphasis on the Annual Screening and Physical Examination referrals.

This was assessed objectively in that of the 54 referrals there were 43 with definite depositions, $K^*_{51}0_B = \frac{43}{54} = 0.80$.

The decision-maker felt that this was extremely difficult to achieve and raised the performance value, $\hat{K}^*_{51}0_B = 0.95$.

6. Performance in the Health Education Program

This program is broken up into many small pieces due to the lack of a single person with responsibility and, of course, resources. Efforts are (and have been) underway for resolving some of the health education problems.

As we have seen health education benefits are derived in a variety of ways. A systematic, explicitly planned health curriculum, is preferred at Radnor. With this in mind, the Nursing Coordinator worked during the summer of 1967 on a project to prepare a pilot curriculum. Instructional packages were prepared for classroom use on a pilot basis during 1967-68 but, as was previously mentioned, overall coordination was lacking.

The Superintendent assessed the performance of the health education curriculum efforts in the Senior High School at $\hat{K}^*_{62}O_D = 0.40$.

According to the Radnor literature, the system also aims at the objective of instilling the notion that each child must take the responsibility for his own health care. This activity, $a_{61}O_D$, was assessed by the Physical Education Coordinator at 0.75. While this assessment was subjective, it was based on data generated by means of a questionnaire given to 619 high school students. Table 16 presents the data and the question asked. The Superintendent let $\hat{K}^*_{61}O_D = K^*_{61}O_D$.

7. Performance in the Physical Education Program

In an effort to assess some of the physical education activities, the pupil questionnaire previously referred to was used. The interpretation of the derived data was left to the Physical Education Coordinator and her staff. She shared the data with her staff before rendering subjective assessments of the extent to which various objectives were met.

Participation($a_{71}O_E$)

Built into the Radnor Physical Education Program is a belief that each child can and should participate in those activities his abilities allow.

The Physical Education Coordinator assessed performance in this sense to be $K^*_{71}O_E = 0.99$.

She remarked, "We can't do much better in that we get them all now. I think we did miss one child for a while."

TABLE 16

STUDENT RESPONSES TO INDIVIDUAL HEALTH RESPONSIBILITY

QUESTION, BY GRADE AND SEX

RESPONSE	BOYS			GIRLS		
	10	11	12	10	11	12
Strongly agree	42	35	62	22	48	44
Agree	56	32	41	70	65	65
Disagree	5	4	2	2	1	3
Strongly Disagree	-	2	2	-	-	1
Dont' Know	1	3	4	2	1	3
No Answer	1	-	-	-	1	-
TOTAL	105	76	111	96	115	116

QUESTION: Do you feel that unless each student takes the responsibility for his (her) health, that his (her) health will suffer a great deal?

The decision-maker kept $K^*_{71}O_E = K^*_{71}O_E$.

Fitness ($a_{72}O_E$)

Fitness testing is done by the physical education teachers. This testing has been done for years and the Physical Education Coordinator is extremely interested in these patterns. She subjectively assessed $K^*_{72}O_E$ but qualified this figure. "We need more emphasis on this phase of our program."

The decision-maker amplified the need for greater emphasis on fitness and lowered $K^*_{72}O_E$ from 0.90 to $\hat{K}^*_{72}O_E = 0.80$.

Physical confidence ($a_{73}O_E$)

In order to assess the extent to which children have confidence in their abilities to engage in physical activities two questions were included in the pupil questionnaire. Table 17 shows the response data. The coordinator said:

> It would have helped on your questionnaire to have had another point on the scale between 'very confident' and 'not so confident'. [a reference to the categories presented to the students on the questionnaire] So what I am saying is that I think they should be higher than the data indicated.

The decision-maker accepted $\hat{K}^*_{73}O_E = K^*_{73}O_E$ at 0.80.

