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DECISION AIDS FOR RESOURCE ALLOCATION IN PUBLIC SECTOR MULTIPLE OBJECTIVE LINEAR PROGRAMMING APPLICATION IN CRIMINAL JUSTICE SYSTEM.

THE OHIO STATE UNIVERSITY, PH.D., 1979

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DECISION AIDS FOR RESOURCE ALLOCATION IN PUBLIC SECTOR
MULTIPLE OBJECTIVE LINEAR PROGRAMMING APPLICATION
IN CRIMINAL JUSTICE SYSTEM

DISSertation
Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By
Gopalakrishna Rao Kodali, B.E., M.Tech., M.S.

* * * * *

The Ohio State University
1979

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ACKNOWLEDGMENTS

I am deeply grateful to Dr. William T. Morris, my adviser, for his guidance, encouragement and very helpful suggestions. I sincerely appreciate the time he spent with me and his willingness to find time readily in his busy schedule. I wish to express my appreciation to Dr. Albert B. Bishop and Dr. Gordon M. Clark for serving on the reading committee and for their suggestions which improved the final draft. Also, I would like to thank Dr. Simon Dinitz for serving as Graduate School Representative and for his helpful comments.

I wish to acknowledge my indebtedness to Dr. Ralph W. Swain for suggesting the Multiple Objective Linear Programming Model as part of his General Examination question. My thanks go to Dr. Clark A. Mount-Campbell for discussing the algorithmic details with me. I would also like to thank Dr. William M. Rhodes for sending me unpublished detailed data from the study reported in "The Economics of Criminal Courts".
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CHAPTER 1
INTRODUCTION

Program evaluation in the public sector has received considerable attention as the effectiveness of the increased funding of the social programs during the past decade has become an important issue. The processes of decision making in resource allocation and program evaluation in the public sector are analyzed to develop decision aiding methods. Decisions have to be made in allocating resources to programs that are continuing and new, that would have impact on different components of the system and that pursue different objectives of the system. Development of decision aiding methodology for resource allocation on a routine basis in the planning process of the public sector is the main interest of this research rather than the evaluation of an individual program in a special study.

The resource allocation process in industry and several other areas has received considerable attention and there are several methods and models available. However, most models consider a single objective and other models which consider multiple objectives need preferences, values or weights for the objectives extracted from the decision maker without providing him much information. The resource allocation process in the public sector is different from other areas in the aspect that the programs have noncommensurable outputs and inputs. The decision aids for program evaluation in the public sector need
solution strategies for solving multiprogram multiobjective planning which is a complex problem.

OBJECTIVES AND SCOPE OF THE STUDY

The nature of the objectives and resource requirements of programs in the public sector increases the complexity of resource allocation decisions in the public sector in comparison to the private business. The basic objectives of this study is to develop a decision aiding method for resource allocation decisions and program evaluation in the public sector using the Criminal Justice System (CJS) as an example. Program evaluation in the CJS has received a big boost with the enactment of the "Safe Streets Program," and the creation of the National Institute of Law Enforcement and Criminal Justice (NILECJ) and the State Planning Agencies.

A Multiple Objective Linear Programming (MOLP) model is considered to provide structure to the definition and data collection efforts to the problem. The solution of vector maximization problem reduces the number of solutions to be considered from the set of all feasible solutions to the set of nondominated solutions by dropping all the inferior solutions. The feasible range for the weights of the objectives associated with each of the nondominated solutions are sources of information that could be provided to the decision maker from the analysis. In the reduction of nondominated solution set to a preferred solution, an interactive approach is utilized to extract the preferences of the decision maker in the form of a range rather than a single number as in direct value assessment. In this approach,
the decision maker is working in the objective space while the analyst and the computer are converting it into the decision space providing a good division of work in accordance with the often quoted statement "Managers should Manage, Analysts should Analyze and Computers should Compute".

A time sharing program that allows the access to the computer through a portable terminal in the decision maker's office and that allows the decision maker to interact with the model is used for the implementation of this approach. The information flow and organizational concepts of the decision aiding methodology developed are shown in Figure 1-1. The emphasis of this effort is in developing meaningful information from the analysis to aid the decision maker in the formulation and expression of his value judgements for multiple objectives. A true decision aid which helps the decision maker in the decision problem of choosing between multiple objectives is expected as a result of this interactive approach rather than the measurement on a single criteria and mechanical ranking of programs provided by the traditional decision making aids addressing the measurement problem.

Joscelyn (1975) addressed the development of Decision Aids for Regional Criminal Justice Planning. Joscelyn concentrated on describing the operating environment of the allocation decision and data collection effort, and used measures of worth based on the concepts of utility theory and augmented by several heuristic models, in developing decision aids. As already stated in the paragraphs above, this study concentrates on treating the multiple objectives explicitly
Figure 1-1 Information flow and organizational concepts of the methodology
and making the model interact with the decision maker in extracting his value structure for the objectives. So this study uses a different approach from Joselyn's study in developing Decision Aids for Resource Allocation Decisions in the CJS.

This research is concerned with development of a decision aiding methodology by formulating the resource allocation decision problem in the public sector as a MOLP model and by demonstrating the implementation feasibility through the development of interactive solution procedures. The methodology of formulating and solving a MOLP model as a decision making aid is developed with the CJS as an example. The fragmented approaches of the performance measures used in the published criminal justice literature are unified and extended in formulating the MOLP model. The model formulated is kept simple so that the coefficients of the model could be estimated from the empirical studies in the published literature. The model had to be kept small also to keep the computational requirements within the available computer time. The formulated model is suggested only as an example or as an initial model to start the development of the model in the organization interested in implementing it. The involvement of the decision makers in defining the objectives is as important for the successful implementation of the methodology as their involvement in the interactive procedure in expressing their preference structure for the objectives. The characteristics of performance measures are discussed in detail to help the definition of performance measures to be used as objectives of the model.

Multicriteria Simplex Method and Decomposition of Parametric Space
developed by Yu and Zeleny (1975) is the basis for the algorithm and the computer programs used in the solution of the formulated MOLP model. The vector maximization program published by Zeleny (1974) is modified to work properly and to pass the nonredundant equations that define the value space of each nondominated solution to the interactive computer program. Zeleny (1973) used two dimensional graphic approach to reduce the nondominated solution set to a preferred solution for a problem with three objectives. He used normalized values and substitution to reduce the dimensions of value space to two. This approach works only for problems with three objectives. The model as formulated has five objectives. The interactive solution procedure developed in this research is applicable to solving the problems with any number of objectives. The two dimensional graphic approach is extended to work with any number of dimensions by solving a set of linear programs to find the limits of value space. These limits are provided by the interactive procedure for each of the nondominated solutions as information input to the decision maker.

The MOLP model identifies separately the measurement problem of mechanical or routine measurement of each program using some performance measures and the decision problem of deciding trade-offs among multiple objectives. The major emphasis of this research effort is in aiding the decision maker with the decision problem. However, the accurate measurement is an essential requisite for valid development of trade-offs in the decision problem. Most of the current evaluation methods concentrate on the measurement problem.
In Chapter 2, the methods used in published evaluation studies indicating the current state of the art in criminal justice program evaluation are described. Most of the recent literature, except for a few econometric studies, concentrates on evaluating a program after it is implemented. But for the resource allocation decisions, a program must be evaluated prior to its implementation. The applicability of the current evaluation methods to evaluate a proposed program is discussed under the classifications: Experimental Methods, Cost-Benefit and Cost-Effectiveness Analyses, Econometric Methods, Simulation Methods, and other methods. Most of the current evaluation methods concentrate on the measurement problem and expect the decision maker to face the decision problem of choosing values for objectives without much help from the analysis. The multiple objective problem present in the public sector is frequently solved by the translation of nonmonetary criteria into monetary terms. The compression of noncommensurable entities reduces their information content and the value judgements of the decision maker are not considered explicitly and sometimes even ignored completely.

In Chapter 3, several Multiple Criteria Decision Making (MCDM) methods which consider multiple objectives explicitly are discussed. The multidimensional scaling techniques and regression methods used in psychological research and marketing research studies are more inclined toward describing the process of decision making in situations involving multiple criteria, and to predict the decision maker's action in future decisions. The weighting methods and the mathematical
programming methods from the management science approach are prescriptive in nature and are directed toward providing practical decision aiding techniques to improve the decision making process. The interactive approach of the mathematical programming methods will be very useful in resource allocation decisions in social systems due to its changing emphasis towards the descriptive approach used by social scientists and its origin in mathematical programming methods used in industrial resource allocation decisions.

The development of decision aids for resource allocation can be effective only when the objectives and performance measures that can be used in all components of the system are developed. The state of the performance measures and their impact on the analysis of resource allocation decision in the public sector is well identified in the following statement by Schultz (Quade, 1975, p. 4)

.....government programs rarely have an automatic regulator that tells us when activity has ceased to be productive or could be made more efficient, or should be displaced by another activity. In private business, society relies upon profits and competition to furnish the needed incentives and discipline and to provide a feedback on the quality of decisions. The system is imperfect, but basically sound in the private sector -- it is virtually nonexistent in the government sector. In government, we must find another tool for making the choices which resources scarcity forced upon us.

As Schultz implies, we must seek alternatives to profits as indicators for automatic regulation of activities and programs. A 'good' set of performance measure would serve this purpose but the problem is in developing an operationally feasible and yet conceptually holistic performance measures.
The major emphasis of this research effort is in routinizing the program evaluation for resource allocation decisions. So the definitional and data reporting problems of the performance measures are addressed in detail in Chapter 4. The crime rate and recidivism deserve special attention because these two performance measures are widely used in law enforcement and corrections effectiveness evaluations reported in the current literature. Deterrence is the basic underlying phenomenon used by the most criminal justice systems in the world and it is also the phenomenon whose effectiveness has drawn considerable attention and controversy in the literature. The performance measures used in the current evaluation studies are mostly developed for the individual components of the CJS. The performance measures for Law Enforcement, Corrections, and Courts need to be addressed separately as subsystems and as a whole for the total CJS. The properties that a set of performance measures should have are discussed to help the development in the specific context. Some of the characteristics of the CJS, eg., fragmentation of the system and diversity of objectives, highlight the differences between the industry and the public sector resource allocation decisions.

The formulation of the problem is described in Chapter 5. The model is formulated for the allocation of the total criminal justice expenditures in the U. S. among Police, Corrections, Prosecutor and Legal Service, Public Defense and Judiciary. The expenditures and crime rate are expressed in per capita basis to avoid the rounding problems due to the difference in magnitudes of the coefficients of the model. The coefficients of the objective functions in the model are
estimated from the conclusions drawn in the published empirical studies.

The algorithmic steps for solving the vector maximization problem are described in Chapter 6. The interactive solution procedure, the extension of graphic approach of two dimensional case for any number of dimensions is also described in Chapter 6, deferring program details to Appendix. Finally, the conclusions of this research are summarized in Chapter 7.
CHAPTER 2
CURRENT EVALUATION METHODS

The evaluation of programs in the CJS and the need for better methods of evaluation have received authoritative emphasis in the Crime Control Act of 1973 which directed NILECJ to evaluate the various programs and projects to determine their impact upon the quality of law enforcement and criminal justice. However, a review of recent literature suggests that there is widespread pessimism about the impact of evaluation studies on implemented policy and allocation of resources (Wholey, 1976, pp. 46 - 51; Adams, 1975; Stanley, 1974; Lewis and Zarb, 1974; Morehouse, 1972). The current evaluation methods are reviewed in this chapter to show some of the difficulties in their implementation, to highlight some of the shortcomings of the methods, and to establish the need for improved methods.

The basic task of decision aiding methodology for resource allocation is the comparison of alternative programs competing for resources. The evaluation research is concerned with the application of social science theory and methodology to improve the rationality of policy making and developing better social programs. The following definition by Adams, an extension of Suchman's definition, shows how evaluation research is addressing the measurement problem in resource allocation decisions.
Evaluation is a procedure for ascertaining whether an event, process or situation (real or conceptualized) is better than another. The procedure may include steps for measuring 'how much better' and for explaining the reasons for the difference.

The discussion of current evaluation methods is started with the cost-effectiveness analysis which is gaining popularity in the evaluation of criminal justice programs.

COST-BENEFIT AND COST-EFFECTIVENESS ANALYSES

Cost-benefit and cost-effectiveness analyses are analytical methods designed to aid a decision maker in choosing a preferred project or program from among possible alternatives. Quade (1971) quoted the following statement from the first treatise on cost-effectiveness he is aware of, a 980 page volume by A.M.Wellington entitled: The Economic Theory of the Location of Railways, 1887.

"...engineering.... In a certain important sense it is rather the art of not constructing; or, to define it rudely but not inaptly, it is the art of doing that well with one dollar, which any bungler can do with two"

The authorization of federal participation of flood-control schemes by the Flood Control Act in 1936, "if the benefits to whomsoever they may accrue are in excess of the estimated costs", increased the practice of making analysis and led to the development and widespread use of cost-benefit analysis (Quade, 1975, p.27). According to Hammond (1958) it was "in origin an administrative device owing nothing to economic theory and adapted to a strictly limited type of federal activity."

In their excellent survey of cost-benefit analysis Prest and Turvey (1965) have the following description of the technique.
Cost-benefit analysis is a practical way of assessing the desirability of projects, where it is important to take a long view (in the sense of looking at repercussions in the further, as well as the nearer, future) and a wide view (in the sense of allowing for side effects of many kinds on many persons, industries, regions, etc.), i.e., it implies the enumeration and evaluation of all the relevant costs and benefits.

In practice this amounts to estimating both the benefits and costs in monetary units using the proven theory, known facts and several uncertain parameters pertaining to the project; and fails to take into account a host of intangible considerations which cannot be expressed in monetary terms. The widely varying views on cost-benefit analysis are well described by Prest and Turvey: "one can view cost-benefit analysis as anything from an infallible means of reaching the new utopia to a waste of resources in attempting to measure the unmeasurable."

In the analysis for military development and procurement decisions, the difficulty in the conversion of benefits to monetary terms led to the cost-effectiveness analysis. In this type of analysis, attention was focused on the comparison of alternative courses of action in terms of their costs and their effectiveness in attaining some specific objective because the costs and effectiveness are not commensurable. The effectiveness estimation and measurement presented several problems and required various scales and units depending on the nature of the objective. A model which abstracts the features of the alternatives being considered is used in predicting the effectiveness. These models could be very diverse in nature ranging from simple verbal descriptions or scenarios to complex mathematical equations or computer programs.
The results of the analysis provide only the estimates of costs and effectiveness of each of the alternatives, but not a ranking of the alternatives unless either cost or effectiveness is fixed at a pre-specified value. The decision maker must interpret the assessments of the analysis in the light of his own value judgements and knowledge of other intangible factors, to select the preferred alternative. The ratio of effectiveness to cost are used in some studies, but Hitch (1953) described ratios as "particularly treacherous as Operations Criteria" citing two interacting reasons: "(a) They ignore the absolute magnitudes of both numerator and denominator. (b) Solutions with ratio criteria tend, in many operations problems to rush to corners." In some simple cases, the alternative with minimum cost that satisfies a program objective or, conversely, the alternative that has maximum value of the effectiveness measure subject to a budget constraint can be selected. Fox (1965) extended this approach to screen clearly inferior solutions when cost and effectiveness are available as a range rather than a point estimate by treating them as random variables.

Admiral Rickover's statements in hearings before a subcommittee of the Committee on Appropriations, House of Representatives, quoted by Raiffa (1970) and Quade (1971), point out limitations in the practice of cost-effectiveness so eminently.

Since the calculations are extensive and complex, the experienced people in positions of management responsibility do not have the time or the detailed understanding to review them. Judgement as to the weight that should be given to various factors in the analysis is left to the analyst himself instead of to the judgement of people who have experience in the field that is being analyzed....
The basis for using cost-effectiveness studies as the rationale on which to make a decision is the assumption that the important factors can be expressed in numerical form and that a correct judgement of the situation can then be calculated mathematically. But for most complex situations this is an unrealistic assumption. Frankly, I have no more faith in the ability of the social scientists to quantify military effectiveness than I do in numerologists to calculate the future.

Far more emphasis has been placed on determining the cost than on studying the military effectiveness. All factors of military effectiveness for which the analyst cannot calculate a numerical value have automatically been discarded from considerations.

Cost-effectiveness analysis may be helpful in arriving at an answer if their limitations are understood and if they are used properly.

Prest and Turvey state an important benefit of the study as that "it forces those responsible to quantify costs and benefits as far as possible rather than rest content with vague qualitative judgments of personal hunches. This is obviously a good thing in itself; some information is always better than none." Williams (1973) also defended cost-benefit analysis on the basis that it is not perfect but it is better than several alternatives. The value of these techniques is greatly improved, if their limitations are openly recognized and they are treated as tools to improve the efficiency of the decision maker while making explicitly clear that it should not be regarded as a substitute for the judgement of the experienced decision maker. The state of the cost-effectiveness analysis is well expressed by Quade in the statement, "After twenty years of experience with defense problems, proponents of cost-effectiveness analysis have nearly but not
completely won over its detractors."

The cost-benefit analysis received a boost in the analysis of social problems with the extension of the PPBS activity throughout the federal government in 1965 (Lyden and Miller, 1972, p. 2). Thurow and Rappaport (1969) used cost-benefit analysis in law enforcement. They analyzed the relationship between economic crimes and enforcement of the Fair Labor Standard Act using for the benefit measure, amount of 'back wages found due' that were actually paid to the employee plus the present value of wages paid as a result of future compliance engendered by the investigative activities. By subtracting investigating costs from the benefits derived, net benefits were calculated for the investigation of various size establishments in different industries. Alternative strategies of investigation to maximize benefits by investigating a given number of workers or spending a given amount of money are developed using the net benefit data for establishments of various sizes in several industries. Deterrent effects on firms other than the one under investigation were not included in the study, so the estimates of net benefits are conservative. The analysis described here indicates that systematic empirical analysis can lead to large improvements in the net benefits received from law enforcement or large cost reductions. Thurow and Rappaport considered the problem of valuing human life and deliberately avoided it, stating that most crimes are economic and that cost-effectiveness analysis could be applied to crimes against both persons and property.

Blumstein (1971) illustrated an approach to cost-effectiveness
analysis of social services and systems by applying it to the allocation of police resources. Several alternatives to reduce the police response time, increasing the public call boxes, increasing the number of complaint clerks to reduce the telephone queuing delay, computerizing the command-and-control center, providing the precise car position to accurately select the closest car, and reducing area of coverage by a car to reduce travel time were evaluated using seconds of delay saved per dollar allocated as measure of effectiveness. The detailed calculations to estimate the measure of effectiveness using the values of several parameters for 100 square miles city with a population of about 500,000, comparable to Atlanta or Indianapolis, indicate that the most useful investment would be computerizing the command-and-control center for the conditions represented in the case. There are several other benefits associated with each of the alternatives besides the reduction of delay in processing a call. More iterations of the analysis, i.e., dropping some obviously inferior alternatives at each stage and analyzing the remaining ones at greater precision, and gaining the confidence of decision makers in the measures of effectiveness, are suggested by Blumstein prior to the implementation of the preferred alternative. The cost-effectiveness analysis as illustrated in this article can be criticised on most of the limitations of cost-effectiveness analysis discussed above; however, it is an illustration of an initial start and suggestion of several iterations to improve it underscores the importance of avoiding some of the pit falls.
Monkman (1974) illustrated several levels of application of cost-benefit analysis in evaluating correctional programs by reviewing three analyses conducted in different agencies. A gross costs-savings approach comparing subsidy costs with construction and operations savings is presented using the extracts from California's Probation Subsidy Program. Analyses of the Dade County Pre-trial Intervention Project and the New York City Supported Work Program are reviewed to present a more detailed approach to cost-benefit analysis.