Variety of skills and games ($a_{74}O_E$)

The program description indicates that the programming was designed to expose the children to a wide variety of skills and games. This was subjectively assessed by the Physical Education Coordinator at $K^*_{74}O_E$=1.00.

She said:

> We do extremely well on the State-mandated programs in terms of the personnel available and the facilities available. Improvement is needed on the basis of our standards and goals as projected in terms of an interest-oriented program aimed at developing interest in lifetime sports.

The superintendent felt that the performance should be assessed relative

TABLE 17

STUDENT RESPONSES TO PHYSICAL CONFIDENCE QUESTION, BY GRADE AND SEX

	Girls-Grade 12 Last Year					Boys-Grade 12 Last Year				
This Year	More	Same	Less	DK*	Total	More	Same	Less	DK*	Total
Very Confident	1	47	7	1	56	1	45	21	1	68
Not so Confident	2	36	11	1	50	4	21	12	1	38
Not Confident	-	7	1	-	8	-	1	--	-	1
Completely not Confident	-	1	-	-	1	-	1	--	-	1
Dont' Know	-	-	-	1	1	-	1	1	1	3
TOTAL	3	91	18	3	116	5	68	34	3	111

	Girls-Grade 11 Last Year					Boys-Grade 11 Last Year				
This Year	More	Same	Less	DK*	Total	More	Same	Less	DK*	Total
Very Confident	1	36	8	1	46	-	22	18	1	41
Not so Confident	5	42	11	2	60	1	11	10	3	25
Not Confident	-	5	2	1	8	-	[illegible]	2	1	4
Completely not Confident	-	-	-	-	-	-	1	-	-	1
Don't Know	-	-	-	2	2	-	-	-	5	5
TOTAL	6	83	21	6	116	1	35	30	10	76

	Girls-Grade 10 Last Year					Boys-Grade 10 Last Year				
This Year	More	Same	Less	DK*	Total	More	Same	Less	DK*	Total
Very Confident	4	33	8	1	46	3	31	20	-	54
Not so Confident	4	27	12	-	43	3	23	18	-	44
Not Confident	-	2	2	-	4	-	2	1	-	3
Complete not Confident	-	1	-	-	1	-	-	-	-	-
Don't Know	-	-	-	2	2	-	-	-	4	4
TOTAL	8	63	22	3	96	6	56	39	4	105

*Don't Know

QUESTION: How confident do you feel in your physical abilities (taking part in games, sports, and new physical tasks)? and what would your answer have been a year ago?

to the Radnor goals and not those of the State. He concluded $\hat{K}^*_{74}O_E$=0.85.

<u>Physical education attitudes($a_{75}O_D$)</u>

The physical education program attempts to develop positive attitudes toward the self, others, etc. The topic was directed to the students in the student questionnaire. Table 18 displays the response data.

The Physical Education Coordinator rated this aspect of the program with $K^*_{75}O_E$ = 0.96. She added that the questionnaire was more narrow than she would have liked:

> Physical education encompasses athletics in the true physical education sense of the word and on that basis we can use your data.

The decision-maker allowed $\hat{K}^*_{75}O_E = K^*_{75}O_E$.

<u>Lifetime sports($a_{76}O_D$)</u>

The physical education program took on an added emphasis on 1967-68. Built into the program was the idea that each child should be prepared to participate in some sport(s) on a lifetime basis. The true assessment of this goal should be made over an extended period of time.

This was evaluated at $K^*_{76}O_D$ = 0.70. It was qualified by the Physical Education Coordinator.

> To a reasonable degree. (This was a reference to the lifetime sports activity). This is a projected aim and the implementation is based on personnel and facilities. It is highly desirable at Radnor.

The Assistant Superintendent lowered the rating to $\hat{K}^*_{76}O_D$ = 0.55. He added that progress seemed to be substantial but that there was a long way to go.