Tropman and Gohlke (1973) considered the value of analysis or the Meta Decision Problem in the terminology of Morris (1972) and discussed the question of whether the benefits of cost-benefit analysis are sufficient to outweigh the cost in its adoption in corrections. The development of style and system of thought required by these approaches is emphasized as step towards significant progress in decision making in corrections rather than the mathematical analysis conventionally associated with the approach. The use of cost-benefit analysis is justified on the basis that it provides structure for the information gathering on alternatives; makes the assumptions of budget decisions explicit; and systematizes decision making process.

Two of the publications in evaluation research by Glaser (1973) and Adams (1975), aimed at routinizing and practical implementation of evaluation function, described cost-benefit analysis as conducive to routinization of evaluative research and as a versatile and powerful technique that increases the ability of the evaluator in providing agency administrator a more precise and convincing language for the
support of productive programs. Among several reasons for introducing monetary criterion into correctional evaluation, Adams stated that the monetary criterion provides a common denominator that translates behaviors into economic consequences and permits easier summation and analysis. It is also suggested that the monetary criterion is more powerful and more versatile than the behavioral criterion. The cost-benefit analysis is new to the correctional evaluation research. So some of these enthusiastic endorsements and use should be tempered in the light of limitations and criticism expressed in the defense evaluation if the application of cost-benefit analysis is to be successful in criminal justice evaluation.

**ECONOMETRIC METHODS**

A number of studies attempting to explain crime using economic analysis of choice have appeared following the attention focused by the President's Crime Commission on need for an objective assessment of the CJS as a whole. Becker (1968) in an attempt to develop optimal policy rules formulated the theoretical model of crime using modern utility concepts and provided the basic structure of the model used in most of the economic studies. The basic equation for the supply of offenses is developed on the hypothesis that there is a function relating the number of offenses by any person to his probability of conviction, to his punishment if convicted and to other variables, such as the income available to him in legal and other illegal activities, the frequency of nuisance arrests, and his willingness to commit an illegal act.
By summing the offenses of all the persons and representing the probability of conviction, punishment per conviction and all other influences by the average values, the supply of offenses function for a geographical entity can be represented as

$$ O = O(p, f, u) $$

where
- $O$ - Number of offenses in the geographical area,
- $p$ - Probability of conviction,
- $f$ - Punishment per convicted offense,
- $u$ - Variable representing all other influences.

The cost of apprehension and conviction is related to the offenses cleared by conviction, represented as the product of probability of conviction and the number of offenses; and the police activity, represented as arrests etc. In a general approach dropping the implication that $p$ and $O$ have identical elasticities, the cost of law enforcement function can be represented as

$$ C = C(p, O, a) $$

where
- $C$ - Cost of apprehension and conviction,
- $p$ - Probability of conviction,
- $O$ - Number of Offenses in the geographical area,
- $a$ - Arrests and other determinants of law enforcement activity.

A criterion function that considers the damages from offenses, the cost of apprehending and convicting offenders, and the social cost of punishments is required for the development of optimal policies. Social loss function which can serve such a purpose can be written as
L = D(0) + C(p, 0, a) + qfp0

Where

L - Social loss

D - Damages to the society due to offenses. Expressed as difference of harm to victims and gain of offenders. Represented as a function of offenses.

C - Cost of apprehension and conviction

qfp0 - Total social loss from punishment; qf - loss per offense; p0 - number of offenses punished.

Harris (1970) extended the Becker's analysis to consider social choice of legal framework. The social costs felt by the over enforcement of the laws is added to the model by Harris. Stigler (1970) used a similar analysis and marginal cost concept in his study of optimum enforcement of laws.

Several empirical studies attempted the test of Becker's comprehensive model which integrated the economic theory of crime and cost of law enforcement or police response to crime. Some of the earlier studies were concerned with the deterrent effect of law enforcement and estimated the model coefficients mainly to show negative coefficients on variables, probability of conviction (p) and punishment per conviction (f) in the supply of offenses function. The econometric approach of specifying the model based on theory and estimating the coefficients using regression analysis is used to evaluate the effectiveness of public expenditure on law enforcement activity in some of the later studies reviewed here.

Chapman (1976) estimated a four simultaneous equation model using cross sectional data of 147 cities in California with population between 20,000 and 100,000. The model specified for estimation
consists of the supply of property offenses function;

\[ O_p = b_{01} + b_{11}a + b_{21}u_1 \]

the supply of violent offenses function;

\[ O_v = b_{02} + b_{12}O_p + b_{22}a + b_{32}u_2 \]

the police production function;

\[ a = b_{03} + b_{13}M + b_{23}u_3 \]

and the police demand function;

\[ M = b_{04} + b_{14}O_p + b_{24}O_v + b_{34}u_4 \]

where

- \( O_p \) - Property offenses per capita,
- \( O_v \) - Violent offenses per capita,
- \( a \) - Arrest rate,
- \( M \) - Police manpower per capita,
- \( u_1, u_2, u_3, u_4 \) - Different sets of economic and environmental variables to reflect the condition in the city,
- \( b_{ij} \) - Coefficients of the model to be estimated by regression.

Chapman concluded that the results of model estimation are good and his empirical study had indicated that a simultaneous approach to the examination of the relationships between crime and police can be fruitful. The estimated coefficients of the model also show that the property crimes have a large effect on the demand for police.

Phillips and Votey (1975) used data for the counties of California in 1966 to estimate a four simultaneous equation model in logarithmic form. The relations specifying the model are the crime generation function,

\[ O = b_{01} p^{b_{11}} f^{b_{21}} u^{b_{31}} \]
effectiveness of criminal justice personnel function,

\[ p = b_{02} b_{12}^p M^{b_{22}} \]

demand for law enforcement personnel function,

\[ M = b_{03} b_{13}^M W^{b_{23}} u_3^{b_{33}} \]

Supply of law enforcement personnel or wage level of law enforcement personnel function,

\[ W = b_{04} M^{b_{14}} u_4^{b_{24}} \]

where  

- \( O \) - Crime in the community,
- \( p \) - Likelihood of conviction,
- \( f \) - Severity of sentence; in the actual estimation this is specified by two separate variables; sentence with probation and jail; and straight probation,
- \( M \) - Criminal justice personnel per capita,
- \( W \) - Wage rate of law enforcement personnel,
- \( u_1, u_3, u_4 \) - Socio-economic variables.

The three equation model estimated by Phillips and Votey is similar to Chapman's model except for the logarithmic form, inclusion of the crime rate in community as an explanatory variable in effectiveness of criminal justice function, and aggregation of both violent and property crimes in the crime generation function. The four equation model has an extra equation for supply or wage rate of law enforcement personnel and treats wage rate as an endogenous variable. The estimates of the four equation model were used to predict the values of the four dependent variables for three counties, however, only one variable for one of the counties is notably accurate. Phillips and Votey concluded that the results for criminal justice
effectiveness indicate that a rising crime rate will lower conviction ratios unless manpower is increased and that there is evidence to show that the demand for law enforcement personnel in communities is in response to minimizing the cost of crime.

Swimmer (1974) in his empirical study estimated a simpler two equation simultaneous model consisting of the supply of crime function and demand for police function. The coefficients of the equation for supply of crimes estimated using two stage least squares show that one dollar per capita increase in police expenditure is associated with 14% less murder, 11% less rape, 4% less robbery and 3% less burglary. Using the data from the report of the President's Commission on Law Enforcement for benefits from reducing each of the individual categories of crime, the total per capita benefits of one dollar per capita increase in police expenditures is calculated for low, medium and high crime rate cities as $.45, $.75 and $1.05 respectively. Swimmer argued that considering the evidence from other studies showing that the police spend only 20% of their time in crime control (remaining time is spent in traffic control and community service), the per capita benefits for one dollar expenditure on crime control on low, medium and high crime rate cities will turn out to be $2.2, $3.7 and $5.2 respectively. The actual benefit figures arrived in this analysis could be suspected because of the significance level of the coefficients in the model and general theory behind the specification of the model, however an extension of the results from econometric model estimation to arrive at the value of police expenditure is accomplished.
Mathieson and Passell (1976) used a similar approach of cost-benefit analysis on the basis of estimates from a simultaneous model of crime control. The data for two crime categories, robbery and homicide, in 1971 for all the precincts in New York City was used to estimate a three equation simultaneous model in logarithmic form consisting of the supply of offenses function, the police services production function and the allocation or demand for police function. The cost-benefit calculations were made using the cost per police officer, saving per victim in each of the robberies avoided by adding more police manpower, and savings in judicial processing and incarceration due to reduction in crime.

Hahn (1972) and Sullivan (1973) presented a review of economic approach and identified some of the areas which need further definition and understanding for the successful implementation of economic models. Tullock (1969) has demonstrated simple computational tools using the approach that society has a goal of minimizing social costs, in the areas of law enforcement such as illegal parking, motor vehicle code violations and tax evasion, where costs and benefits can be estimated easily. The suggestion that similar approach could be extended for other crimes has drawn the criticism and the discussion of validity of economic approach by Firey(1969). The argument by Firey is based on the calculability and dimensionality of utility used to express the relationships between private interest of the offender and the social interest of the executor or punishment. He suggests that a multi-dimensional concept of utility should be used to adequately express
the relationships, and identified the problems in application as rank ordering alternatives using Pareto optimality (vector maximization).

**SIMULATION AND ANALYTICAL MODELS**

Simulation is a process of model building and the recent use of the word refers to the mathematical or logical models developed on a digital computer for evaluating alternative operating policies. Naylor (1966) quoted the following definition by Shubik which is typical of the popular definitions.

A simulation of a system or an organism is the operation of a model or simulator which is a representation of the system or organism. The model is amenable to manipulation which would be impossible, too expensive or impractical to perform on the entity it portrays. The operation of the model can be studied and, from it, properties concerning the behavior of the actual system or its subsystems can be inferred.

An important advantage of computer simulation models is that models can be developed and solved for large systems which are so complex that it is impossible to describe them in terms of a set of mathematical equations, or impossible to solve the model even if it can be described mathematically. The detailed observation required for describing the model can lead to the better understanding of the system. A descriptive computer model is easier to explain than a mathematical model to a decision maker. A simulation model could be used for descriptive or predictive purposes. The validation of the model and verification that the important characteristics of the system are included in the models are crucial for its successful use in predicting outcome. The model could be validated by running it with
the historic data and checking for the accuracy in reproducing the outcomes that are being predicted.

The simulation of the processing of felony defendants through the court system in the District of Columbia developed by Navarro and Taylor is reported in the President's Commission's Task Force Report: Science and Technology (1967). The simulation model, called COURTISM, was operated, to pretest and evaluate the relative impact of various proposed policies.

The simulation models of the CJS help in the identification of crucial points of interaction among the components of a system and provide the capability to calculate the system-wide impact on flows and levels in the system such as number of criminals sent to prisons by courts, number of persons arrested and brought to trial and number of criminals in all prisons. The Flow Model, Police Submodel, Juvenile Court Submodels developed by Wilson, Bishop, et. al (1972) are the type of models that can provide estimates and projections of system flows through all the components of the system considering the total system. Belkin and Blumstein (1970) and Cohen, et. al (1973) have also presented similar models to understand the interaction in the system and to estimate changes in cost and system states due to policy or program change.

The fact that the assumptions of the model are explicit, and that the model can be run for several cases and the results can be duplicated is very useful for the fragmented CJS where a sizable organization with differing interests is interacting on a program. However, in some cases simulation is likely to be slow and cumbersome method of
attacking a problem in comparison to formulating an analytical model and solving it.

The Signal Flow Graph Model of Resource Flow in CJS described by Deutsch (NILECJ, 1976) to show the resource flow relationships between the component organizations is an example of an analytical model that could serve the same purpose as some simulation models. The feedback model of the CJS described by Bishop (1975) is more analytical in its approach and it can be used to estimate the impact of programs or policy changes on work loads and flow levels in different components of the system.

All of the models, both computer simulation and analytical, assume that the parameters used in the model such as branching ratio or probabilities of some events happening are available to model. These parameters have to be estimated from the historic data in available operations records or the data from past experimental studies. The predicted results from the models are only as good as the parameters input to the model. The effective use of the models will require good information systems of operations.

Another problem in use of models in the CJS is that the fundamental laws of behavior -- social or psychological -- are not as well accepted scientific principles as in the physical science disciplines. The use of models can be a powerful method for estimating the consequences of some programs from the knowledge of basic phenomena governing the human behavior. However, the estimated consequences can only be as credible as the theoretical assumptions built into the model describing
the system. The impact of recommendations derived by using models can be improved only with accumulation of theoretical knowledge of the cause-effect relationships gained by conducting and repeating properly designed experimental studies and careful observation of the system. The models cannot replace the experimental methods, they can only be used to extend the insights gained by the experimental methods.

EXPERIMENTAL METHODS

An experiment is carefully controlled observation and its rationale and procedures have been carefully refined in the basic science disciplines. The experiment is used in evaluation research in the attempt to design an experimental or demonstration program so that the results can be used by decision makers in the implementation of a full scale program. Some of the experimental studies in correctional experience are Pilot Intensive Counseling Organization (PICO) Project; Silver Lake Experiment; and Community Treatment Project developed from Preston Impact Study. In the experiments of physical sciences, measurements can be repeated another day and essentially the same result can be obtained. However in the experiments involving people the process of measurement can influence the results. The 'Hawthorne Effect' which refers to the improvement in all experimental subjects because of the knowledge that they are being measured, has to be considered in experiments with people. In measuring the effects of drugs, a placebo is used to avoid the confounding due to just paying attention to one group; however, the criminal justice programs do not
lend themselves to such techniques in all cases. This aspect of experimentation, i.e., the process of measurement influencing the results, is the basis for two of the nine threats of internal Validity, Instability and Testing, discussed by Campbell (1973). One of the key requirement of experiment is the ability of the researcher to manipulate an independent variable to measure its impact on the dependent variable while controlling all other variables. It is possible to control the experimental conditions in a laboratory for experiments in physical sciences, but serious difficulties come up in social sciences in controlling the other variables and manipulating the independent variable over a big enough range to produce measurable changes in the dependent variable. The heterogeneous nature of subjects in criminal justice programs create masking effects as treatments may have opposite effects upon different kinds of subjects. Because of the heterogeneity in subjects, even the random assignment of subjects to controlled and treatment groups may not result in similar groups in all characteristics.

In the controlled experiment, the effect of the treatment program is measured by applying it to a randomly selected group out of all eligible candidates, called the treatment group while withholding treatment from the other group referred as the control group. The controlled experiment has its unquestioned place in the basic research in testing hypothesis on cause and effect relationships and accumulation of scientific knowledge, however, its use in evaluative research of people changing programs is impractical, expensive or even impossible. One of the major problems is the moral issue of depriving the
individuals in the control group of treatment in random assignment. The quasi-experimental method which evaluates the effect of treatment program by means of information on a treatment group and a comparison group has gained wider application. To overcome the moral issue of treatment denial, the comparison group is not made by forming a control group using random assignment, but, by selecting a group similar to treatment group on the basis of historic information on characteristics that are known to influence the treatment effect. This method of selecting a comparison group from past history reduces the time required for evaluation and make the quasi-experimental method convenient and flexible.

All experimental methods using a controlled group or comparison group are prone to criteria problems in the criminal justice evaluation studies. Recidivism defined on a dichotomous scale is used in several studies without any consideration of so many other immediate effects that could result from the treatment. The experimental methods assume that a program has well defined objectives and that impact of programs on these objectives can be measured using proper experimental designs. In most of the evaluation efforts, the major task is the definition of objectives and it cannot be left entirely up to the researchers who are the experts in using the experimental methods as the choice of performance measures is not merely a technical task.

OTHER METHODS

Several other methods were discussed in the literature on the evaluation research. Most of them are specific data collection
procedures or special cases of the methods already discussed. Some of the more popular methods are discussed in this section.

Survey Methods

Surveys are systematic data collection procedures for collecting data from several sources with the purpose of drawing conclusions. The importance of the survey methods in criminal justice evaluation is highlighted by the following statement in the Report of the President's Commission on Law Enforcement and Administration of Justice, "The survey technique has great untapped potential as a method for providing additional information about the nature and extent of our crime problem and the relative effectiveness of different programs to control crime." Surveys can be conducted for collecting a variety of data from the respondent such as the extent of his knowledge on issues and problems, his attitudes towards policy alternatives, his future actions and his opinions. The popular victimization survey by LEAA is an example where the data based on the knowledge of the respondents is collected to determine the extent of unreported crime. Surveys can be directed to be either descriptive or evaluative. The descriptive surveys summarize the response and a profile of the target population is the result. In evaluative surveys, the responding groups are evaluated separately to provide data for comparison.

Some of the problems in using survey methods in criminal justice evaluation are discussed here. The accuracy and reliability of the sources could vary considerably and in general surveys, the data are aggregated without any regard to these issues. However the techniques
such as Delphi Method attempt to resolve the problem of reliability by attaching weights based on the level of expertise of the respondents in the area of subject in question. Similar to any other study, the survey methods have the problem of whether the sample used in the study is representative of the population. This issue is important in criminal justice evaluation because of the tendency to survey the general population on their attitudes towards criminal issues while the attitudes of potential criminals or convicted criminals that are really important. In attitude surveys, most people have a natural tendency to express their public view and the response obtained is only a sentiment rather than any reflection of the tendency to act. The responses expressed are dependent upon the context of the question and the wording of the question and the researcher can never be sure of the results unless the procedures are standardized.

Cohort Analysis

The evaluation of the programs with objective of changing the behavior of people cannot limit its observation and measurement of people to the program period. There is a tendency for the erosion of treatment effect as time passes, so it is important that any evaluation effort include the follow-up of the people after completion of the program. Glaser (1973) quoted Ryder's definition of Cohort as "an aggregate of individuals ..... who experienced the same event within the same time interval." All the persons participating in a program during a time period, all the students graduating from a school, all
the children born on a day are some examples of a cohort. Cohort Analysis is the process of collecting data on the performance of a group over an extended period of follow-up.

The release cohort which refers to all the prisoners released from the prison during a time period is one of the most familiar cohorts and several recidivism studies have followed the prisoners after release to evaluate the effectiveness of alternative methods of treating the prisoners. Usually the collection of follow-up data are difficult unless the cohorts to be followed are under the control of the evaluating organization. The duration of the follow-up period is a source of bias in the evaluation efforts. Some of the problems discussed in using the recidivism data in the chapter on Performance Measures are due to the follow-up period.

Most of the cohort studies have been retrospective, that is, based on selected groups of offenders. So the cohort study that analyzed the delinquency among general population using a birth cohort by Wolfgang, Figlio and Sellin (1972) stands out. The delinquency and its absense in a cohort consisting of all boys born in 1945 and residing in Philadelphia from a date no later than their tenth birthday and until at least their eighteenth were studied to note the age of onset and the progression or cessation of delinquency.

The cohort analysis is discussed by both Glaser (1973) and Adams (1975) as a separate method of evaluation. It could be considered as a special case of quasi-experimental method where the treatment group is a cohort and the measurement is done at several time periods after
program completion in addition to the measurement during the program. The cohort analysis is a specific method of selecting the experimental units rather than an evaluation method.

**SCOPE AND CONTEXT OF THE EVALUATION METHODS**

The evaluation methods discussed in the previous sections are not mutually exclusive. A combination of methods can be more effective in evaluating one program or a package of programs to be funded in a budget period. A learning model used by Morris (1968) to model management process, is used to identify the proper application areas and the scope of different methods in the accumulation of scientific knowledge and the development of decision aids to improve the managerial style and experience.

The learning model is shown in Figure 2-1. A stimulus which calls for action from management or which starts a scientist on a research effort is the beginning of the learning process. For a manager, the stimulus could be, appropriation of money by a funding authority to achieve a certain objective, a request to fund an activity, final report of a successful program implementation in another jurisdiction, or a problem in operations of the agency is reported. The stimulus for a scientist could be the observation of an incident, receipt of an article on the field of interest, or discussion of the theoretical models of phenomena. The scientist using the accumulated theoretical knowledge of his discipline formulates a hypothesis. Based on the formulated hypothesis, some predictions are made about the outcome of certain events. An experiment is designed to measure
Figure 2-1. Schematic of the Learning Model
(Adapted from Morris, William T., Management Science: A Bayesian Introduction, Page 6)
the outcome efficiently. The designed experiment is conducted to verify the predictions of the hypothesis using the results of the experiment. If the experimental results contradict the hypothesis, the cycle could be started all over again with new hypothesis. If the hypothesis is not contradicted additional experiments could be conducted to reinforce the hypothesis before the hypothesis is accepted as a general principle and added to the accumulated knowledge of the discipline.

The controlled experiment is the traditional method of science and vast theoretical knowledge has been accumulated in basic sciences using carefully designed controlled experiments. In social sciences and in evaluation research, the experiment is most effective in establishing the cause-effect relationships and system-wide process evaluation. The quasi-experimental methods are proposed for social science experiments to overcome the criticism on the moral grounds that treatment is denied to some eligible candidates for the sake of experimentation. The lack of success in many experimental studies in corrections can be traced to the absence of well-defined hypothesis, sensitivity of the scale of measurement and application in improper context. In the absence of a well-formulated hypothesis, the experiments result in accumulation of observations, rather than well-proven principles of the discipline. The use of experimental methods in operational or routine evaluation projects which have very restricted time schedules have led to the criticism that controlled experimental methods lack in producing impact. The following conclusion by Adams
"... surveys, case studies and time series analyses may be capable of greater impact on corrections than controlled experiments" highlights this problem. The predictions of time series analysis and other methods using models would be susceptible to the serious problems of reliability and validity unless they use sound models based on proven cause-effect relationships and the accumulated theoretical knowledge of the discipline. The experimental methods have proven themselves in the physical sciences as to their impact in developing theoretical knowledge and could also be used in the CJS.

The administrator or the manager uses his management experience to conceptualize the decision required for the stimulus. It is in this conceptualization phase that most of the decision aids are useful to the decision maker. Based on the predicted outcomes, and his experience and intuition, the manager makes the decision and implements the decision. The process of learning from experience is greatly improved when the results of implementation are analyzed in comparison with the predicted outcomes so that current experience can be added to the vast pool of experience in a form readily useful for making future decisions and for modifying the process of future decision making. The process of learning from experience can be improved in the organization as a whole by making the process of deciding, implementing and learning more explicit through the use of well-defined objectives, properly conducted analysis and precisely identified alternatives.

In Figure 2-1, three stages of management conceptualization, i.e., Search, Data gathering/prediction, and Value clarification, are
identified. The first stage, search, is an attempt to identify all possible courses of action or alternatives. The theoretical knowledge accumulated by conducting experiments is a basic source of alternatives available and is helpful in conceptualizing and identifying the alternative projects that would achieve the objectives of the decision situation at hand. The surveys of other administrators and case studies of programs in other agencies are useful in identifying alternatives. One of the key issues of this stage is when to stop the search. One of the concepts of Bayesian approach, Expected Value of Sample Information, and analysis of the Meta Decision Problem are helpful in deciding when to stop. The impact of decision aids is much greater in the other two stages, data gathering/prediction and value clarification, so they are discussed in more detail than the first stage, search.

The second stage of management conceptualization, data gathering/prediction, is a very important stage of the decision making process and it is in this stage, that the measurement problem of the resource allocation decisions is considered and that most of the current evaluation methods are helpful to the decision maker. The main objective of data gathering effort is to predict the outcome of the alternative on all the measures of effectiveness defined. The Figure 2 - 2 illustrates some of the problems in predicting the outcome of a program. Several measures of effectiveness are usually required in evaluating the program. The dynamic effect of the program on a measure of effectiveness is shown in the Figure 2 - 2.
$M_1$ - Level of Measure of Effectiveness $i$ before the program period.
$M_2$ - Level of Measure of Effectiveness $i$ after the program period.
$M_3$ - Level of Measure of Effectiveness $i$ at the scheduled program completion time when there is no program.

Simple experimental designs such as Pre-Post comparison and some elementary models used in model oriented analysis methods, i.e., cost-benefit analysis, econometric methods and simulation methods, assume that the measure of effectiveness $i$ would not have changed if the program was not implemented i.e., $M_3 = M_1$ and calculate the effect of the program as $M_2 - M_1$. More powerful experimental designs such as Pre-Post control group design and comprehensive models used in model oriented analysis methods do not make this restrictive assumption and try to predict what the value of measure of effectiveness would be at the scheduled completion time of the program if the program is not implemented and calculate the effect of the program as $M_2 - M_3$. 

Figure 2-2. Program Impact on Measures of Effectiveness
Cost-effectiveness analysis because of its origin in economics is often viewed as an alternative to quasi-experimental methods used by social scientists in evaluation research. But it could be used as a logical extension of experimental methods. In the cost-benefit analysis studies conducted on engineering projects, the values of measure of effectiveness are estimated using models based on vast accumulated knowledge of the disciplines and the data from available records and statistical series. The values of measures of effectiveness are estimated from original data collection procedures using experimental methods when there is little accumulated knowledge to identify cause-effect relationships. The data collection procedures could use survey methods or any other measurement techniques. The models used in predicting outcomes could be econometric models, analytical models or simulation models.

The third stage of management conceptualization, value clarification is the place for addressing the decision problem of resource allocation decisions and considering the preferences of the decision maker towards several objectives of the program being evaluated. The cost-effectiveness analysis provides a frame work for identifying all the benefits and cost of the program and orderly collection of outcome data on all benefits and costs using several of the available data gathering methods. But it does leave the final selection of preferred alternative or ranking of the alternative to the decision maker. The Figure 2 - 3 illustrates some of the problems in selecting a preferred alternative. To illustrate the basic problems in value clarification, a composite measure of effectiveness is used to represent all benefits
Composite Measure of effectiveness

Figure 2-3. Dominance in Cost-Effectiveness Analysis

for each of the alternatives and cost is used to represent all the resource requirements of each of the alternatives. In cases where one alternative is more effective than the other and costs no more than the other, the choice is obvious and the nondominated alternative is preferred to the dominated alternative. In the Figure 2-3, alternative B is dominated by alternative A, so A is preferred to B. However, when one alternative is more effective and costs more than the other, the choice between alternatives depends on how much more to pay for unit of composite measure of effectiveness.

In cost-effectiveness analysis, the main thrust is in estimating effectiveness and cost while value clarification is left to the implicit consideration of the decision maker. In referring to the decision rule or criterion of choice missing in the analysis but needed in choosing between alternate programs, Poland (1974) highlighted the problems present in the current evaluation methods when it comes to
the decision problem of trading off between objectives. The following statement by Washington emphasizes the problem: "one of the assumptions upon which this book is written is that program evaluation among the human services has not included an adequate balance between measures of both costs and benefits." The learning process of the decision makers would be greatly enhanced if the trade-offs between objectives or the value clarification process is made explicit.

Another aspect of the problem in evaluating criminal justice programs is identified in the following excerpts from Blumstein (1973):

A fundamental aspect of all such systems is their measures of effectiveness, which are complex vectors rather than the simple scalars characteristic of industrial systems.

...with at least two functions in the objective function, the mathematics of optimization becomes particularly difficult to apply.

The multiple criteria decision making methods discussed in the later chapters are helpful in the explicit consideration of value clarification process.
CHAPTER 3

MULTIPLE CRITERIA DECISION MAKING METHODS

The decision situations in program evaluation and resource allocation are characterized by several conflicting and complementary objectives that impact upon different organizational components of the system in different time frames. Decision making and public policy formulation are made on the basis of a mostly qualitative integration of numerous noncommensurable objectives. The evaluation methods discussed in the previous chapter concentrate on data gathering and efficient use of the available information to estimate the value of performance measures for the alternative programs, but there is no explicit treatment of preferences or trade-offs among multiple objectives. In Clarke's (1974) review of the present practice of research project selection, the inadequate handling of multiple objectives by the mathematical models is cited by several researchers as one of the reasons for not using the formal models. The multiple criteria decision making methods consider multiple objectives explicitly, so some of the methods and their applicability to program evaluation are discussed in this section.

The multiple criteria decision making methods (MCDM) have received considerable attention in the past five years, but some of the methods were in use for a long time. MacCrimmon (1973), in his comprehensive review of multiple objective decision making methods cited a letter
written by Benjamin Franklin in 1772 in which the essence of trade-off method is discussed. In the modern Operations Research Literature Klahr (1958) addressed the issue of multiple objectives in mathematical programming models and discussed some of the concepts of goal programming method. In the recent literature, the application of multi-objective mathematical models is widespread in water resource planning and project evaluation.

In this section some of the more popular methods which address the issue of preferences among objectives differently are discussed, without attempting a full review of the Multiple Criteria Decision Making Methods. Several good reviews, Terry (1963), MacCrimmon (1973), Huber (1974), Loucks (1975), Cohon and Marks (1975), and Starr and Zeleny (1977) are available with different classification schemes and varying emphasis on different methods. The characteristics of MCDM methods and some of the notation used are introduced before starting the description and discussion of the applicability to resource allocation problems.

The main characteristic of the MCDM methods is the explicit treatment of the multiple objectives or goals involved in the decision. One or several performance measures could be used to measure the achievement of an objective. The terms, attribute, criteria, effectiveness measure, benefit measure, output measure and utilities are also used to refer to performance measure or objective. The attribute is used in consumer research problems, where the consumer's decision making behavior is studied in terms of the attributes of the alternatives, such as, fuel economy, maintainability, size and acceleration.
in selecting among cars. Some of the concepts proposed by Archer are
used to discuss the other terms.

Each of the alternatives, a proposal or criminal justice program,
produces outputs which reflects its performance. The resource require­
ments can be considered as negative outputs of the program. The terms,
output measures and benefit measures usually refer to the outputs of
the alternative. The utilities and effectiveness measures are used to
refer to the degree of fulfillment of the objectives by the output of
the alternative. The term criteria is used vaguely to refer to
attributes, output measures and utilities. The overall merit of an
alternative is a function of both the degree of fulfillment of each
of the objectives and the preferences of the objectives. The following
notation is used in the further discussion of the MCDM methods.

\[ x_{ijk} \] - Output \( k \) of alternative or program \( i \) contributing
to objective \( j \)

\[ h_{ijk} \] - Functional relationship used in converting output \( k \)
of alternative \( i \) to a degree of fulfillment of
objective \( j \)

\[ Q_k \] - Composition operator used in combining all outputs
of an objective. In most cases summation is used
for the composition. Other possible operators are
multiplication, maximum, minimum, etc.

\[ V_{ij} \] - Degree of fulfillment of objective \( j \) from program \( i \)

\[ V_{ij} = Q_k h_{ijk} (x_{ijk}) \]

\[ g_j \] - Functional relationship used in expressing preferences
for objective \( j \)

\[ 0 \] - Composition operator similar to one defined above,
used in combining objectives
$U_i$ - Overall merit of alternative $i$ which expresses preference ordering of alternatives

$U_i = \sum_j w_j g_j(V_{ij})$

WEIGHTING METHODS

The weighting methods are the most widely applied methods of all the MCDM methods. They have been in use longer than other methods. Terry (1963) and MacCrimmon (1973) have described several specific weighting schemes. Some of the characteristics of weighting methods are discussed here before presenting some of the popular ones. The weighting methods discussed in this section are diverse in several aspects, however, they have common characteristics listed below.

1. a well specified composition scheme, $\omega$, for combining the preferences of objectives into a single number to represent the overall merit of the alternative.

2. unless the preferences for objectives, $g_j(V_{ij})$, are assumed to be same or not required for the composition scheme, the decision maker or the analyst has to explicitly state the preferences or trade-offs between objectives at the initial stages of analysis without having access to any information from the analysis. It is assumed that the true preferences of the decision maker for the multiple objectives can be extracted in terms of real value importance ratings or as rankings of objectives.

3. consider the relationship between outputs and objectives as a special case of one output measure or attribute for one objective, or treat the outputs and objectives without significant distinction. Usually multiple measures are not considered for one objective.

Simple Additive Weighting

This type of weighting is most widely applied in the form of index number or weighted score calculations because of the ease of
application. The composition operator for combining the objectives is summation. The functional relationship used in expressing preferences of objectives, \( g_j(V_{ij}) \) is a simple importance weight used to multiply the numerical rating of objective \( V_{ij} \). The overall merit of an alternative is calculated from a formula shown below.

\[
U_i = \sum_{j=1}^{m} W_j V_{ij} \quad \text{for } i = 1, 2, \ldots, n
\]

\( W_j \) = importance weight of objective \( j \) or \( g_j(V_{ij}) = W_j V_{ij} \)

After the calculation of overall merit score of all alternatives, the alternative with the highest score is considered as the preferred alternative. An excellent discussion of this method is presented by Morris (1964, Chapter 7). Several applications are described and references are cited by Terry (1963) and MacCrimmon (1973) for additive weighting and some of the other weighting methods discussed here. The average score method described by Terry is a special case where all objectives are weighted equally at a value of 1 (\( W_j = 1, j = 1, 2, \ldots, m \)). Deutsch (NILECJ, 1976) referring to the simple additive weighting model as most commonly used model for overall organizational effectiveness suggested the use of higher order model which can be written using the above notation as shown below:

\[
U_i = \sum_{j=1}^{m} W_j V_{ij} + \sum_{j=1}^{m} \sum_{k \neq j}^{m} t_{jk} V_{ik} V_{ij}
\]

This model is useful when there is interaction between the objectives.

**Multiplicative Weighting**

The multiplicative form is very similar to additive weighting.
The composition operator for combining the multiple objectives is multiplication and it had gained popularity because of logical appeal when combining the fulfillment of objectives expressed in probabilities. The multiplication of individual ratings which are marginal distributions results in joint distribution of the objectives if the objectives are independent. The overall merit of an alternative is calculated from a formula shown below.

\[ U_i = \prod_{j=1}^{m} V_{ij} \text{ for } i = 1, 2, \ldots, n \]

After the calculation of the values of \( U_i \) for all alternatives, the preferred alternative is chosen as the one with highest score.

de Neufville and Keeney (1972) have used multiplicative weighting in their analysis for the study of Mexico City airport facilities.

**Special Weighting Schemes**

Several weighting schemes are discussed by Morris (1977) for principles of choice under uncertainty, all these schemes are applicable to weighting multiple objectives. All the weighting schemes discussed here can be used as different forms of the composition operator for combining the multiple objectives.

The Maximin, Minimax and Maximax principles of choice have logical appeal when the overall merit of the alternative depends on the weakest or strongest objective. The preferred alternative is chosen using one of the following formulae.

Select the alternative \( i \) associated with
In using these formulae, the alternative is represented by the objective with lowest or highest numerical value. These formulae can be considered as special cases of additive weighting where the best or worst objective is assigned an importance weight of 1 and all others zero and the importance weights are assigned separately for each alternative. Hurwicz principle is a special case of additive weighting where the best objective of an alternative is assigned an importance weight of \( \alpha \), the index used in Hurwicz Criterion, and the worst objective of an alternative is assigned an importance weight of \( 1 - \alpha \). The preferred alternative is the alternative \( i \) associated with

\[
\max_i \left\{ \alpha \max_j V_{ij} + (1 - \alpha) \min_j V_{ij} \right\}
\]

Savage Principle considers the relative values of alternatives with reference to the maximum on each objective in computing and using the regret matrix. The preferred alternative is chosen as the alternative \( i \) associated with

\[
\min_i \left\{ \max_j \left\{ \max_p (V_{pj} - V_{ij}) \right\} \right\}
\]

All these special weighting schemes appear arbitrary, but each of them can be justified in a decision situation based on the ratings used to measure the fulfillment of objectives and the nature of objectives.
Trade-off Method

In the trade-off approach, the preferences of the decision maker for one objective against another is extracted by direct questioning using pairs of objective values of two alternatives at a time. This approach contrasts with additive weighting where importance ratings are extracted with the assumption that marginal rates of trade-off between objectives is constant overall the possible values of the objective. In this approach the composition operator, $O_j$, used in combining objectives and the functional relationship $g_j(v_{ij})$ used in expressing preference of an objective are not separated, but the decision maker is considering them implicitly and selecting one alternative over the other. By making relevant trade-offs between some objectives, the dimension of the decision can be narrowed to smaller number of objectives at each iteration until the preferred alternative is selected.

Sequential Elimination Methods

In this approach alternatives are compared sequentially on the basis of one objective value at a time so that alternatives can be eliminated or retained. At the outset, this approach does not appear as a weighting method, but it can be shown as a special weighting scheme.

In the Lexicographic approach, the objectives are ranked in terms of importance. The objective values of all alternatives are compared for the objective ranked to be most important, and the alternative with
highest value for this objective is selected as the preferred objective. In cases where several alternatives have the same value on the objective used for comparison, the objective ranked next in importance is used. The comparison on the objectives ranked lower in importance is continued until a single or acceptable number of preferred alternatives emerge. This Lexicographic approach can be considered as a special case of additive weighting if the importance ratings have the property shown below,

\[ W(j) > r \cdot W(j) + 1 \] for any real number \( r \)

Parenthesis around \( j \) are used to denote the Lexicographic ordering of the alternative. \( W(j) \) refers to the \( j^{th} \) ranked objective instead of the \( j^{th} \) objective from the original problem.

Another sequential elimination method very similar to lexicographic approach is elimination by aspects. Similar to lexicographic approach, this method also requires ranking of alternatives on one objective at a time. It differs in what it compares against, it uses standard instead of another alternative. The comparison on lower ranked objectives is continued until a preferred alternative emerges.

Both of these sequential elimination methods are used in mathematical psychology and marketing research literature in developing models for consumer behavior.