8. <u>Performance in the Adapted Physical Education Program</u>

<u>Posture and orthopedic appraisal($a_{81}O_A$)</u>

While data were available on the number of children screened, it was difficult to assess the extent to which eligible children were appraised. It was decided to allow the Physical Education Coordinator

TABLE 18

RESPONSE	BOYS			GIRLS		
	10	11	12	10	11	12
Very Successful	48	18	43	22	45	41
Mildly Successful	42	42	52	57	49	53
Not Successful	7	8	12	15	22	17
Complete Not Successful	6	6	1	--	--	3
Don't Know	2	2	2	2	--	2
No Answer	--	--	1	--	--	--
TOTAL	105	76	111	96	116	116

QUESTION: How successful do you feel physical education is in bringing out good attitudes in students? (such as, the importance of team play, fair play, how to be a good spectator) to subjectively evaluate this activity, $K^*_{81}O_A = 1.00$.

She commented, "We screened them all." The decision-maker accepted $\hat{K}^*_{81}O_A = K^*_{81}O_A$.

Improvement in terms of defects ($a_{82}O_B$)

The major part of the Adapted Program, in terms of pupil and teacher time expended, is aimed at correcting postural deviations through exercises and activities directed to individual problems.

Some qualifying remarks were

> This is based on one year of diagnosis and work on exercises for deviations. It is not adequate to show strong improvement. A three-year basis would be a more reliable length of time. Referrals from medical exams could be better.

The decision-maker assessed $\hat{K}^*_{82}O_B = K^*_{82}O_B = 0.82$.

Attitudes($a_{83}O_D$)

This program also hopes to improve the attitudes of the participating students. A question in the pupil questionnaire asked how well the student felt the program helped his desire to improve. Table 19 shows the response data.

The Physical Education Coordinator subjectively interpreted the data and rated the performance of this activity at $K^*_{83}O_D = 0.90$. Her qualifying remarks were:

> The creation of attitudes takes more than a one-year stand. This was a new program - the orientation of participants, parents and faculty created a more favorable attitude.

The Superintendent allowed $\hat{K}^*_{83}O_D = K^*_{83}O_D$.

Participation($a_{84}O_E$)

The Physical Education staff at Radnor feel that the child could participate in more physical activities after realizing improvement in his physical state. A question on the pupil questionnaire was directed toward this. Table 20 displays response data.

TABLE 19

STUDENT RESPONSES TO ATTITUDES TOWARD IMPROVEMENT, BY GRADE AND SEX

RESPONSE	BOYS 10	BOYS 11	BOYS TOTAL	GIRLS 10	GIRLS 11	GIRLS TOTAL
Very much so	10	1	11	5	1	6
Moderately so	15	13	28	11	10	21
Not at all	1	2	3	8	5	13
Don't know	2	1	3	4	--	4
TOTAL	28	17	45	28	16	44

QUESTION: To what degree do you feel that the adapted program created a desire for you to improve your physical status?

NOTE: 12th grade pupils had already graduated when this questionnaire was given

TABLE 20

STUDENT RESPONSES TO ADAPTED PARTICIPATION QUESTION, BY GRADE AND SEX

RESPONSE	BOYS 10	BOYS 11	BOYS TOTAL	GIRLS 10	GIRLS 11	GIRLS TOTAL
About the same as before	13	11	24	18	15	33
More confident in my ability	14	6	20	3	1	4
Less confident in my ability	1	-	1	1	-	1
Don't know	-	-	-	6	-	6
TOTAL	28	17	45	28	16	44

QUESTION: As related to your participation in the adapted program, how well did it improve your desire to participate more fully in the physical education program?

NOTE: 12th grade pupils had already graduated when this questionnaire was given.

The Physical Education Coordinator assessed activity performance at $K^*_{84}O_E$ = 0.75 and made the following qualification:

> Good plus - the ratio of participation is increased in relation to the student's understanding and orientation. This is a staff responsibility.

The Supterintendent let $\hat{K}^*_{84}O_E = K^*_{84}O_E$.