**Regression Methods**

The regression methods are used for different types of decisions than the weighting methods. The regression methods are used in
decisions of repetitive nature where considerable amount of history is available on the past choices of the decision maker. The historical data and regression analysis are used to identify the objectives used and their functional relationship, and to estimate the coefficients of the variables in the functional relationships. In the regression approach the preferences of the decision maker are inferred from his past choices rather than from direct verbalization by the decision maker.

The selection of graduate students by the admissions committee is studied with the regression method. Dawes (1971) cited several other studies and used a linear combination of the criterion variables in simulating the decision making behavior of the admission committee. The model used is same as the one used in simple additive weighting and it is shown here

\[ U_i = W_1 V_{i1} + W_2 V_{i2} + \ldots + W_m V_{im} \]

In this case \( U_i \) is a faculty rating of the student \( i \), while \( V_{i1}, V_{i2}, \ldots, V_{im} \) are values of criterion variables used and \( W_1, W_2, \ldots, W_m \) are coefficients estimated by regression. Other widely used model, referred by Slovic and Lichtenstein (1971) as the ANOVA model, are extensions of the above model. Adding interaction terms to the above model results in the ANOVA model and it can be estimated by regression analysis as well. The model with interaction terms would be as shown below.

\[ U_i = \sum_{j=1}^{m} W_j V_{ij} + \sum_{j=1}^{m} \sum_{k=1}^{j-1} t_{jk} V_{ik} V_{ij} \]

This type of model is applicable when the contribution of one criterion
variable to the overall merit of the alternative depends on the value of another criterion variable. Use of nonlinear forms of functional relationships for expressing preferences of an objective, \( g_j(V_{ij}) \), is referred as curvilinear model.

The regression methods are useful in replacing the decision maker to screen obviously unacceptable alternatives rather than to develop decision aids. In some cases, the model simulating the decision maker has performed better than the decision maker. This is a case where the model is good representation of the judgemental process and the consistency of the model in repetitive applications is better than a human decision maker. The insight gained by the development of the model could be fed back to the decision maker to improve his decision making process. In this feedback mode, the regression methods could function as decision aids, but, the resource allocation decisions are not repetitive to fulfill the data requirements of regression methods.

**MULTIDIMENSIONAL SCALING METHODS**

Multidimensional scaling methods are concerned primarily with the construction of a spatial representation for the decision makers preferences and perceptions. It differs from simple unidimensional scaling or measurement using simple interval scales in that the points representing the alternatives are allowed to assume positions within a two dimensional plane or a higher dimensional space. Individuals are characterized as having an ideal alternative which can also be located in the multidimensional space. The "closeness" of the alternative represented by Euclidean, city block metric or other
distance functions, is used to rank the alternatives in terms of preference.

Green and Carmone (1970) have developed several applications of multidimensional scaling methods. The consumers' judgments of pairs of car models for eleven car models are represented in a two-dimensional space in a configuration such that interpoint distances come as close as possible to the pairwise comparison. In another application, the judgments of fifty Wharton graduate business students as to the similarity of the schools on the criteria of their choice were used to construct a spatial representation. In the two-dimensional space constructed, "Quantitateness of the School's curriculum" and "School's prestige and market value" could be used as labels for two criteria used.

The representation of decision makers' preferences and perception of alternatives on an Euclidean space of minimum dimensionality and ordering each alternative on each dimension is the basic nature of multidimensional scaling. The determination of number of dimensions and their orientation involves the balancing between statistical reliability and goodness of fit which increase as dimensions are added and visualizability which decreases with increased number of dimensions. The multidimensional scaling methods are classified on the basis of the scales used for inputs and outputs. Fully metric methods require interval-scaled measures for inputs. Fully nonmetric methods do not assume more than rank order on the input, but only produces rank order of each alternative on each dimension. Shepard
(1972) developed the nonmetric methods which only require rank order input data and produce metric solutions and the computer programs for multidimensional scaling methods that made the wider application possible. Green and Carmone (1970) briefly described several computer programs, M-D-SCAL, SSA, TORSCA, MDPREF, INDSCAL, etc.. Most of these programs and algorithms are quite similar in objective but they differ only in computational detail. The essential parts of a representative algorithm described by Green and Carmone are presented here.

The dissimilarities or psychological distances perceived by the decision maker are available for n alternatives and are represented by $\delta_{ij}$ ($i = 1, 2, \ldots, n - 1$ and $j = 2, 3, \ldots, n$). The objective of the algorithm is to find a r-dimensional vector for each alternative to represent it in a r-dimensional space such that the ranks of computed distances $d_{ij}$ between two alternatives i and j reproduce the input ranks $\delta_{ij}$.

The algorithm should be able to identify when it found the n r-dimensional vectors and a computational formula to calculate the next set of vectors better than the current one. An index of fit is used to identify if the current solution is appropriate to represent the input data. It is in the type of index of fit and the computational formula used to move from one solution to another that most of the currently available computer algorithms differ. A representative formula used in the calculation of index of fit and the next improved solution are shown below.
Index of Fit = \left\{ \frac{\sum_{i=1}^{n} \sum_{j=1}^{n-1} (d_{ij} - \hat{d}_{ij})^2}{\sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij}^2} \right\}^{\frac{1}{2}}

New coordinate of alternative i on axis k

\[ X'_{ik} = X_{ik} + \frac{\alpha}{n-1} \sum_{j=1}^{n} \left( 1 - \frac{\hat{d}_{ij}}{d_{ij}} \right) (X_{jk} - X_{ik}) \]

where \( X_{ik} \) - Current coordinate of alternative i on axis k
\( d_{ij} \) - Distance between alternatives i and j
\( \hat{d}_{ij} \) - Real numbers (that may not be distances) which are monotone with the input psychological distances \( d_{ij} \)
\( \alpha \) - Coefficient of proportionality that determines step size

The algorithm iterates on the coordinates for a given dimensionality until the index of fit is satisfactorily small and then repeats the process in the next level of dimensionality to choose the lowest dimensionality.

One characteristic of multidimensional scaling methods, the requirement for a large number of inputs from several individuals make it suitable to represent the preferences of a group. This explains its widespread use in marketing research applications. Its applicability to resource allocation decisions is somewhat limited because of the small number of decision makers.

MATHEMATICAL PROGRAMMING METHODS

The interest in the multiobjective mathematical programming has grown considerably in the past five years, however, the mathematical
programming models of an economy were proposed by Von Neuman in 1937. The linear programming models were used in allocation problems from the early fifties. To apply the familiar linear programming model with its readily available simplex algorithm and computer codes, several multiobjective problems were transformed into single objective problems. Before getting into the discussion of linear programming models as a multiple criteria decision making method, some of the characteristics of mathematical programming methods that distinguish them from the other types of methods discussed in earlier sections, are presented here.

. Several alternatives or programs that maximize some objectives while satisfying the resource limitations are selected instead of one preferred alternative or program. In a typical mathematical programming formulation, a package of programs is selected rather than one program.

. A very large number of alternatives, all possible combinations of programs that can be selected within the resource constraints are considered.

. Selection of a preferred solution involves a procedure or algorithm to find a better solution from the current solution rather than enumeration of all alternatives.

. Resource limitations are specified as constraints while objectives are incorporated into the objective functions of the model being formulated.

The interdependent program relationships can be specified as additional constraints in the model formulation. All the methods discussed in earlier sections treat alternatives or programs as independent. Some programs could be mutually exclusive, i.e., the acceptance of one program renders several other programs clearly unacceptable while other programs could be contingent, in that the
acceptance of one program is dependent on the acceptance of another program. Mathematical programming methods can easily consider all these relationships among projects along with compound projects which are combinations of contingent, independent and mutually exclusive projects. Weingartner (1967) has discussed the type of constraints that could be added to the model to incorporate interdependent program relationships in very good detail.

**Linear Programming**

The capital budgeting problem is formulated as a Linear Programming (LP) model by Weingartner (1967) using the maximization of present value as the objective function. Several other LP models have been implemented for resource allocation decisions involving multiple objectives. To satisfy the requirement of single objective function, multiple objectives are converted into a single objective by attaching importance ratings to each of the objectives. The formulation of a single objective from multiple objectives is similar to the development of overall merit score for each of the alternatives in a simple additive weighting method. The functional relationships and composition operations used in expressing the preferences toward multiple objectives, and the procedures used in extracting the preferences are similar for linear programming and simple additive weighting. Because of the simplicity of the model and the availability of computer codes to solve the formulated model, the LP model has been used very extensively in widely varying multiple objective decision situations.

The model oriented approach in formulating the multiple objective
problems without due consideration of the basic realities and the non-commensurability of the objectives is the underlying cause of some of the implementation problems encountered. In the LP approach, the decision maker is expected to express his preferences for objectives as real valued importance ratings in a single number without receiving any information from the model. The difficulty involved in expressing a single number for importance rating and the lack of confidence in the expressed importance rating is an important factor in the decision maker's questioning the validity of the recommended solutions. The other mathematical programming methods discussed in this section are techniques developed to remedy some of these problems.

**Goal Programming**

Charnes and Cooper (1961) developed the model and coined the name Goal Programming (GP). The problem of multiple objective maximization is handled by converting all goals into constraints of a LP. The deviations from the predetermined goals are represented by additional variables and the objective function is used to minimize these deviations. For the cases where exact achievement of goal is desired, both negative and positive deviations are included in the objective function, while only the negative deviations are considered when the over achievement of the goal is acceptable.

The specification of objective function which reflects the preferences of the decision maker is the key to the applicability of GP as MCDM. Several priority levels are used in ordering the goals.
The improvement of a lower order goal is considered only when a higher order goal cannot be improved any further. Ijiri (1965) extended the concept of adding coefficients to deviation variables in the objective function to assign proper importance for the goals within the same priority level, and developed the generalized inverse approach as the solution procedure.

The GP model for resource allocation problem can be written as:

$$\text{Min } \sum W_j d_j$$

Subject to

$$V_j X + d_j = G_j \text{ for } j = 1, 2, \ldots, m$$

$$A X \leq B$$

$$X \geq 0$$

where

- $V_j$ - $n \times 1$ vector of program contributions to objective $j$
  - $V_{ij}$ represents contribution to objective $j$ by program $i$
- $A$ - $n \times p$ matrix of resource requirements
  - $a_{ik}$ represents requirements of resource $k$ for program $i$
- $B$ - $1 \times p$ vector of resource limitations
  - $b_k$ represents limit on resource $k$
- $G_j$ - Predetermined level for objective $j$
- $d_k$ - Under achievement of objective $j$
  (over achievement of goal is assumed to be acceptable)
- $X$ - $1 \times n$ Decision vector
  - $X_i = 1$ Program $i$ is selected
  - $X_i = 0$ Program $i$ is not selected
- $W_j$ - Priority factor for objective $j$

The priority factors have the relationship
\[ w_j > r w_j + 1 \quad \text{for any real number } r \]
to assure that low order goals are considered only after the higher order goals are achieved or cannot be improved.

The GP problem can be solved by the simplex method when the algorithm is modified to realize the preemptive relationships of priority factors. Lee (1972) has explored the application of GP to various functional areas and developed the new format of simplex tableau and the computer programs which enabled the application of GP by eliminating the difficulties in obtaining the solution after the problem is formulated. Lee and Morris (1977) have adapted the cutting plane method and the branch and bound method for solving integer goal programming problem.

The use of priority factors in GP is based on the assumption that the decision maker has only rank order preferences between objectives. The functional relationship used in expressing preference of objective \( j \), \( g_j(V_{ij}) \), is assumed to be linear and is represented by \( V_{ij} \) itself. The concept of improving a lower order goal only after accomplishing all higher order goals is based on the assumption that some type of "satisficing" or "aspiration level" decision making is involved. In this aspect, treatment of the preference structure of the decision maker in GP is similar to the sequential elimination methods discussed earlier. The specification of goals into different priority levels is an important element of GP, but the assumption that a slight improvement in one goal (higher order goal) outweighs a very large improvement in another goal (lower order goal) does not have logical appeal.
in applying GP as MCDM. In many resource allocation decisions, several goals have to be considered simultaneously using trade-offs rather than in a sequential process of one goal after another.

The GP can be used by specifying all goals at the same level, but this would be equivalent to LP formulation. The Multiobjective Linear Programming discussed next has some advantages in the way it considers the preference structure of the decision maker.

Interactive Programming

In recent years, several approaches to obtain an acceptable or preferred solution to a mathematical programming formulation of multiple objective decision problem with a vector-valued objective function have been proposed and implemented in some studies. In this section the term, interactive programming is used to refer to all these approaches. In all these interactive programming methods, the perception of the decision maker's capabilities and attitudes towards explicit verbalization of preferences is different from all other MCDM methods discussed so far. Some of the underlying assumptions about the decision making behavior used in interactive programming methods are listed here.

1. The decision maker can express trade-offs between objectives in the neighborhood of an alternative in simple preference statements even if he cannot express the global relationships as analytical functions.

2. The decision maker is assumed to subscribe to a set of beliefs, however his judgements and value structures develop and become more expressible as more information is available from analysis of the problem.

3. A preferred or an acceptable solution to a decision problem is any alternative acceptable to the decision maker, whether it maximizes some objective functions or not.
Acceptability of an alternative or desires change over time as a result of learning the levels of individual objectives for some feasible alternatives.

The decision maker is not assumed to be either 'satisficing' or 'optimizing', he could be using different combinations of the two at different times or for different objectives during a single decision problem.

The decision maker's preferences are assumed to be monotonically increasing or decreasing with respect to each of the objective levels depending on maximization or minimization of vector optimization problem.

In interactive programming methods, the priority structure or importance ratings for the objectives are not required to formulate the model or to start the solution procedure of the model. The dominance relationships or Pareto optimality is used to solve the vector maximization problem. The model for resource allocation problem using interactive programming methods can be written as

\[
\begin{align*}
\text{Max } Z &= \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_m \end{bmatrix} = \begin{bmatrix} g_1(V_1X) \\ g_2(V_2X) \\ \vdots \\ g_m(V_mX) \end{bmatrix} \\
\text{Subject to} & \\
AX &\leq B \\
X &\geq 0 \\
\end{align*}
\]

where

- \( V_j \) - n x 1 vector of program contributions to objective j
- \( g_j \) - Functional relationship used in expressing preferences of objective j
- \( A \) - n x p matrix of resource requirements
- \( B \) - 1 x p vector of resource limitations
element \( x_i = 1 \) program \( i \) is selected
\( x_i = 0 \) program \( i \) is not selected

A solution that maximizes all objective functions simultaneously does not exist, except in some special cases. The first stage in the solution of the model is to find all nondominated solutions of the problem. The nondominated solution is defined formally by Geoffrion (1968). In the notation of the model, it can be stated as:

\( \bar{X} \) is said to be nondominated if \( \bar{X} \in \left\{ X | AX \leq B, X \geq 0 \right\} \) and there exists no other feasible solution \( X \) such that

\[ Z_j(X) \geq Z_j(\bar{X}) \quad \text{for all } j = 1, 2, \ldots, m \]

and \( Z_j(X) \neq Z_j(\bar{X}) \) for at least one \( j \).

The set of all nondominated solutions is also referred as efficient set, admissible set and Pareto optimal set.

To solve the vector maximization problem, i.e., finding all nondominated solutions, when all constraints and objectives are linear, several algorithms have been developed. Evans and Steuer (1973) developed revised simplex method and reported their computational experiences for several options to test for the efficiency of any extreme point. Yu and Zeleny (1975) have introduced Multicriteria Simplex Method to identify all nondominated solutions in linear cases. Zeleny (1974) has developed a Fortran program for Multicriteria Simplex Method and included a revised version of the program which works in his publication, Multiple Criteria Decision Making (1976). Zionts and Wallenius (1976) have studied the methods to solve multicriteria
problems involving integer variables.

The underlying assumption in finding the nondominated solution set is that it would be much smaller in comparison to the set of all possible feasible solutions and in some cases that it could be so small that the decision maker can choose the acceptable solution without any further analysis. Unfortunately, even in some small problems of real world applications, the nondominated solution set could be very big and some technique to reduce this set to an acceptable solution is required. Successive reduction of the nondominated solution set through an interactive procedure of providing information to decision maker from the analysis and incorporating the additional information about the preference relationships extracted from the decision maker into the analysis, is the basis for the name, interactive programming.

Steuer (1976) has explored the use of interval criterion weights for extracting the preference relationships of the decision maker to solve multiple objective linear programming problem. In this approach, it is assumed that the decision maker would be more receptive to expressing that the trade-off between the objective \( i \) and \( j \) is greater than 0.5 rather than expressing that it is 0.53. Zeleny (1974) has also discussed the approach and demonstrated the technique with examples. Zeleny has studied Multiparametric Programming and the decomposition of the parametric space containing all possible vectors representing trade-offs between objectives. Yu and Zeleny (1976) have identified some of the algorithmic difficulties accompanying the decomposition. A major advantage of the decomposition approach is that multicriteria simplex method can calculate a set of weight intervals associated
with each of the nondominated solutions for that solution to be optimal. These weight intervals provide considerable information to the decision maker in selecting the preferred solution.

Another approach for reducing the nondominated solution set uses the concept of ideal solution. The ideal solution, perfect solution; 'utopia point' or 'point of bliss' are conceived as point of reference and they are identified as the solution at which all objective functions would attain their maximum feasible values. If the ideal solution is a feasible solution, there is no decision problem. Compromise programming approach introduced by Zeleny (1973) uses the ideal solution and the closeness of a solution to the ideal solution. The alternatives that are closer to the ideal solution are preferred to those that are not so close. The measure for "closeness" is metric or distance function which includes importance weights for objectives or attributes.

Several other approaches, other than solving the vector maximization problem and reducing the nondominated solution to a preferred or acceptable solution, have been developed and applied. One of the early and most quoted methodology of interactive programming is developed by Geoffrion, Dyer and Feinberg (1972). The operation of an academic department was formulated as multicriteria optimization problem. The decision maker is expected to provide only local trade-offs at the current feasible solution between two objectives while all the other criteria stay at their current values. The indifference trade-off or marginal rate of substitution is assumed to hold only in neighborhood of the current solution for the step size specified by
the decision maker. Frank-Wolf Algorithm is used to solve the mathematical programming model with the interactive approach. This approach does not assume constant trade-offs between objectives and as the trade-off weights are extracted for each iteration to hold only locally, the nonlinear relationships in the trade-offs could be handled through the implicit consideration by the decision maker.

Belenson and Kapur (1973) presented a two person - Zero Sum Game with Mixed Strategies approach to obtain the relative values of the objectives. The pay-off matrix entries are normalized objective values of the multiobjective problem, when it is solved for each objective function individually. An approach like this does not consider the preferences of the decision maker at all. It is a mechanical approach for solving the multiobjective problem, and it is very difficult to gain confidence of the decision maker using such an approach. The calculated relative values can be presented to the decision maker for validation, however, it is questionable whether an approach like this really helps the decision maker or confuse the issue as the meaningful interpretation of the calculated relative values is not straightforward.