9. Performance in the Dental Program

Since the Dental Program did not operate in the Senior High School du ng 1967-68, the performance rating assigned to $a_{91}O_A$ and $a_{92}O_B$ was 0.00.

APPENDIX D

Supplementary Evaluation Outputs

It was pointed out that a decision-maker with overall responsibilities is more interested in the system's capabilities relative to overall objectives and programs, and, therefore, less interested in detail on activities. This comment can be appreciated better if one envisions the many such sub-systems for which a school administrator has responsibility. This appendix provides detail on productivity at the program activity level in Tables 21 and 22.

The basic elements that form productivity outcomes are production outcomes at the activity level. These were shown in Table 6 and are reproduced in Table 21. In addition, it was seen earlier that relative performance at the activity level reduces to the performance score, i.e. $\hat{K}^{*}_{mJ} O^{*}_{\ell}$. Consequently Table 22 is a carry-over from Table 4.

Ordinarily, costs would also be carried over at the activity level and effectiveness-cost calculations could be given by activity. These figures would not be prescriptive for the coming year but would provide information as to the relative economic merits of the activities as they were conducted. These cost figures, as was indicated, are not available nor can it be expected that they will be available in most school systems.

TABLE 21

VALUE PRODUCED BY ACTIVITY, PROGRAM AND OVERALL OBJECTIVE

	Annual Screening		Physical Examination		Communicable and Infectious Disease		Emergency	
O_A	a_{11}	10.1	a_{21}	8.6	a_{34}	6.8		
	a_{12}	9.5	a_{22}	8.6	a_{33}	0.0		
	a_{13}	9.3	a_{23}	8.2				
			a_{24}	9.5				
			a_{25}	9.5				
Total		28.9		44.4		6.8		
O_B	a_{14}	4.1	a_{26}	3.0	a_{35}	6.6	a_{44}	11.0
	a_{15}	3.3	a_{27}	5.5	a_{36}	5.3	a_{45}	5.5
	a_{16}	4.2	a_{28}	2.5	a_{37}	5.5	a_{46}	5.5
	a_{17}	2.2	a_{29}	4.4				
Total		13.8		15.4		17.4		22.0
O_C							a_{41}	65.9
							a_{42}	39.1
							a_{43}	29.6
Total								134.6
O_D	a_{14}	8.2	a_{29}	13.1	a_{32}	6.6		
Total		8.2		13.1		6.6		
O_E		50.9		72.9		30.8		156.6

	Follow-up	Health Education	Physical Education	Adapted Physical Education	Other	Total
				a_{81} 9.1	a_{91} 0.0	
(total)				9.1	0.0	89.2
	a_{51} 5.0			a_{82} 1.9	a_{92} 0.0	
(total)	5.0			1.9	0.0	75.5
(total)						134.6
		a_{61} 11.8	a_{75} 15.2	a_{83} 14.2		
		a_{62} 6.3	a_{76} 8.7			
(total)		18.1	23.9	14.2		84.1
			a_{71} 24.5	a_{84} 16.4		
			a_{72} 23.3			
			a_{73} 21.0			
			a_{74} 17.5			
(total)			86.3	16.4		102.7
(total)	5.0	18.1	110.2	41.6	0.0	486.1