In the recent years, multiple objective optimization has been applied in project evaluation procedures in Water Resource Planning (Cohon and Marks, 1973; Miller and Byers, 1973). In water resource projects, the functional relationships used for constraints and objectives are well-defined engineering formulae which are nonlinear in many cases. So the application of multiple objective optimization in water resource planning concentrated more on nonlinear multiobjective
Reid and Vemuri (1971) have developed the noninferior index approach for solving multiple objective optimization problems in water resource systems. A scalar index is defined as a linear combination of the multiple objective functions. The set of weights on all objectives could be derived if the scalar index used is a positive polynomial. The method is powerful for the problems that satisfy the requirements for functional relationships, but it is severely limited in the sense that not many practical problems fit the functional requirements and that only unconstrained optimization is possible on objective functions. Without constraints involved, the project evaluation decisions become trivial in that all projects could be implemented.

Monarchi, et al. (1973) introduced a Sequential Multiobjective Problem Solving technique, SEMOPS, which allows the decision maker to trade-off one objective versus another in an interactive manner. An objective function which includes only the unsatisfied objectives is used in cyclical optimization to generate information for the decision maker. Each cycle involves an evaluation phase which is the true interactive segment of the algorithm, between two successive optimization cycles. The decision maker is expected to provide information to revise the problem being optimized in next cycle, i.e., change some objectives to constraints if they have to be met or drop some objectives if they have reached a satisfactory level. The SEMOPS uses an optimization technique to generate information for the decision maker, and treats the optimization technique as only a means to the end of finding
an acceptable solution for the decision maker. The SEMOPS is not limited to a single model in optimization, nonlinear programming model or integer programming model could be used in the optimization cycle. The SEMOPS does not solve the problem by using an algorithm, it is very interactive and generates information for decision maker so he can develop a ranking of goals or revise his preferences during the course of the interaction. The same general approach is also published by Monarchi et al. (1975) as sequential information generator for multiple objective problems, SIGMOP.

Haimes and Hall (1974, 1975 and 1976) presented the surrogate worth trade-off method which is concerned with the relative value of additional increments of the various noncommensurable objectives at a given value of each objective function rather than with their absolute values. The concept of duality and Lagrange multipliers as well as the specification of all but one objective as constraints is utilized in this approach to provide information needed and the basis of the trade-off matrix. The trade-off functions show the relationship between a weight on one objective with reference to another and the levels of that objective. The trade-off functions give the analyst the required information to extract surrogate worth functions from the decision maker. The intent of extracting the surrogate worth function is to attach decision makers' preferences to the computed trade-offs at non-dominated solutions.

APPLICABILITY OF MULTIPLE CRITERIA DECISION MAKING METHODS

Several methods ranging from simple weighting methods to complex
mathematical programming methods have been described in earlier pages of this section. One of the methods or combination of the methods could be used for a decision problem. The applicability advantages and disadvantages of these methods are discussed here. The Table 3-1 presents a classification of these methods on preference structure and problem setting.

The linear regression methods and multidimensional scaling methods are classified as descriptive models of the decision process. When they are used to make decisions in place of the decision maker to screen the obviously undesirable alternatives, they are used in a prescriptive mode. However, the major emphasis of these methods is the study of the decision making process rather than development of decision aids, so they are classified as descriptive. The regression methods and multidimensional scaling methods require large amounts of historic data, which are not available in resource allocation decisions in the context of program evaluation. The models could be used as an aid in better explaining the decision making process to the decision maker to improve his performance. These models used widely in psychology, political science and marketing research are presented here for completeness rather than for their usefulness as decision aids in resource allocation decisions.

The weighting methods and the traditional mathematical programming methods (LP, GP, and NLP) depend on direct assessment of preferences. The weighting methods use the model representing the decision maker's preference structure to calculate a score representing the overall merit for all the alternatives while the mathematical programming methods
### Table 3 - 1

**Classification of Multiple Criteria Decision Making Methods**

<table>
<thead>
<tr>
<th>Problem Setting</th>
<th>Descriptive</th>
<th>Normative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preference Structure</strong></td>
<td>Analysis of History</td>
<td>Mathematical Programming Formulation</td>
</tr>
<tr>
<td><strong>Fixed Value importance ratings or weights</strong></td>
<td>Inferred Preferences</td>
<td>Direct Assessment</td>
</tr>
<tr>
<td>Simple Linear Regression</td>
<td>Simple Additive Weighting</td>
<td>Linear Programming</td>
</tr>
<tr>
<td><strong>Ordinal ranking of objectives</strong></td>
<td>Sequential elimination methods Lexicographic elimination by aspects</td>
<td>Goal Programming</td>
</tr>
<tr>
<td><strong>Complex functional relationships: preferences are related to the levels of objectives (nonlinear)</strong></td>
<td>ANOVA Model Curvilinear Model</td>
<td>Multiplicative weighting maximin minimax and other special weighting schemes</td>
</tr>
<tr>
<td><strong>Closeness to ideal point represents desirability</strong></td>
<td>Multi-dimensional scaling</td>
<td></td>
</tr>
</tbody>
</table>
move from one feasible point to another in search of an optimum. The basic method of resolving conflicts between objectives using the directly assessed importance weights has several problems. Psychological experiments conducted by Shepard (1964) to test the human ability to arrive at overall evaluation by weighting and combining diverse objectives show that the explicit importance weighting process is unstable. Slovic and Lichtenstein (1971) also concluded that judges have a very difficult time weighting and combining information. The traditional mathematical programming methods require directly assessed importance weights to formulate the model. The Figure 3-1 shows the schematic of the steps involved in using mathematical programming model to solve the decision problem. The traditional mathematical programming models are computationally efficient, however they expect value judgements to be extracted from the decision maker without any prior knowledge of the alternatives. Priority structures are clarified as a result of the analysis and its input to the decision maker. The particular weighting structure appropriate for the current problem must be acquired by decision maker through learning provided by the analysis, but it is seldom available as the independent possession of the decision maker which can be extracted.

The noninferior index approach and the game theory approach used by Belenson and Kapur do not even require any input from the decision maker as to his preferences for multiple objectives. The relationships implicit in the data and the functional forms are used to infer the preferences. There is no reason to assume that these inferred preferences represent the decision maker's value judgements. In these two
Identification of ends
Definition of objectives

Identification of means
Definition of constraints

Specification of preference structure of objectives

Formulate and solve optimization problem

Optimal solution is the solution of the decision problem

Figure 3-1. Schematic of the Traditional Mathematical Programming Model
methods, there is no decision involved on the part of the decision maker, it is simply using the algorithms to solve the model.

The approach of the traditional mathematical programming model is same as the rational, comprehensive or root method and is subject to several criticisms. Quade (1968) among several other pitfalls and limitations of analysis cited use of side issues as criteria, substitution of the model for the decision maker, neglect of the subjective elements and failure to reappraise the work. Schlesinger (1968) warns that objectives are contingent on nonquantifiable and often unknowable future states of environment and cautions against "the royal road to quantitative conclusions" based upon some rather questionable initial assumptions. Attaway (1968) discusses the difficulties and desirability of specifying detailed criteria before the results of the analysis are available to determine what goals are in fact attainable. Lindbloom (1959), one of the serious critics of the rational method, proposed another approach referred as successive limited comparisons, branch method or incremental analysis. Some of the characteristics of this approach described by Lindbloom identify the problems in using rational method very well. They are listed below.

Selection of value goals and empirical analysis of the needed action are not distinct from one another but are closely intertwined.

Since means and ends are not distinct, means - ends analysis is often inappropriate or limited.

The test of a good policy is typically that various analysts find themselves directly agreeing on a policy.

Some of the developments in mathematical programming methods are
attempts to overcome some of the criticisms. Goal programming recognizes the need for "satisficing" or agreement among analysts and decision maker as a test for good policy. However, goal programming requires ordinal ranking of objectives at the initial formulation stage and is subject to the argument that the solution is sensitive to the hierarchical ordering which may not be realistic.

The interactive approach of value extraction addresses the problems with selection of values and evaluation being intertwined. The interactive approach recognizes the ability of the decision maker to make incremental comparisons from the current state of the environment. Most of the strategies used in the interactive approach ignore issues of preference structure and absolute weights of multiple objectives and concentrate on marginal rate of substitution between two objectives at a particular feasible alternative. The solid boxes and line in Figure 3-2 represent the essential characteristics of the interactive approach. The information from the computations on the model is provided to the decision maker in the form of shadow prices or trade-off functions in case of surrogate worth trade-off method.

The sequential processing of SEMOPS with an evaluation phase between optimizing cycles is an attempt to overcome the shortcomings in the treatment of means and ends as distinctly different. The objectives included in the optimizing cycle are changed on the basis of the inputs from the decision maker. However, there is no explicit provision in SEMOPS to change the means as objectives becoming meaningful through understanding of the interaction between means and ends.
Figure 3-2. Schematic of the Interactive Approach to the Mathematical Programming Model
Johnsen (1976), based on his research and experience in multiobjective problems in practice, concludes that objective setting process never stops, and that objectives change all the time, partly due to the situation and partly because people become more aware of their "true" objectives through the process. The dotted part of the Figure 3-2 is a feedback loop and provides for the revision of objectives and constraints as ends and means are reformed.

Interactive approach resolves the shortcomings of the traditional mathematical programming models using some of the concepts of incremental analysis without losing its comprehensiveness or gaining the fragmentation and arbitrary exclusion of alternatives prevalent in the incremental analysis. Most recent developments in mathematical programming methods are changing their traditional emphasis on optimizing some objective function towards the emphasis of descriptive approaches on means and finding an acceptable end. The interactive approach of mathematical programming suits resource allocation decisions in social systems very well. Its changing emphasis towards descriptive approach used by social scientists and its origin in traditional mathematical programming methods used in industrial resource allocation decisions which are accepted as very efficient should give it a good start in practice.
CHAPTER 4
PERFORMANCE MEASURES

The need for explicitly defined objectives and operational measures of effectiveness cannot be over emphasized in the process of allocating resources to the criminal justice programs. The need for a good set of measures of effectiveness is well recognized by the administrators and the researchers, however, the task of defining a good set of measures for monitoring a single program or evaluating several programs is not easy. The greater need for properly defined performance measures for programs in public sector in comparison to the private sector is well asserted by Hitch (1967) in the following statements.

In a free enterprise economy we have a price mechanism and a system of incentives which, imperfectly but pervasively, enforce some measure of consistency between the lower level criteria used by individuals and firms in making their economic decisions and certain higher level criteria appropriate to the economy.

... (and indeed in the government generally) there is no comparable mechanism that tends to insure consistency between high level and low level criteria.

The performance measures that are useful for any organization in implementing the resource allocation decision methodology cannot be defined outside that organization. Several performance measures used in the evaluation studies in the CJS are reviewed in this chapter to serve as examples or as an initial list in starting the definition of
performance measures. To help further in the selection of performance measures, some of the properties that a set of measures should have and the pitfalls that should be avoided in defining the measures are discussed here before reviewing the measures used by several researchers in their studies.

The first and the most important property of a set of Measures of Effectiveness (MOE) is related to the basic objectives and goals of the organization to reflect accurately the achievement of ultimate goals intended in the specific areas in which they are to be utilized. Hatry (1970) discussed several inadequate approaches to criteria selection often used in government. Most of these approaches: Input or program cost as the only MOE; Immediately observable products such as work load measures and physical standards as MOE are cases where the relevance to the organizational goals are not considered.

The five categories of criteria proposed by Suchman (1967) -- Effort, Performance, Adequacy of Performance, Efficiency and process -- highlight several aspects of relevance to the ultimate goals. They can be considered as categories of criteria with different degrees of relevance to the goals of the organization. The criteria in the category of effort are concerned with the assessment of input or energy regardless of output. Performance criteria measure the results of effort rather than the effort itself. The Criteria of Adequacy of Performance refer to the degree to which effective performance is adequate to the total amount of need. Efficiency criteria are concerned with assessing effort and performance for various programs to determine
which are most effective. The criteria in the fifth category, study of process, attempt to determine the relative contributions of process to goal achievement such as attributes of the program that make it more or less successful, recipients of the program who are more or less benefited, conditions under which the program is more or less successful, and the impact or outcome produced by the program. Four of the important performance measures, efficiency, equity, responsiveness and effectiveness, cited by Deutsch (NILECJ, 1976), are another type of classification based on the relevance and consistency.

The measurability is another essential property. To be useful the individual criterion in a set of MOE should be measurable in some manner. It would be ideal for evaluation if all the MOE are capable of meaningful quantification in commensurable units, but the real world programs do not lend themselves to such simple measures. The need for the most objective criterion and the independent evaluative research personnel expressed by Glaser (1973) reflect the preference of the "hard" or objective measures to the "soft" or subjective measures susceptible to the evaluators interests and bias. Besides objectivity, the ability to identify the degree of attaining the goals rather than dichotomous classification of success and failure is an important aspect of measurability. The measures can be defined as absolute or relative depending on the nature of the objective. The scales used should be sufficiently sensitive to measure the achievements of the programs however small or large they are. Although the evaluation will be objective and is easier with highly measurable MOE,
the important thing is to avoid excluding major considerations of the ultimate goals of the organization. It is important to include all the factors that should be measured without being restricted by the current practices and ability to measure.

The commensurability of the MOE is another property that needs discussion because of its emphasis in several studies rather than lack of it. Several methods such as 'weighting techniques' and 'cost-benefit analysis' where benefit is defined in limited sense in monetary terms, combine measures that are expressed in different units into a single overall index. The evaluation procedure is simpler when all measures are converted to a common unit of measure, however, the key value judgements that are required for such conversion should be given considerable attention by the decision making authorities and should not be buried in the procedures used by the analysts. It is important to develop a set of MOE that reflect the basic objectives as realistically as possible in the most appropriate units.

The flexibility of the MOE is a property that is required in the evaluation of on-going programs in continuously changing environment of the CJS. The MOE should be sufficiently flexible to permit change as the program and the system change to respond to the needs as time passes.

The directness of the MOE to the performance being measured is also an important property that should be considered in defining the performance measure. Indirect measures or surrogate measures are useful in cases where the fulfillment of an objective cannot be
measured directly because of the difficulties in collecting data or expenses involved.

The acceptability and credibility of the MOE being used is very important in the practical use of the performance measures. Widespread acceptance in the organization of the measures that are being used is crucial for successful performance measurement. The two properties that refer to the set of measures as a whole rather than to individual measures, comprehensiveness and nonredundancy are identified by Robinson (1972). The comprehensiveness of the measures refers to the specificity necessary for evaluation of alternatives while representing all aspects of the more fundamental objectives. It also refers to the subjective determination by the decision makers whether the set of objectives selected is sufficiently comprehensive or whether additional objectives are needed. The comprehensiveness of MOE used in resource allocation is very important, because the broader goals of the organization can be displaced by stressing the accomplishment of specific measures. Redundancy in the set of measures should be considered along with comprehensiveness to determine whether there is an overlap or duplication in the set. Redundancy of measures should be avoided because of the double counting that results in some aspects of the programs.

There have been a large number of attempts at defining performance measures and applying them in different components of the CJS. Lejins (1975) in his overview of developments in criminal justice in the United States in the first half of this decade, identified the concern
over rising crime rates and public's fear of crime as a prime factor for the Commission on Criminal Justice Standards and Goals to propose 50 percent reduction in crime over the following ten years. The crime rate is used in several studies as performance measure. Some of the problems in defining and using the crime rate are discussed in this chapter. The recidivism is another measure used in many studies and it is also an important phenomenon that needs to be measured in light of the evidence that a very high percentage of serious crimes are committed by convicted offenders. The deterrence is discussed in a separate subsection after recidivism because it is the basis for all the criminal laws in the society. Due to the fragmentation present in the CJS, the performance measures used in most of the evaluation attempts are developed for the individual components of the CJS. The decision aiding methodology developed in this study can be implemented in any component of the CJS or for the whole CJS. The performance measures are discussed separately for law enforcement, corrections and courts with the assumption that they can all be incorporated into the overall measures needed for the whole system.

In routinizing the evaluation and implementing the decision aiding methodology, it is necessary to use the available records and the existing data collection procedures. So some of the definitional and reporting problems with performance measures described are discussed in detail to avoid some of the misinterpretations and pitfalls.

**CRIME RATES**

The reduction in crime is the basic objective of the CJS. The
number of crimes or crime rates are the obvious measures and are commonly used. In Ohio, the funds to Administrative Planning Districts and Regional Planning Units are distributed by Administration of Justice Division using a crime/population ratio. The problems associated with using crime rates are discussed in detail because of their widespread use and their relevance to the basic objectives of the system.

The crime statistics are compiled by local police agencies and are sent to FBI in the form of Uniform Crime Reports (UCR). So the first problem is that only the reported crimes are included in these statistics. Often the local police agencies change their procedures for responding to minor crimes because of their work loads and public pressures. This can considerably change the reported crimes even when there is no change in actual crime. On the other side, as the police become more effective in apprehending the criminals and in recovering the property more citizens may be inclined to report, increasing the reported crime even though the level of criminality is unchanged. The Law Enforcement Assistance Administration's (LEAA) survey of the population to determine the victimization rate emphasizes the problem in using UCR data alone in evaluating crime control aspects of the CJS.

The crimes are reported by type of crime for a geographical area, so a reduction in number of crimes need not necessarily mean that crime is reduced, it could only signal shift in crime to other areas or to other types of crimes.

The gross number of crimes in a geographical unit does not reflect the victimization probability even when they are reported and recorded
accurately and completely. An increase in crimes in proportion to the population does not change the victimization probability though there will be considerable growth in number of crimes. The crime rate, a ratio measure of number of crimes to a defined number of population (1000, 10000, or 100000) measures the probability of an individual being victimized more accurately and measures the criminality in the society properly.

The types of crimes included in the UCR are very heterogeneous and are not equally serious. The total number of crimes reported in UCR by FBI is a simple addition of the seven reported classes of index crimes. A murder and a $50 robbery are treated equally when the total number of index crimes is used as a measure. Sellin and Wolfgang (1964) have developed a weighting scheme to attach seriousness values to the various crimes and calculated the Crime Seriousness Index (CSI). The weights were derived from the seriousness scores in arbitrary units attached on questionnaires by different groups of people. Though the CSI is a significant improvement over the total number of crimes, it has been widely critized. The weights are derived for different types of bodily harm and different values of property lost rather than for different crimes.

For property related crimes the CSI does not consider the number of victims or the level of hardship to an individual victim. The same amount $100 causes different hardships to the victims, when it is stolen from 10 victims in a street car, a single wage earner or a rich businessman. The CSI does not make any distinction between the Physical and Psychological effects of crime and treats the harm done to the
victims collectively. The same physical injury that required hospitalization has different psychological effects depending on the location of crime, residential neighborhood or high crime district, and the circumstances under which it is committed. For example, the injuries resulting from a family argument have considerably less psychological impact than the same injuries inflicted by a store robber or an organized crime hit man. The concepts of utility theory were applied to develop additive disutilities of all types of UCR index crimes in the Task Force Report of the President's Commission (1967).

The CSI is a scalar measure of crime and it attempts commensuration of multidimensional losses caused by crime, physical and psychological, into a single index using a weighting scheme. Maltz (1975) proposed a vector measure based on different types of harm caused by crime—property loss, physical injury and psychological injury. Several other characteristics of crime that are not included in the UCR classifications or in the CSI are proposed for consideration with the vector measure. Some of the factors listed by Maltz are shown in Table 4-1.

For the property loss element in the vector measure, Maltz suggested the time the victim has to work to earn the dollar value lost rather than direct dollar value itself. The use of working hours, required to regain loss considers the different value of the same dollar amount for victims of different financial status and accounts for the inflation without having to include it explicitly. For the physical injury, measures are considered separately for temporary and permanent injuries. For temporary injuries the time needed for recovery and the time value of the costs of treatment on the same lines as for property
Table 4 - 1
Components of Vector Measure for Crime Proposed by Maltz

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victims</td>
<td>- number</td>
</tr>
<tr>
<td></td>
<td>age of each</td>
</tr>
<tr>
<td></td>
<td>sex of each</td>
</tr>
<tr>
<td>Offenders</td>
<td>- number</td>
</tr>
<tr>
<td></td>
<td>age of each (estimate)</td>
</tr>
<tr>
<td></td>
<td>sex of each</td>
</tr>
<tr>
<td></td>
<td>known by victim(s)?</td>
</tr>
<tr>
<td>Incident</td>
<td>- type (hold up - break in etc.)</td>
</tr>
<tr>
<td></td>
<td>weapons* or tools used</td>
</tr>
<tr>
<td></td>
<td>location (street, alley, park, store)</td>
</tr>
<tr>
<td></td>
<td>time of day, week, month, year</td>
</tr>
<tr>
<td>Apparent goal</td>
<td>- money, goods or property</td>
</tr>
<tr>
<td></td>
<td>harm to victim(s)</td>
</tr>
<tr>
<td></td>
<td>sexual gratification</td>
</tr>
<tr>
<td></td>
<td>'kicks'</td>
</tr>
<tr>
<td>Victim reaction</td>
<td>- passivity</td>
</tr>
<tr>
<td></td>
<td>resistance</td>
</tr>
<tr>
<td></td>
<td>call for police</td>
</tr>
<tr>
<td></td>
<td>flight</td>
</tr>
<tr>
<td>Results</td>
<td>- property destroyed *</td>
</tr>
<tr>
<td></td>
<td>property taken</td>
</tr>
<tr>
<td></td>
<td>extent of injury *</td>
</tr>
<tr>
<td></td>
<td>extent of insurance coverage</td>
</tr>
<tr>
<td></td>
<td>(items with an asterisk are included in the CSI).</td>
</tr>
</tbody>
</table>
loss is a better measure than the conversion into monetary terms. For the permanent injuries Maltz suggested an index similar to Fanshel and Bush's (1970) Health Status Index. A model for developing similar indexes is presented later in this chapter using the concepts developed by Torrance (1976) for his Health Status Index Model of which Fanshel and Bush's index is a special case. For the psychological injury, the psychological effects on both the victim and the community have to be considered. Maltz proposed an index for gauging the effect on community, using the methodology of the CSI but with a more representative sample of the population rather than only the groups connected to the CJS, and a scale for the psychological abridgement of freedom of the victim similar to Fanshel and Bush's health scale, but did not present any details or specific models. The quality of life parameters - percent of population feeling unsafe, percent of places that people are unsafe, percent of people moving because of crime in neighborhood, percent of people keeping firearms and watchdogs--suggested by Hoffman (1971) for performance measures in crime control could be used for measuring the psychological effects on the community. Maltz's vector measure of crime is oriented around the harm to victims and other potential victims but does not consider society as a whole. Several economic analyses and Blumstein in his cost-effectiveness analysis refer to "social disruption", "social cost of crime" and "disutility of crime". These are attempts to develop a single dimensional measure for a complex multidimensional problem. The problem in such a conversion is that in many cases, the values used
are not made explicit, the values are not extracted from the proper
sources or the value estimates are obtained without providing much
information to the person providing the estimate.

Maltz (1977) reviewed the historic development of UCR and Crime
Statistics and observed that the issues about crime statistics that
were discussed in 1930, the year UCR reports were started, are still
relevant. Skogan (1977) examined some of the problems in light of
new crime-victim data gathered in a national sample survey. The
accuracy of the data collected and reported is the major issue. The
comprehensive set of procedures to audit a police department's UCR-
related records system developed by International Association of Chiefs
of Police would be helpful in improving the accuracy of the reported
data. As these procedures are implemented throughout the country, the
accuracy of the UCR data can be reliably estimated. However, the
accuracy of historic data used in establishing functional relationships
in econometric studies cannot be improved. Besides the problems due
to the reporting, scaling and aggregating problems, the use of crime
rates as performance measures presumes that crime rate data accurately
reflect true victimization probability of a citizen, and that crime
rates are affected by the CJS activities only. The empirical investiga-
tions of historic data show strong correlations of crime rates with
several demographic and economic variables. So it is important that
several other measures besides crime rates are used in evaluating the
CJS programs.
RECIDIVISM

All the components of the CJS, police, courts, and corrections share the objective of reducing crime. But each uses different methods and concentrates on different measures of effectiveness. The police and courts focus on deterrence - posing a threat of apprehension and consequent penalties. The corrections focus on incapacitation - removing individuals from places where they might commit further crimes, and rehabilitation - treatment of individuals during the period of incapacitation. Recidivism has been widely used as a measure of effectiveness of rehabilitation of the individuals coming in contact with the components of the criminal justice agencies. However, there is no universal agreement among the criminal justice researchers and practitioners in the definition, units, calculation, use and meaning of the term recidivism. Some of the problems in defining and using recidivism are discussed in this section. Webster's New World Dictionary describes recidivism as

Habitual or chronic relapse or tendency to relapse into crime or antisocial behavior patterns.

One established aspect of recidivism is relapse, falling back or return, but one of the problem areas is the state "before and after falling back" as they are interpreted by each of the components or the jurisdictions of the CJS. The criminal justice practitioners are interested in the probability of an individual committing a crime or recidivating after being released into the society. This event of recidivism is known only when the individual comes into contact with the CJS by being reported, arrested, convicted, sentenced or
incarcerated. The problems of recidivism with reference to jurisdiction are brought into focus by the recidivism matrix constructed by Blumstein and Larson (1971), which is shown in Table 4-2. The diagonal elements of this matrix are of major importance. Courts are interested in the recidivism as committing at least one more crime, given that an offender has just committed a crime, \( P(C/C) \). The police agencies usually measure recidivism as "rearrest", \( P(A/A) \) and correctional agencies refer to recidivism as "reincarceration", \( P(I/I) \). Blumstein and Larson have developed expressions for three diagonal elements of the matrix in terms of the probabilities of the individual subsequent events based on a Markov Model. The calculations using three expressions show that the rearrest probability is 0.69 and the reincarceration probability is only 0.36 for the crime repetition probability of 0.9 when the probability of apprehension after committing

<table>
<thead>
<tr>
<th>Current Event for Current Crime</th>
<th>Subsequent Event occurring at least once</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Commit Crime (C)</td>
</tr>
<tr>
<td>Commit Crime (C)</td>
<td>( P(C/C) )</td>
</tr>
<tr>
<td>Arrest (A)</td>
<td>( P(A/C) )</td>
</tr>
<tr>
<td>Incarceration (I)</td>
<td>( P(I/C) )</td>
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<td>Arrest (A)</td>
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<td>Arrest (A)</td>
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<td>Incarceration (I)</td>
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Table 4-2
Recidivism Matrix Showing the States 'Before and After'
a crime and the probability of incarceration after apprehension are 0.25. One of the debates between police who claim that recidivism is high and correctional officials who claim that recidivism is low can be attributed to these definitional differences rather than to factual differences. The probation departments are in the executive branch (in correctional agencies) in some states and in the judicial branch (under direct control of courts) in some other states. The reporting relationship of the probation departments can considerably change the reported recidivism data.

The definition of crime is another problem area in defining and measuring recidivism. The term "crime" generally includes both felonies and misdemeanors throughout the United States. However, there are problems about the definition of felony and misdemeanor. Different jurisdictions show different distinction between major offenses and minor offenses. The possession of burglary tools is a felony in about half the states and a misdemeanor in the other half. The practice of sending only the offenders convicted of felonies to state institutions and others to local jails is not common in all states and creates problems in interpretation of the compiled statistics. It is possible for a person to be termed a recidivist without having a new crime proved against him if he is incarcerated for failure to maintain parole conditions. The parole conditions and the application of these parole conditions vary considerably between jurisdictions (between states and even within a state between parole regions and parole officers). The disposition of first crime has considerable impact on the recidivism statistics. The use of parole/probation instead of
incarceration for different types of offenses varies considerably among the states and is another source of considerable error in comparing recidivism statistics. The consequences of being termed recidivist also vary according to the laws of different states. The sentencing for a crime depends on whether the offender is a recidivist or not. This creates differences in the severity of the second crime required for an offender to be termed a recidivist, and the number of subsequent offenses is also a point of discussion. Some of the early studies have argued that the total of two offenses is too strict a requirement and used three or even more offenses before classification as a recidivist. About the sentencing consequences, preventive detention as used in England is reserved for those who have three or more (Wilkins, 1969) offenses in certain categories beyond juvenile status.

The duration of the follow-up period for counting as failure is another problem area in defining and measuring recidivism rates. Should a treatment program in a youth institution keep a man law abiding all his life, and a reconviction as a senior citizen be counted as failure? The data for the distribution of time lags between arrests from the FBI criminal careers study indicated that rearrest, if it happens, occurs within 5 years after release in about 99% of the cases and within 2 years in over 60% of cases (President's Commission, 1967, p.60). These figures indicate that the recidivism rate is clearly dependent on the follow-up period, however the studies were conducted from the beginning of this century using recidivism rates without any standard on the follow-up period (Sparks, 1971, p. 212; Simon, 1972;
Ganzer and Sarason, 1973; Babst and Mannering, 1965). This problem is identified by Hood (1971, p 172) with the following statement.

Most studies take two or three year period after treatment has ended; others regard five years as essential. A few studies have a variable follow-up period, sometimes with offenders being assessed after only a few months at liberty. This should be avoided since all offenders do not have an equal period at risk for reconviction, and analysis of results comparing successes and failures become suspect.

There are several data collection problems in measuring recidivism besides definitional problems discussed above. There is a considerable amount of unreported crime because of the understandable reluctance on part of the offenders and because of lack of confidence in the law enforcement or reasons of privacy on part of the victim to report the event. There is no reason to assume that the ratio of unreported crime is same during the time periods and the geographical areas of the individual studies. There are several problems even with the reported crime. The crimes reported in other states, other counties or local reports for minor offenses below the threshold for reporting to a national level system tend to under estimate the recidivism rates. The identification of offenders and adding a subsequent crime to his prior offense record is a problem because of several aliases and identifications used by the offenders. Ball (1968) in his study cited the name changes and incompleteness of reporting as one of the factors contributing to the under-representation of recidivism phenomena. The fingerprint matching avoids the problems due to name changes, but it is not being used extensively. Most of the problems in data collection on recidivism can be traced to the fragmentation of the CJS. This
A common deficiency can be corrected as the national retrieval of criminal histories and information exchange becomes easier through the computerized information networks that are being developed. The discussion so far only points to the type II error, nonreporting of crime or non-counting of crime due to data collection problems, but the type I error which includes erroneous arrests, convictions and sentences is not considered. There is a tendency for greater error of type I with reference to offenders with prior record as Guze (1964) indicated in the following excerpt.

Many of the arrests were for "suspicion" or "investigation" and as former criminals, the men were particularly vulnerable to such treatment. Conviction and imprisonment, however, occurred only in 32% of all arrests...

The data collection problems mentioned so far refer only to the numerator in the recidivism rate calculation, but there are reporting problems arising out of the different definitions of the denominator which are very important when the recidivism rate is used in program evaluation. The recidivism rate as calculated would vary considerably depending upon how the individuals dropping out of the program are treated, whether they are included or not. The results of the Addiction Research Center of Rio Piedras, Puerto Rico referred to by Glaser (1973) highlights the problems in the definition of the denominator in recidivism rate calculation. This center had several phases of treatment: Encounter Phase, Induction Phase, Reentry Phase. The initial part of the study, the encounter phase started with 10,000 people and the induction phase started with 1800 while the final part, the reentry phase started with 124. The relapse rate of 5.6% is calculated from 7
who relapsed after the study of 124 from the reentry phase ignoring the 9,876 who dropped out of the study and relapsed completely. This type of reporting problem will not be obvious from the results reported for any program in the grant oriented atmosphere of evaluating the programs, but it definitely does not mean that the program is more successful than the other programs for which the recidivism rates are calculated using all the individuals entering the program.

Another aspect of the probability of the recidivism discussed by Wilkins (1969) is also a reporting problem. The probability of recidivism means the probability of the commission and detection of the \((n + 1)\) offenses where the value of \(n\) is unstated. Wolfgang, Figlio and Sellin (1972) used a Markov model to show that the probability of committing \((n + 1)\) offense, given that the delinquent has committed \(n\) offenses increases with the number of offenses \(n\). Many of the reports in talking about recidivism do not disclose and not even consider some of these problems.

The problems with recidivism rate discussed so far are due to the different interpretations of recidivism by the different components of the CJS in different ways. So the required standardization in interpretation of several events that create recidivism could be achieved when all the components utilize the explanation published by the National Advisory Commission on Criminal Justice Standards and Goals (1973, Standard 6.7, p. 513).

Recidivism is measured by (1) criminal acts that resulted in conviction by a court, when committed by individuals who are under correctional supervision or who have been released from
correctional supervision within the previous three years and by (2) technical violations of probation or parole in which a sentencing or paroling authority took action that resulted in an adverse change in the offender's legal status.

Besides this description the following explanations and directions are also published.

Technical violations should be maintained separately from data on reconvictions. In addition it is important to report recidivism so that patterns of change can be discerned. At the minimum, it should be possible to ascertain from the statistical tables the number of recidivists in each annual disposition or release cohort at six-month intervals for the three year follow-up period...

The above description and explanation does not cover the level of seriousness that separates those criminal acts that are minor or non-serious from those major or serious. The offenses are identified by the State Penal Codes, and at the present time, there is no commonly accepted categorization of offenses covered by penal codes of several states into minor or major categories. The Model Penal Code, Proposed Official Draft, which will solve some of these problems is available, but until the state legislatures approve a penal code containing uniform classification of crimes, the commission suggests length of sentence as guide in determining the seriousness of offense.

Some of the definitional, measurement and reporting problems of recidivism rate can be solved by utilizing proper standardized procedures; however, there are several other problems in using it as an effectiveness measure in program or system evaluation. The time required to get feedback is very long when recidivism rate is used as a MOE and consequently the results may come too late for some types of evaluations. The measures for a program which offenders go through at the beginning of their incarceration cannot be obtained till the
offenders complete incarceration and the follow-up period used in defining recidivism (3 years). Even when the results are available they are confounded with so many other events that happened during the incarceration and follow-up period. Another important factor in using recidivism as MOE of a program is correlation and causation, perhaps it is not participation in the program that causes success but success that causes participation in the program. Putting it another way, that the success is not due to any thing that was done during the program but the fact that he did not require any correctional services to begin with. Another important aspect of counting success for those not returning is suggested by McClintock and Gibson (Hood and Sparks, 1970) in their study of robbery in London. After noting that offenders who had carried out robberies on persons in charge of money or goods in transit had the lowest reconviction rate of any type, 28% compared with the average of 45%, they concluded that 'these offenders' apparently greater success is illusory; they are merely better at escaping detection.

The use of recidivism concentrates on failures and the inference that can be made from counting the failures is limited. The failures can be differentiated on wide range from the inevitable to the accidental. Avoidance of failure is not same as promotion of success. The offender may not have committed a new crime but has become a public dependent of some other kind, a welfare recipient, a patient in a mental hospital or an alcoholic. Several positive aspects of rehabilitation, adjustment of offender to society, quality of personal and family relationships, participation in religious or community service
activities, and job placement and success are not considered at all when recidivism rate is used as MOE. Peter P. Lejins, (1971) after observing that recidivism has been used more frequently than anything else as a criterion of success or failure of corrections, suggests that there may be other positive results which could justify a positive evaluation of what has been done even if criminal acts continue.

Recidivism rates use a simple dichotomy of "success" and "failure" which is not precise enough to account for several differences in circumstances under which subsequent crimes are committed. Glaser in his study of federal prisoners went further and distinguished between 'clear' and 'marginal' groups among both the success and failures. The calculation of recidivism rate by simple dichotomous classification of conviction and nonconviction loses information in the data. The failure rate analysis using the times till conviction has occurred and reliability theory by Stollmack and Harris (1974) and Harris and Moitra (1978) point out this problem through the contradicting conclusion that their analyses give about effectiveness of the program to the standard analysis using recidivism rate.

The problems in using recidivism rate as a MOE are very well identified in the following excerpt from the book by Hood and Sparks (106, p. 132).

It is possible that where two types of treatment have the same overall results (as measured by reconviction rates), each is having different effects for different types of offenders; what is effective in reducing the recidivism of one type of offender may actually increase the chances of recidivism for another type, and these differences may simply be cancelling each other out.
This problem of heterogeneity in the population may be the reason for the conclusion of Bailey (1966), and Robison and Smith (1971) that the recidivism rates for the prisoners who receive special treatment in the institutions is apparently about the same as for those who do not. Another problem with recidivism calculation and heterogeneity of population is identified by Waldo (1971). The higher success rate or lower recidivism rate reported by the parole department in comparison with the institutions may not indicate that parole is more successful than release at expiration of sentence, it may merely indicate that parole board is successful in selecting for parole those who are likely to have a lower recidivism rate.

The National Advisory Commission on Criminal Justice Standards and Goals (1974, Standard 6.7, pp. 93 - 95) has identified the problems in using recidivism rates in distinguishing two types of review, System Review and Program Review. The performance of the entire system in achieving its goal is the object of measurement in system review and the measurement of recidivism is suggested as the primary but not the only evaluative criterion. The effectiveness of the program in the achievement of an immediate objective is the purpose of the program review, and the identification of specific goals and appropriate measures for determining whether they are achieved is called for this evaluation.

DETERRENCE

The deterrence is the primary and essential postulate of the criminal law systems in the world. The hypothesis that attaching
unpleasant consequences to behavior will reduce the tendency of people
to engage in that behavior is the basis for well proven theories such
as the law of demand in economics. The principal aims of criminal
sanctions are: posing a threat of penalties for the future misconduct
of the criminal and other potential criminals in the society; Isolation
of individuals from the society to protect the public from the further
crimes they might commit; Rehabilitation of offenders by correctional
agencies. In the evaluation of criminal justice programs, the
importance of the deterrent effect of punishment, a method used by most
of the criminal law systems cannot be over emphasized. The deterrence
theory hypothesizes that an increase in the celerity, certainty or
severity of punishment for a crime reduces the rate of occurrence of
that crime when all other factors remain same. The state of the early
research on deterrence is well reflected in the following statement
by Tullock (1974).

...there were no efforts to test the deterrent effect of
punishment scientifically until about 1950. At that time,
several studies were made investigating the question whether
the death penalty deterred murder more effectively than life
imprisonment. These studies showed that it did not, but they
were extremely primitive statistically.