TABLE 22

ADJUSTED PERFORMANCE SCORES $\hat{K}^*_{mJ}O_i$ BY PROGRAM AND OVERALL HEALTH AND PHYSICAL EDUCATION OBJECTIVE

Program	Appraisal (O_A)	Follow-up (O_B)	Emergency (O_C)	Health Education (O_D)	Physical Education (O_E)
	OVERALL OBJECTIVES				
Annual Screening (P_1)	11=0.97 12=0.91 13=0.98	14=0.75 15=0.75 16=0.80 17=0.40		14=0.50	
Physical Examination (P_2)	21=0.90 22=0.90 23=0.90 24=0.91 25=0.91	26=0.45 27=1.00 28=0.45 29=0.80		29=0.80	
Communicable and Infectious Disease (P_3)	33=0.30 34=0.95	35=1.00 36=1.00 37=1.00 44=1.00	41=1.00	32=0.50	
Emergency (P_4)		45=1.00 46=1.00	42=0.95 43=0.90		
Follow-up		51=0.95			
Health Education (P_6)				61=0.75 62=0.40	
Physical Education (P_7)				75=0.96 76=0.65	71=0.99 72=0.80 73=0.80 74=0.85
Adapted Physical Education (P_8)	81=1.00	82=0.40		83=0.90	84=0.75
Dental (P_x)	91=0.00	92=0.00			

APPENDIX E

Cost-Effectiveness Data by Program

The information in this appendix was provided by the two Radnor coordinators. The basic consideration was to ask them what would happen to performance, in each program, if the level of expenditure was varied in the neighborhood of the 1967-68 level of expenditure.

1. Annual Screening Program

The Nursing Coordinator felt that paperwork was the biggest handicap for improved performance in this program. She indicated that more could be done in the way of follow-up and health education if the paperwork could be reduced. In her opinion an increase in resources should be devoted to part-time help so as to free the nurse for professional duties.

When the Nursing Coordinator was questioned about decreasing the level of expenditure for this program, she indicated that the program was state-mandated and could not be cut.

It should be emphasized that while only $2,961 was tied to this program in 1967-68, a substantial number of physical examinations were conducted by private doctors. The policy at Radnor is to encourage patronage of private doctors. This policy would not work well, for example, in the Philadelphia School System since family income for many pupils is low. Therefore, the cost per pupil for the same program would probably be higher since the school system would be forced to hire more doctors.

The Nursing Coordinator's estimates of relative effectiveness responses to selected cost investments were:

	Cost($)	Relative Effectiveness
	2,500	Not Rated
1967-68 level -	3,000	0.75
	4,000	0.80
	5,000	0.92

2. The Physical Examination Program

In considering the Physical Examination Program, the Nursing Coordinator felt that increases in program performance could be realized by adding medical doctor resources to the program. The disposition of cases would speed up and bring about better performance scores on follow-up efforts. As in the case of the Annual Screening Program, the comment on private physicians also applies here.

Small reductions in expenditures from the 1967-68 level would result in serious losses in relative effectiveness, according to the Coordinator, while increases in resources would not contribute very much.

The Nursing Coordinator's estimates of relative effectiveness responses to selected cost investments were:

	Cost($)	Relative Effectiveness
	2,000	Not Rated
	2,400	0.50
1967-68 level -	3,400	0.82
	4,400	0.83
	5,400	0.84
	6,400	0.85

3. The Communicable and Infectious Disease Program

The Nursing Coordinator indicated that the diseases included in this program did not usually present serious problems in the Senior High School at Radnor. She did point out that the nature of the problem was different in lower grades. To communicate the nature of the high school problem she cited the Tuberculosis screening effort for school 1967-68. The effort yielded no positive reactors.

Her feeling was that it would be fruitful to provide classroom instruction on communicable and infectious diseases. When questioned about a $500 reduction from the 1967-68 expenditure level, she remarked that this would be sufficient to "wipe out the program." The estimates of the cost-effectiveness relationships were:

	Cost($)	Relative Effectiveness
	400	0.30
1967-68 level -	900	0.73
	1,400	0.75
	1,900	0.76

4. The Emergency Program

The Nursing Coordinator had responsibility for the Emergency Program. She felt that additional money could increase effectiveness by freeing the nurse from paper work.

A $500 cut from the present level of expenditures would have to be absorbed by medical supplies or the time spent by the nurse in the program. The nurse indicated that either of these alternatives would reduce relative effectiveness to a 0.65 level. Interestingly enough, a $1,000 reduction would not do very much more damage to the program.

The estimates of cost-effectiveness relationships provided by the nurse were:

	Cost($)	Relative Effectiveness
	2,600	0.60
1967-68 level -	3,100	0.65
	3,600	0.97
	4,600	0.99

5. The Follow-up Program

The nurse's comments here were related to the need for paraprofessional assistance to reduce the burden of paper work. As a result the nurse would be able to spend more time on the telephone for follow-up purposes. The Author did not discuss dollar resources with the Nursing Coordinator in connection with this effort. (The 1967-68 cost-effectiveness point was described by a $180 expenditure and a 0.95 index of relative effectiveness.)

6. The Health Education Program

Since no administrator at Radnor had coordinated health education matters, the Assistant Superintendent accepted this responsibility. He indicated that by 1970 the Health Education Program could be expected to be more effective. This change would come about when a health education lecture room would be made available and when a person would be assigned the coordination of these functions.

A slight increase in activity level could be brought about in 1968-69 by providing film strips and other educational materials for teachers to use. The Assistant Superintendent for Curriculum's cost-effectiveness estimates were:

	Cost($)	Relative Effectiveness
	2,000	0.50
1967-68 level -	3,000	0.57
	3,500	0.58
	5,000	0.80

7. The Physical Education Program

The Physical Education Program accounted for approximately one half of the 1967-68 total expenditure of $53,000. The Physical Education Coordinator indicated that there was competition between this program and the newly instituted Adapted Physical Education Program. The competitiveness centered on the need for equipment. Other important needs were physical facilities and physical education personnel. The possibility of facilities being increased is remote, but personnel are needed to lower class size so that increased emphasis can be given to individual sports and individual needs.

Increases of $1,000 and $2,000 should be accompanied by increases in effectiveness in the area of fitness since these resources would be directed to the purchase of equipment. Pupil confidence could also be expected to improve.

A $5,000 increase would go toward hiring an additional physical education teacher as would a $7,000 addition. These resources would be devoted toward program performance aimed at lifetime sports.

A drop of $1,000 would reduce effectiveness substantially. The largest losses could be expected in the lifetime sports activity and the variety of offerings activity. Still greater decreases in the level of resources would "push effectiveness way down".

The Physical Education Coordinator's cost-effectiveness estimates were:

	Cost($)	Relative Effectiveness
	24,300	0.60
	25,300	0.70
	26,300	0.78
1967-68 level -	27,300	0.85
	28,300	0.88
	29,300	0.90
	32,300	0.93
	34,300	0.95

7. The Adapted Physical Education Program

The Physical Education Coordinator indicated that improvement for this program is tied to three factors - space, personnel and equipment (this comment is similar to the Physical Education Program discussion).

In response to the question "what would be helped if you add $1,000?" she replied that the money could be used for more equipment. As the amount of available funds increased she would apply the expenditures to personnel.

With a large increase to $17,800 she could purchase equipment and hire 70% of a new person. Her estimate was that program effectiveness would rise to about 0.95.

The Coordinator felt strongly that the program would experience decreases in effectiveness across all objectives if expenditures were reduced.

Cost-effectiveness estimates from the Physical Education Coordinator were:

	Cost($)	Relative Effectiveness
	10,800	0.70
	11,800	0.81
1967-68 level -	12,800	0.82
	14,800	0.85
	17,800	0.95

APPENDIX F

ELASTICITY OF COST-EFFECTIVENESS CALCULATIONS

This appendix provides the data and calculations underlying the seven sets of Elasticity of Cost - Effectiveness outputs.

1. The 1967-68 basic outputs
2. The addition of $6,000 to 1967-68 funds, allocated by strategy B and resulting outputs
3. Strategy S outputs
4. Strategy H outputs
5. The triple $V(O_C)$ case and resulting outputs under 1967-68 outcomes
6. The triple $V(O_E)$ case and resulting outputs under 1967-68 outcomes
7. The triple $V(O_E)$ case with $5,500 allocated by strategy B and resulting outputs

The seven output sets are presented on the next seven pages. Each set is referenced to the page of the text first showing the results.