The central question of deterrence, the effect of punishments on
general crime rates, was addressed by Gibbs (1968) in his examination
of the relationship between the severity and certainty of punishment
and the homicide rates using the data for 48 states in the United
States. He used Chi-square analysis with the justification that the
data does not meet the assumptions of normality called for the calcu-
lation of coefficient of multiple correlation. His Chi-square values
and Phi-coefficients revealed that the certainty and severity of imprisonment are related to the criminal homicide rate and that the degree of relationship is much greater for certainty. His analysis also suggests that the combined effects of the severity and certainty of punishment are additive in their effect on homicide rates. Gibbs concludes "consistent with the insistence that deterrence be treated as an open question, all that can be said of the findings is that they question the common assertion that no evidence exists of a relationship between legal reactions to crime and crime rate." Gray and Marin (1969) re-analyzed Gibb's data using multiple correlation and regression techniques. From the analysis using simple linear model, Gray and Martin conclude that Gibb's assertion of an additive effect of certainty and severity is justified, while the conclusion that certainty has greater effect is thrown into a state of doubt. Gray and Martin conclude "Gibb's suggestion that punishment may indeed deter crime seems to be reinforced by this analysis."

Logan (1972) analyzed official statistics published in National Prisoner Statistics and Uniform Crime Reports using correlation techniques to identify the relationship between certainty and severity of punishment and crime rates for all index crimes. He concluded that the major finding of moderately strong negative relationship between certainty of imprisonment and crime rate is consistent with deterrence theory. The correlation coefficient between severity of imprisonment and crime rate does not have the expected negative value but the partial correlation coefficient calculated after removing the effect of certainty of imprisonment, does have the expected negative value
adding support to the deterrence theory. Bailey (1974) conducted a similar analysis and concluded that the severity and certainty of punishment and offense rates for major index crimes produced results consistent with the predictions of deterrence theory. For the several cases in which the predicted evidence of deterrence was absent, Bailey regards these findings as possibly reflecting the multiplicity of political and legal differences in the handling of crime data.

Title and Rowe (1974) tested the deterrence theory further by examining the effect of arrest clearance rates on offense rates in cities and counties of Florida. They argued that the probability of punishment must reach a critical level before a deterrent effect is possible and analyzed the data separately for two cases, cities and counties with arrest clearance level below and above 30 percent, to show that the correlation coefficients between certainty of arrest and crime rate are higher for those cases with arrest clearance rates above 30 percent. Several socio-economic and demographic variables were considered in the analysis and Title and Rowe state that the socio-economic status of the county appears to be the best predictor of crime rate. Bailey (1976) partially replicated and extended the analysis of Title and Rowe by considering several levels of arrest clearance rather than two and concluded that the threat of legal sanctions can no longer be ignored in considerations of etiology of crime. Bailey's analysis indicates that the threat of arrest does not have a uniform deterrent effect for all felonies.

The studies discussed so far considered aggregated official statistics to test the deterrence hypothesis, however, several issues
discussed by Zimring (1973), general deterrence, special deterrence, applicability and communication raise questions that can only be tested by a different methodological approach. Special deterrence refers to the response the threat of punishment generates among the delinquents who are punished while the general deterrence refers to the general prevention which is applicable to all members of the community who are not punished. The individual's subjective perceptions of certainty and severity of punishment are more important than the true condition for the deterrence of crime. The improvement of communication through publicity about crime detection rates to make the threatened audience believe that the threat is applicable to them could have considerable impact on crime rates. Waldo and Chiricos (1972) approached the questions about perception of severity and certainty of punishment through the data collected in interviews of undergraduates at the Florida State University. The deterrence relationships for crimes that are wrong in themselves (mala in se) because of moral codes of the society such as larceny are distinguished from the crimes that are wrong because they are prohibited by law (mala prohibita) such as marijuana use. Waldo and Chiricos conclude that perceptions of the certainty of punishment appear most viable as deterrent when they involve the potential criminal's estimate of his own chances for arrest and harsh penalties for a particular crime — independent of the chances for any 'generalized other'. They also conclude that the data for marijuana use and theft indicate that no relationship exists between perceptions of severe punishment and admitted criminality. Teevan (1976) conducted a similar analysis
using a broader sample from the Canadian secondary school students and supported the hypothesis that the more certain the punishment, the less the deviance. Teevan also stated that the perceived severity of punishment lends only limited support to deterrence hypothesis.

All the studies reviewed so far were conducted by Sociologists, but they do not address the differences among people in areas of attitude toward risk and social status discussed by Zimring (1973). The criminal behavior and in particular the deterrence hypothesis has received considerable attention from economists in the past decade. Becker (1968) in his pioneering article used the usual economists' analysis of choice and proposes that a person commits an offense if the expected utility to him exceeds the utility he could get by using his time and other resources at other activities. This approach differs from several other theories of crime and does not require ad hoc concepts of differential association, deviant behavior, anomic and the like. Becker argues that some persons become 'criminals', not because their basic motivation differs from that of other persons, but because their benefits and costs differ. The supply of offenses or crime rates can be reduced by increasing the costs of committing an offense; decreasing the benefits from an offense; or increasing the opportunity cost of crime, i.e., increasing the benefits from other legal activities. In this section, because the main point of interest is deterrence, only the first approach of increasing the costs of crime is discussed.

There are two ways of increasing the expected cost of committing an offense for the individual offender: an increase in the severity of the punishment or an increase in the probability of being arrested,
convicted and punished. The effectiveness of certainty and severity of punishment in deterring crime depends upon the individual offender's attitude toward risk. The effectiveness of increasing the certainty of punishment is less controversial than the effectiveness of increasing the severity of punishment in the studies reviewed above. Becker has shown in his article that optimal crime rates are in the region where offenders are risk preferrers, that is in regions where 'crime does not pay'. The elasticity of response of offenses to changes in the probability of conviction being in excess of response to changes in severity is consistent with the optimality conditions. Ehrlich (1973) has extended the theoretical model developed by Becker and distinguished in his analysis the difference between the deterrent and preventive effects of punishment by imprisonment on the crime rate. The preventive effect of punishment refers to the reduction in criminal activity due to the separation of imprisoned offenders from potential victims in the society. The results of this empirical investigation show that the absolute magnitudes of the estimated elasticities of specific crimes with respect to estimates of probability and severity of punishment are not inconsistent with the hypothesis that law enforcement activity has a deterrent effect on offenders, which is independent of any preventive effect of imprisonment. The independent empirical investigations by Sjoquist (1973), and Votey and Phillips (1974) confirm the deterrent effect of law enforcement activity. These empirical investigations include socio-economic and demographic variables, and variables related to opportunity cost of illegal activity.

Cloninger (1975) conducted an empirical analysis on the cross
section of 113 Southern Cities for which data on offenses and enforcement were available in 1969, 70 and 71. In his regression analysis, Cloninger tested additive and multiplicative models and included the law enforcement variable as first and second degree term besides several other socio-economic and demographic variables. In all of the models for the individual crimes where the law enforcement variable entered in the step-wise multiple regression analysis, it carries a positive sign which is significant at .05 level. Cloninger concludes that the evidence of his analysis, with respect to levels of enforcement and crime, is not clearly consistent with a deterrence theory. Cloninger argues that the evidence of deterrence effect in Ehclich and Sjoquists' studies could be because of their use of arrests and convictions per offense as the enforcement variable. In both of these studies crime rates are correlated with probability of arrest and/or conviction, the number of offenses being in the denominator of the dependent variable and numerator of the independent variable is cited as a source of spurious negative correlation. Cloninger cites three other studies which used either per capita expenditure or officers per capita as enforcement variable and found no evidence of a deterrent effect. Cloninger included several socio-economic variables in his step-wise regression analysis, but does not address the well identified problem with signs of coefficients due to multicollinearity.

Swimmer (1974) in his empirical analysis used a simultaneous equations approach on the data for all cities with 100,000 or more residents in 1960. The total expenditure on police per capita is used as enforcement variable and the findings of Swimmer's analysis
contradict the Cloninger's findings, Swimmer reports positive simple correlations between index crime rates and per capita police expenditures, but when his simultaneous model separates the effect of police expenditure on probability of arrest and the effect of probability of arrest on the crime rate, the evidence supports the deterrence hypothesis.

Most of the studies reviewed here use the aggregated official statistics which are subjected to the reporting and several other problems in the section, crime rate. The victimization survey and other efforts started by Law Enforcement Assistance Administration are directed at improving the accuracy of the official crime statistics. The improved statistics would enable the research on deterrence theory to draw more definitive conclusions. However, the statistical testing of the deterrence hypothesis is not easy, because the effects of several factors are confounded. The crime rate is affected by socio-economic conditions besides the deterrence or the prospect of punishment. Even when the effect of socio-economic conditions are separated by proper specification of the model, the rehabilitative effect of imprisonment and deterrent effect of punishment are not easy to separate.

Nagin (1978) reviewed the theoretical models to estimate incapacitation effect of incarceration in an attempt to show the confounding of incapacitation and deterrent effects in empirical studies of deterrence theory. The difficulty of testing deterrence hypothesis with empirical studies is identified by Palmer (1977) in his conclusion: "Generally, the research of economists is more successful at establishing the effects of unemployment and income inequality than the
effect of punishment", Nagin and Palmer have presented an excellent review of literature on deterrence. Nagin cited the identification problem present in simultaneous systems as a really significant problem in empirical studies to test the deterrence hypothesis. The problem is in showing cause and effect even if negative correlation is estimated, because it is not clear whether increased punishments are deterring crime or increased crime has negative impact on punishment because of overloaded criminal justice facilities.

All the studies reviewed in the section test the certainty and severity parts of the deterrence hypothesis, but the celerity part of the hypothesis is not covered. The effectiveness of the processing time to convict on the crime rate is an important performance measure, specially in light of the current criticism of long delays in courts. Tullock's counter argument for the crimes committed in passionate rage, (eg. person about to kill his wife in rage) being not deterred by punishment serves as an example of effectiveness of celerity of punishment. He argues that the prisoners in Nazi Concentration Camps must frequently have been in a well-justified rage against some of their guards; yet this almost never lead to their using violence against the guards, because punishment was so immediate, obvious and certain.

PERFORMANCE MEASURES FOR LAW ENFORCEMENT

The system wide performance measures are required for the resource allocation and the program evaluation in the CJS. The Crime Rate and the Recidivism Rate are system wide measures relevant to the ultimate
objectives and have received considerable attention in the literature and in the practice. However, several other intermediate measures that are readily identifiable with programs and that can be directly estimated are also required. Most of the literature addressed these measures from each of the CJS components' (police, corrections or courts) point of view. So they are discussed here in separate sections for each of the components. It is a fragmented approach for developing the performance measures, but the reality of the fragmented system and the nature of the current literature make it more meaningful to discuss the performance measures separately for each of the components of the CJS.

The law enforcement agencies perform the functions: processing calls for service, investigating the crime reported during these calls, patrolling streets to prevent crime by being visible in community, and working with social organizations to improve community relations. The primary function of crime control starts when the police respond to a call and continues through the stages of investigating the reported crime, clearing it by either arresting the offender or closing it for lack of evidence or leads, and helping the prosecution in presenting the evidence to convict the offender. The measures of effectiveness are presented here in the order of these stages of crime control. The MOE for police are discussed (Larson, 1970 and Olson, 1975) in the context of police patrol and effort allocation, measurement of police output, and evaluation of crime reduction programs. Most of the measures discussed in the following pages could be extended to evaluate
individual police officers, precincts or divisions of police departments and Hoffman (1971) has discussed several others. They are not discussed in detail because the purpose of the discussion here of Performance Measures for Law Enforcement is to consider their impact on the CJS.

Response Time

The response time is the time taken by the police to reach the scene of a crime from the time the call is made. The response time is an output measure of the police servicing the individuals call. It is related directly to the probability of apprehending the offender or the probability of saving the victim if he is injured or is threatened. Though the response time is not a direct measure of crime reduction, it is widely used as a proxy measure with the belief that shorter response time would provide a high risk of apprehension to the offender and result in greater deterrence. The data presented by the President's Commission on Law Enforcement and Administration of Justice (1967) shows that the percent of arrests is higher for the cases with shorter response time. However, like any other proxy measure, it poses the danger of the proxy measure being maximized instead of improving the ultimate objectives of crime prevention and control. It is an objective measure that can be expressed in well defined units of time and is easily implemented through the normal operating procedures.

Clearance Rate

The clearance rate is the ratio of crimes solved or cleared by apprehending the offender to the total number of reported crimes. The
UCR explain clearance in the following statement.

...Police clear a crime when they have identified the offender, have sufficient evidence to charge him and actually taken him into custody. Crime solutions are also recorded when some element beyond police control precludes formal charges against the offender,...

This is also an output measure of the police operations and is more closely related to the ultimate goal of crime control than the response time. It measures what the police do after they get to the scene of crime. It has gained acceptance through the argument that the police do not have direct control over total amount of crime but they do have control over their performance in the cases brought to their notice. This also is an objective measure that can be calculated easily from the operating records of the agencies. Though this is a better measure of police performance than the crime rate, it can change significantly when the reported crime changes even though the police performed at the same level and cleared the same number of cases. It only considers the number of cases cleared but it does not consider the time taken to clear or quality of investigation. The time taken to apprehend the offender from the occurrence of crime is important because of the psychological anxiety it creates in the law abiding citizens and the deterrence it creates to the prospective offenders.

The clearance rate is dependent upon the type of crime and hence may change considerably when the distribution of cases changes even though there is no change in the police performance. The data presented in the Report of President's Commission (1967) shows that the clearance rate of "named suspect" cases is much higher than the "unnamed suspect"
cases" (86% against 12%). The clearance rate as defined does not explicitly consider the multiple clearance due to plea bargaining when an offender is arrested. Greenwood's Analysis of the Apprehension Activities of the New York City Police Department, referred by Hoffman, (1971) shows that some types of crimes have higher multiple clearances than other. To account for the multiple clearances, Hoffman suggests that the number of cleared crimes, the numerator in the clearance rate, be adjusted by subtracting the total extra clearances in the multiple clearances from it, for calculating the clearance rates.

**Arrest Rate**

The arrest rate is the number of arrests in a specified interval of time. National Advisory Commission on Criminal Justice Standards and Goals (1974), suggested average number of arrests per officer as one of the sample output measures for apprehension. The arrest rate can be calculated by several other classifications – arrest rate by type of crime, arrest rate per capita, arrest rate per a specified dollar amount of police budget, and arrest rate by geographical regions of precincts. The arrest rate as defined here does not consider the number of crimes or the reported crime and is different from clearance rate in this respect. The arrest rate is an output measure of the police; it is an objective measure; it can be easily implemented through the existing operating procedures; but it does not indicate the quality of the arrests. The arrest rate, unless it is used with other indicators, does not distinguish between the changes in amount of crime in the area and the corresponding change in the arrests and the change
in the arrest rate because of the changes in police effectiveness.

**Conviction Rate**

The conviction rate is the ratio of the number of arrests resulting in conviction and sentencing to the total number of arrests made. This measure is used with the argument that an offender cannot be assumed guilty until he is convicted and that it reflects the quality of arrests to some extent. However, it includes factors such as prosecutors' performance, caseloads and backlogs in courts, and the quality of defense, which are beyond the control of a law enforcement agency. The percent of arrests that are upheld by the first court before appeals is an indicator of quality of arrests. The conviction rate is not a direct measure of police performance, but it is a MOE that reflects the performance of the CJS in processing a reported crime and making the offender go through the due process of law. The conviction rate is more closely related to the ultimate goals of the CJS than the clearance rate, and arrest rate. In Suchman's categorization of criteria, the conviction rate belongs to the category of highest form of evaluation, the study of process while arrest rate and clearance rate belong to the category adequacy performance while the response time belongs to the category performance. The conviction rate is an objective measure that can be implemented readily through the existing operating procedures. The conviction rate on both the original charge and a reduced charge should be used so that the level of plea bargaining and the ultimate effectiveness of arrests could be evaluated. The conviction rate considers only the number of cases convicted, but it does not consider
the time taken to convict the offender. Becker in his economic analysis of crime showed that the offenders would be more sensitive to the certainty of punishment or probability of punishment than the severity of punishment. The offenders perceived probability of punishment is more important than the real probability of punishment in deterring crime. There are no data available to show the relationship between the time taken to convict and the level of deterrence, but the conventional wisdom suggests that the shorter conviction times would result in greater perceived deterrence. The two measures, time taken to convict and the conviction rate, are indicators of the responsiveness of the CJS to a reported offense. The clearance rate and conviction rate are ratio measures. Like any other ratio measure, it overlooks the absolute size. If the ratio does not alter with the changes in the absolute or in other words the system is linear over the total range of possible values, the higher ratio would indicate better performance no matter what the absolute size is. In reality, the world is not necessarily linear, so the caution must be exercised in using the ratio measures without considering the absolute size.

**Crime Preventive Effectiveness of Patrol**

The police patrol units perform preventive patrols when they are not responding to requests for emergency police service. Olson and Wright (1975) quoted from the queueing studies conducted at the Chicago Police Department, that the utilization rate of patrol units seldom exceeds 60 percent. Because police patrol units often require a significant portion of the total police effort there is considerable
interest in police circles about the crime preventive effectiveness of the patrol. The following statement by Larson (1970) on the basis of studies reported by President's Commission (1967 b) indicates the problem in this area.

Most "experiments" which have been performed to measure this effectiveness have been marred by poor experimental design and by the irregular way in which crimes are reported.

Larson (1970) used "response time" and crime-in-progress detection probability as effectiveness measure in his quantitative approaches to optimal sector design and allocating patrol units. Olson and Wright used the expected number of incidents of at least one space-time coincidence per unit of time as the objective function in their linear programming model for allocating police preventive patrol effort. Space-time coincidence occurs when a police patrol unit is in a location at the same time that a viewable crime is occurring there. Space-time coincidence is same as crime-in-progress detection used by Larson. The response time and the crime-in-progress detection probability are intermediate measures, but the deterrence that the preventive patrol creates is the ultimate objective of the patrol and some measures for the perceived deterrence are required for the evaluation from total CJS point of view. The difficulty with the perceived deterrence is in measuring the "non-crimes" that were deterred, assuming that they would have been committed but for the deterrence provided by the preventive patrol. Some survey approach similar to victimization survey have to be developed for measuring the perceived deterrence.
Most of the measures discussed so far are output measures of police service concentrating on quantity rather than quality and calculated from the records maintained by police agencies. The quantity measures unless they are used along with quality measures are unsatisfactory as sole criteria, because there is a tendency to maximize the quantity measure at the expense of quality. National Advisory Commission on Criminal Justice Standards and Goals quotation of the American Bar Association emphasizes the weakness in using arrest rate as MOE in dealing with crime.

Even though the prevention of crime and the apprehension of offenders must be a primary responsibility of the police, the use of arrest as measurement of performance without inquiring into the quality of the arrest or the ultimate disposition of the case is improper. To measure the quality of police performance based upon the number of arrests made is analogous to the measuring the performance of a doctor on the basis of the number of operations performed - without any regard for the need for the operations or for its success.