<u>Output Set 1</u>

	ΔE	ΔC ($)	$E-\Delta E$	$C-\Delta C$ ($)	$\frac{\Delta E}{\Delta C}$ ($)	$\frac{E-\Delta E}{C-\Delta C}$ ($)	$\frac{\Delta E/\Delta C}{E-\Delta E/C-\Delta C}$
1	50.9	2,961	435.2	50,157	0.01719	0.008677	1.98
2	72.9	3,385	413.2	49,733	0.02154	0.008308	2.59
3	30.8	913	455.3	52,205	0.03374	0.008721	3.87
4	156.6	3,595	329.5	49,523	0.04356	0.006653	6.55
5	5.0	180	481.1	52,938	0.02778	0.009088	3.06
6	18.1	3,000	468.0	50,118	0.00603	0.009338	0.64
7	114.1	27,259	375.9	25,859	0.00404	0.014536	0.28
8	41.6	11,825	444.5	41,293	0.00352	0.010764	0.33
	486.1	53,118					

Note: The last column is shown on page 124 as $(E/C)_m$.

Output Set 2

	ΔE	ΔC ($)	$E-\Delta E$	$C-\Delta C$ ($)	$\frac{\Delta E}{\Delta C}$ ($)	$\frac{E-\Delta E}{C-\Delta C}$ ($)	$\frac{\Delta E/\Delta C}{E-\Delta E/C-\Delta C}$
1	62.8	4,961	455.2	54,157	0.01266	0.008405	1.51
2	72.9	3,385	445.1	55,733	0.02154	0.007986	2.70
3	32.7	1,413	485.3	57,705	0.02314	0.008410	2.75
4	159.8	4,595	358.2	54,523	0.03478	0.006570	5.29
5	5.0	180	513.0	58,934	0.02778	0.009804	3.19
6	25.1	4,500	492.9	54,618	0.00558	0.009024	0.62
7	118.1	28,259	399.9	30,859	0.00418	0.012959	0.32
8	41.6	11,825	476.4	47,293	0.00352	0.010073	0.35
	518.0	59,118					

Note: The last column is shown on page 135 as $(E/C)_m$ (Strategy B).

Output Set 3

	ΔE	ΔC ($)	$E-\Delta E$	$C-\Delta C$ ($)	$\frac{\Delta E}{\Delta C}$ ($)	$\frac{E-\Delta E}{C-\Delta C}$ ($)	$\frac{\Delta E/\Delta C}{E-\Delta E/C-\Delta C}$
1	62.8	4,961	462.9	60,157	0.01266	0.007695	1.64
2	72.9	4,385	452.8	60,733	0.01685	0.007456	2.26
3	32.7	1,413	493.0	63,705	0.02314	0.007739	2.99
4	159.8	4,595	365.9	60,523	0.03478	0.006046	5.75
5	5.0	180	520.7	64,938	0.02778	0.008018	3.46
6	25.1	4,500	500.6	60,618	0.00558	0.008258	0.68
7	118.1	28,259	407.6	36,859	0.00418	0.011058	0.38
8	48.3	16,825	477.4	48,293	0.00287	0.009885	0.29
	525.7	65,118					

Note: The last column is shown on page 135 as $(E/C)_m$ (Strategy S).

Output Set 4

	ΔE	ΔC (\$)	$E-\Delta E$	$C-\Delta C$ (\$)	$\frac{\Delta E}{\Delta C}$ (\$)	$\frac{E-\Delta E}{C-\Delta C}$ (\$)	$\frac{\Delta E/\Delta C}{E-\Delta E/C-\Delta C}$
1	62.8	4,961	475.2	70,157	0.01266	0.006773	1.87
2	75.6	6,385	462.4	68,733	0.01184	0.006727	1.76
3	33.1	1,913	504.9	73,205	0.01730	0.006897	2.51
4	159.8	4,595	378.2	70,523	0.03478	0.005363	6.48
5	5.0	180	533.0	74,938	0.02778	0.007112	3.91
6	25.4	5,000	512.6	70,118	0.00508	0.007310	0.69
7	127.5	34,259	410.5	40,859	0.00372	0.010047	0.37
8	48.8	17,825	489.2	57,293	0.00272	0.008538	0.32
	538.0	75,118					

Note: The last column is shown on page 135 as $(E/C)_m$ (Strategy H).

Output Set 5

	ΔE	ΔC ($)	$E-\Delta E$	$C-\Delta C$ ($)	$\frac{\Delta E}{\Delta C}$ ($)	$\frac{E-\Delta E}{C-\Delta C}$ ($)	$\frac{\Delta E/\Delta C}{E-\Delta E/C-\Delta C}$
1	50.9	2,961	709.4	50,157	0.01719	0.014144	1.22
2	72.9	3,385	687.4	49,733	0.02154	0.013822	1.56
3	30.8	913	729.5	52,205	0.03373	0.013974	2.41
4	425.9	3,595	334.4	49,523	0.1184[illegible]	0.006752	17.54
5	5.0	180	755.3	52,938	0.02778	0.014268	1.95
6	18.1	3,000	742.2	50,118	0.00603	0.014809	0.41
7	114.1	27,259	646.2	25,859	0.00418	0.024989	0.17
8	41.6	11,825	718.7	41,293	0.00352	0.017405	0.20
	760.3	53,118					

Note: The last column is shown on page 139 as $(E/C)_m$.

Output Set 6

	ΔE	ΔC ($)	$E-\Delta E$	$C-\Delta C$ ($)	$\frac{\Delta E}{\Delta C}$ ($)	$\frac{E-\Delta E}{C-\Delta C}$ ($)	$\frac{\Delta E/\Delta C}{E-\Delta E/C-\Delta C}$
1	50.9	2,961	649.6	50,157	0.01719	0.012951	1.33
2	72.9	3,385	627.6	49,733	0.02154	0.012619	1.71
3	30.8	913	669.7	52,205	0.03373	0.012828	2.63
4	156.6	3,595	543.9	49,523	0.04356	0.010983	3.97
5	5.0	180	695.5	52,938	0.02778	0.013138	2.11
6	18.1	3,000	682.4	50,118	0.00603	0.013616	0.44
7	291.0	27,259	409.5	25,359	0.01068	0.015836	0.67
8	74.2	11,825	626.3	41,293	0.00627	0.015167	0.41
	700.5	53,118					

Note: The last column is shown on page 143 as $(E/C)_m$.

Output Set 7

	ΔE	ΔC (\$)	$E-\Delta E$	$C-\Delta C$ (\$)	$\frac{\Delta E}{\Delta C}$ (\$)	$\frac{E-\Delta E}{C-\Delta C}$ (\$)	$\frac{\Delta E/\Delta C}{E-\Delta E/C-\Delta C}$
1	62.8	4,961	655.5	53,657	0.01266	0.012213	1.04
2	72.9	3,385	645.5	55,233	0.02154	0.011687	1.84
3	30.8	913	687.6	57,705	0.03373	0.011916	2.83
4	156.6	3,595	561.8	55,023	0.04356	0.010210	4.27
5	5.0	180	713.4	58,438	0.02778	0.012208	2.28
6	25.1	4,500	693.3	54,118	0.00558	0.012811	0.44
7	291.0	29,259	427.4	29,359	0.01053	0.014558	0.72
8	74.2	11,825	644.2	46,793	0.00627	0.013767	0.46
	718.4	58,618					

Note: The last column is shown on page 146 as $(E/C)_m$ (After \$5500).

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