The conviction rate and the percent of arrests upheld by the first court before appeals are indicators of quality of arrests; however, there is no indication whether crime control is improved at the expense of privacy or due process consideration. The two criteria suggested by Hatry (1973) in his list of criteria for the evaluation of personal safety programs: Number of apparently justified complaints of police excesses by private citizens, perhaps as adjudged by the police review board; and Number of persons subsequently found to be innocent who were punished and/or simply arrested; could be used to measure the quality of police performance.
Community Assistance and Control

Police agencies spend a considerable amount of time and resources in noncriminally related public services and some measures are needed for these community service activities. Hoffman (1971) quoted from studies in several United States cities to show that his result of 70 percent for noncriminal activities by police is consistent with a range of 69 to 72 percent. Hoffman suggested developing measures of the community willingness to exercise social control such as the number of criminal activities reported by citizens who are not victims or direct complainants; number of reports commending police action or criticizing police misbehavior; percent of cases reported by nonpolice personnel; percent of cases in which individuals voluntarily assisted police in their duties; and percent of cases in which testimony or support witness were available. The number and percent of police contacts referred to noncriminal justice sources, suggested as a measure for diversion by National Advisory Commission (1974), would also reflect the level of community cooperation and involvement.

Quality of Life Parameters

The ultimate objective of the CJS and one of its components, law enforcement, is to improve the safety and quality of life in the society. The perspective on police is very well expressed by Lind and Lipsky (1971) - "The police are essentially in the position of a firm that produces an intermediate product that will be used as an input to the production of a final product called justice. That is, they produce
services that are not desired as such, but only because they contribute to a final objective". Hoffm an suggested that some parameters could be utilized to measure the positive and negative changes in the effects of criminal activity upon the quality of life. Some of the measures would be: percent of people feeling unsafe; percent of places that people are unsafe; percent of people moving because of crime in neighborhood; percent of people keeping fire arms, watch dogs, etc. The cost of obtaining the information on these quality of life parameters at periodic intervals would be a problem but it can be minimized by adding them to the victimization surveys.

PERFORMANCE MEASURES FOR CORRECTIONS

The courts use sentencing as a deterrent in reducing crime and send offenders to correctional institutions to reduce the crimes that would have been committed if the offenders were not isolated and to rehabilitate the offenders. The requirement of corrections to isolate the offenders is fulfilled because of legal requirements, giving credibility to the criticism that prisons are being used as human warehouses. Sometimes even this requirement is not fully met when offenders are paroled prematurely because of overcrowding of prisons. The corrections have the primary mission of rehabilitating the offender or more recently reintegrating the offender into the normal community life.

The recidivism is one of the direct measures for rehabilitation and is used in numerous correctional evaluations. However, the recidivism rates alone cannot serve all the evaluation needs of
corrections. Some of the problems in using recidivism are discussed in the section on recidivism. Hood and Sparks (1970) argued the penal measures aimed at reforming the offender are intended to do more than simply ensure the avoidance of reconviction and identified some of them as: change attitude towards authority, educate, improve personal relationships, make the inadequate more adequate, provide trade training, develop constructive use of leisure. While discussing the problem of multiple goals in evaluation, Glaser lists several objectives for a prison operation such as low escape rate, small number of mass disturbances, few inmates receiving disciplinary reports, high proportion of prisoners completing educational and vocational programs, and high productivity of institution farms and industries as well as low recidivism rates of its inmates. Gibbons, Lebowitz and Blake (1976) suggest that an evaluation not only may deal with the technical issues involved in, say, recidivism reduction, but also may focus on elusive human changes such as fostering of independence, lowering of alienation and bolstering of self-esteem.

In an attempt to analyze the scientific proof that certain correctional measures are actually effective in eliminating criminal behavior, Peter P. Lejins (1958) considered three methods of proof for justification: the direct check, proof through a theory or a frame of reference; the indirect check. The direct check means the direct observation that the offender actually stopped being a criminal and refers to the recidivism which is not convenient instrument to allow relatively quick checking of the effectiveness required in the managerial
control of programs. The second method of justification, through a theory or frame of reference has severe problems considering the state of the art represented by the statement, "The sad truth is that in the field of criminology we have very few items of knowledge which can be considered proven scientific theories..." (Lejins, 1958 p.427). The third method, the indirect check only checks the items that are in some way supposed to be connected with the criminal behavior. In view of difficulties with the first two methods of scientific proof, the direct check and proof through a theory, Lejins suggested that the correctional personnel at all levels should accept the use and development of both psychological and sociological instruments for an indirect checking of the effectiveness of correctional programs. Several MOE that are indirect checks of effectiveness are discussed here.

**Correctional Institution Environment Scale**

The Correctional Institution Environment Scale (CIES) is a testing instrument (Moos, 1970; Wenk and Frank, 1973) to achieve an assessment of the social climate factors in an institution as they are perceived by individual inmates and staff members functioning within it. The development of CIES is based on the assumption that the attributes of the people and the attributes of the environment and the resulting interaction determine the quality of life in an institution. The CIES has nine subscales organized around three principal dimensions shown in Table 4 - 3. The people-to-people relationship's dimension uses three subscales of involvement, support and expressiveness and measures to what extent inmates tend to become involved in the unit, the extent
to which staff support inmates and inmates support and help each other, and the extent of spontaneity and open expression within these relationships. The next dimension of institutional treatment programs assesses the extent to which inmates are encouraged to be self-sufficient and independent and to take responsibility for their own decisions, the extent of practical preparation for the inmates' release from the institution, and the extent of personal problem orientation towards self-understanding and insight, using three subscales - Autonomy, Practical Orientation, and Personal Problem Orientation. The last dimension of institutional functioning uses three subscales of order and organization, clarity, and staff control which are system oriented in that they are related to keeping the correctional unit or institution functioning in an orderly, clear, organized and coherent manner.

Table 4 - 3
Subscales of CIES

<table>
<thead>
<tr>
<th>Correctional Institutional Environment Scale</th>
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</thead>
<tbody>
<tr>
<td><strong>People to People Relationship</strong></td>
</tr>
<tr>
<td>1) Involvement</td>
</tr>
<tr>
<td>2) Support</td>
</tr>
<tr>
<td>3) Expressiveness</td>
</tr>
</tbody>
</table>
The goal of correctional institutions is behavior modification of inmates, consequently, the inmates perception of the institutional environment is very important and a scale to assess it in a standardized procedure should be included in MOE of institutional programs. However, institutional environment is an intermediate product which contributes to the final product of behavior modification. The CIES is a proxy measure of the institutional programs. Similar to all proxy measures, the use of it poses the problem of it being maximized instead of the basic objectives. Duffee (1974) suggests that the climate data can provide a way of controlling variance in the prediction of outcomes.

**Successful Completion Rate of Programs**

The number of people completing the program provides a workload measure of the programs. The ratio of people completing the program to the people entering the program provides a measure of the program effectiveness from the point of view of the people for whom it is intended. However, it is important to consider how the people are selected for the program and how the completion of the program is defined and what is happening to the persons not completing the program. Another aspect of the selection process is whether the offenders being dealt with by the program are the same type as those for whom it is intended. Gibbons, Lebowitz and Blake cite an example of alcoholic treatment programs ending up with a clientele of middle-class chronic drinkers rather than the skid rowers for whom they were intended. The use of completion rate as a MOE confounds the program dropouts due to
the program quality and the heterogeneity of the people going through the program.

**Infractions of Institutional Rules**

Wenk and Moos (1972) list reduction of infractions of institutional rules, especially individual and collective violence inside the prison as one of the correctional objectives that is a practical concern of institutional administrator. The ultimate objective of corrections is rehabilitation of the offenders, however, the maintenance of law and order within the institutions is an essential prerequisite for accomplishing the rehabilitation objective. Moreover, the attitude of the offender towards the institutional rule would be a good indicator of his law abiding behavior after release from the institution. The number of institutional rule infractions by type of infraction is an outcome measure of correctional programs very closely related to the ultimate objective of rehabilitation. It is an objective measure which can be implemented easily through the existing operating procedures and records.

**Vocational Skills Improvement**

The National Advisory Commission on Criminal Justice Standards and Goals (1974, standard 6.6) recommends that the data describing the offenders corrections experiences should be added to his statistical data prior to his release so it can be used in association with post release outcomes in evaluating correctional programs. Some of the data items recommended for inclusion are work and training experience,
attitude, job placement, educational experience and accomplishments, and participation in treatment and counseling programs. These data items could be used for monitoring and evaluating the programs even before offenders release, if the data are captured at the completion of programs and they are summarized by program from the offender based data systems. With the increasing uses of computerized information systems in the corrections, the cost of the reorganization and summarization is considerably reduced and the whole effort becomes feasible. By capturing the ratings of the vocational skills of the offenders by the treatment staff at periodic intervals for the data on work and training experience, a people oriented vocational skills index can be constructed using the approach described in one of the later sections. The Ohio Department of Rehabilitation and Correction (ODRC) in its Offender Information System used a four point scale of excellent, good, fair and poor for employment potential ratings by treatment staff.

Educational Improvement

From the educational experience data during incarceration and the data on education level at the admission, an index for educational improvement can be constructed on the same lines as vocational skills improvement. The ODRC used Scholastic Aptitude Test and several other instruments to assess the educational level of the offenders at the time of admission and at several other significant periods. An index based on these test scores can be used for monitoring and evaluating educational programs and several other related programs.
Psychological Attitude Improvement

The Offender Information System of ODRC had data elements, Psychological Personality Characteristic and Psychologists Behavior Rating in the Offender's Record. In addition, tests are administered to all offenders to get their Personality Inventory Score and Attitudinal Inventory Scores. An index for psychological attitude improvement can be constructed on the lines similar to others discussed above. The construction of an index raises several questions about measurability and scales of the ratings used for various skills of the offenders and the units for the index, so, it is important that some of the problems in building an index discussed in the section on People Oriented Program Index are considered. The ultimate objective of the corrections is rehabilitation, but in the absence of proven theories on the relationships between recidivism and improvement in vocational, educational skills and psychological attitudes, the use of these indices can only be justified on the basis of conventional wisdom that an educated, employed and psychologically sound individual is less likely to recidivate.

PERFORMANCE MEASURES FOR COURTS

The increasing crime rates and the growth in the nation's crime consciousness have focused attention on all the components of the CJS and in particular on the ability of the courts to perform their critical role in crime control. The problems in the court system, too many defendants, enormous backlogs, and increasing work loads were
highlighted by the National Conference on the Judiciary held in Williamsburg in March 1971. It is made clear in the consensus statement adopted at the conference that the fight against crime should closely scrutinize the processing of accused persons by the courts. The basic ingredient of the deterrence, the threat of incarceration and penalties can only be imposed by the courts. The trial delays and the sentencing practices have raised the questions about the courts' performance in criminal cases. The conclusion of the National Advisory Commission on Criminal Justice Standards and Goals that the first priority should be given to speed and efficiency in achieving final determination of guilt or innocence of a defendant, highlights the importance of the performance measures for courts.

**Processing Time**

The time delay between arrest and the final disposition is important on one side because of the individual's right for a speedy trial and on the otherside because of its impact on the perceived probability of conviction by offenders. For those who are found not guilty, it is equally important to clear them of their charges. Landes (1971) and Rhodes (1976), in their multiple regression analysis of court dispositions, considered the court delay as an independent variable. Their conclusion on whether court delay increases the demand for trials as opposed to guilty pleas are contradicting, however, the evidence deteriorates over time and the probability of conviction can only decrease as the court delay increases. The length
of processing time is not a direct measure of the crime reduction or
due process considerations, but is a measure of performance of the
courts. The processing time is an objective measure that can be
implemented easily from the existing records and can be used to compare
different courts or the same court with different operating policies
and procedures.

Case Loads

The number of cases processed by a court system is a measure of
its output and can be used in comparing the productivity and efficiency
of a court. However, there are several measurement problems because
there is no standardized definition of a "case". The other units or
terms used by court systems in publishing their output statistics are
indictments, defendants, and charges. The number of cases does not
represent the output in comparable units because of the varying
activity in the case. A case can have a single defendant or multiple
defendants; single or multiple indictments and charges; charges arising
from a single event or a set of unrelated events connected only because
of the same individuals committing them; and a single offense or several
offenses. Because of the lack of standardization in reported statistics,
it is difficult to infer the number of defendants, number of indictments
or number of offenses from the number of cases. The relationships
between charges, offenses and defendants vary considerably depending
upon the structure of the state criminal code, the nature of events
leading up to the offense and the local customs. To alleviate this
problem, the National Commission on Criminal Justice Standards and
Goals (1974, Standard 5.6) has presented the case counting standard. For data elements recording what happens to individuals, the standard limits the recording to action taken in regard to one individual and one distinct offense where as the recording of the number of events regardless of the number of defendant transactions involved is suggested for the data elements describing the events. Eisenstein and Jacob (1973) suggest the use of defendants as the unit of analysis in measuring the performance of courts because in most instances the primary concern is what happens to people rather than what occurs to descriptions of events.

**Efficiency and Productivity of Courts**

The primary goals of court systems are the protection of rights, consistency in sentencing and reduction in delays, but the courts use considerable resources. In some cases such as witnesses and jury, the payment is at arbitrarily set prices rather than the existing market prices for the resources used by the courts. The efficient use of jury and witnesses by the courts is not directly related to the quality of justice, but it has considerable impact on the image of the courts in view of the law abiding citizens who come to the court only as jury or a witness. The excessive jury and witness idle time contributes to some of the criticism leveled against the courts. Mason and Johnson (1976) suggest the problems in formulating technically and politically acceptable MOE as the reason for poor implementation of productivity improvement efforts in local government and state that there are no
measures agreed on a broad scale, within the courts, to date. The jury and witness idle time can be reduced in some instances by the procedures that cause delay in conducting the trial. The solution is not to ignore the productivity improvement efforts in the name of constitutional right for speedy trial, but explicit clarification of value of resources and rights by the responsible authorities in the CJS.

Conviction Rate

The conviction rate is the ratio of the number of defendants convicted to the total number of defendants appearing before the court. There are several definitional problems with this widely used output indicator of the criminal courts besides the problems discussed in case loads. There is no generally accepted definition of conviction. It could refer to pleas of guilt together with findings of guilt by a judge or a jury. Besides conviction and acquittal, there are several intermediate dispositions such as prosecutor declining to prosecute defendant jumping bail and dismissing of charges. The conviction rate as reported is subject to wide fluctuations depending on how the intermediate dispositions are treated. The following sentence by Eisenstein and Jacob highlights the problem: "The lack of standardization in published statistics and deficiencies in internal record keeping procedures creates the reliability problems." Even when definitional and reporting problems are solved by standardizing the procedures, the convictions are not homogenous and the total number of convictions or conviction rate treats the conviction of a murder committed by an organized crime enforcer equal to the conviction
of a minor theft. The objective of the prosecutor, maximization of the expected number of convictions weighted by their sentences, as in the model of plea bargaining developed by Landes (1971) can be used as an output of the courts also. The sentencing is not uniform in the courts across the country, some courts provide maximum and minimum terms, some only maximum terms, and some average terms. Eisenstein and Jacob suggest using the "real" sentence - that is the amount of time that the defendant is likely to spend in prison. The conviction rate is an outcome measure rather than the output measure and is not related to the performance of the courts. The conviction rate is influenced by the agencies that are not in control of the courts such as prosecutor and police and it only concentrates on conviction ignoring the protection of defendant's rights which are a primary responsibility of the courts. However, the conviction rate is a MOE that considers the overall effectiveness of the CJS and it is a quantitative measure that can be implemented easily.

Quality of Justice

Most of the measures discussed so far are MOE of courts concentrating on quantity rather than quality. The improvement of quantity measures could sometimes happen at the expense of quality, so it is essential in the evaluation of courts where the quality of decisions is the major objective, that some measures of quality be used along with quantity measures. The relationship between quantity and quality of output by courts is implied in the following summarizing of sentences by Reder (1974). "... a community has a choice among
alternative methods of repressing such violations. ... it can achieve the implied degree of crime repression by spending more on police, courts, etc., or by permitting citizens less freedom to engage in activities that facilitate evasion of police surveillance." The primary output of the courts are the rulings on the guilt or innocence of the defendants which can deprive the freedom of the defendants or cost them considerably. So the quality of the rulings is very important or the errors of type I, ruling of guilty when the defendant is innocent, and type II, acquitted when the defendant is guilty, are very expensive both to the defendant and the community. Some measure of type I error and type II error is very much useful in evaluating the courts, but the practical implementation is not very easy because of the conditions and expense. The ratio of rulings reversed in a higher level court can be used as indicators of the quality of rulings in a court. Even this ratio may not reflect the level of type I or type II errors, because the rulings may be reversed on technical grounds, however, it is important because even in case of reversals due to technical grounds, it is an indicator of protection of defendants' rights in the lower level court. The conviction is only part of the court ruling, the sentence that accompanies it is a major concern of many defendants and the society. The consistency of sentencing within a court over time and between court districts is an essential element of quality of justice to uphold the doctrine of equality before law. Rhodes (1976) in testing the sentencing hypothesis in plea bargaining used measures: the fraction of guilty plea defendants who receive prison sentences; the ratio of the fraction of guilty plea
defendants receiving prison sentences to the fraction of defendants receiving prison sentences following the trial; the comparative sentence weight as published by the Administrative Office of the United States Courts. All these measures can be used as measures for consistency of sentencing. Hagan (1977) used a dichotomized variable, disposition of case with fine option and no fine option to compare sentencing patterns for North American Indians and whites in urban and rural criminal communities.

Wildhorn, et al. (1977) in their comprehensive study of performance measurement of prosecution, defense, and court agencies involved in felony proceedings identified several issues of concern to criminal justice practitioners for defining and selecting indicators of performance. Four of the five issues identified, Evenhandedness, Sentencing Variation, Plea Bargaining, and Case Screening are concerned with the quality of justice. The charging standards or threshold and charging accuracy by type of offense are suggested as measures for case screening while the frequency of plea bargaining and the balance of systemwide effects and systemwide concessions to defendants by the category of highest offense charged are suggested for plea bargaining. For measuring evenhandedness and sentencing variation, use of four alternative sentence severity indices is considered. For gauging overall performance measures, Wildhorn, et al. considered construction of an aggregated performance measure out of separate indices of performance, but did not suggest any method in making them commensurable, and stated that criminal justice community shows clear preference for retaining the separate identities of different functions.
and integrating their performance subjectively according to the evaluators' view of their relative contributions. This identifies the need for multiple measures and some methodology to clarify the relative values of multiple measures and to treat them explicitly.

**PEOPLE ORIENTED PROGRAM INDEX**

Most of the criminal justice programs have the basic objective of improving some skill or attitude of the target population. An index to measure the effect of the program is developed using the model developed by Torrance (1976) for health status index. The methodology outlined here is general enough that it can be used to measure such a diverse effects as: Vocational Skills Improvement, Educational Improvement, Psychological Attitude Improvement, Physical and Psychological Injury Caused by Crime. The use of an index can become an exercise in compressing noncommensurable measures into a single measure with the resulting loss of information content. On the other hand, it is not practical to get explicit value judgements for some minor attributes of one of the performance measures of a program. So it is necessary to strike a proper balance. The Figure 4-1 illustrates the costs of building an index to show that there is an optimum level for aggregating individual performance measures. The optimum level of aggregation varies considerably depending on the sensitivity of value structure for the performance measures and the cost of decision makers' time, and the personal style of decision makers in the organization.
Figure 4-1. Total Cost of Building an Index
The basic concept in developing the index is identification of discrete function states for the attribute being measured and establishing the value of being in each of the identified discrete function states. The continuous function states could be used and the index can be built on same lines changing summation to integrals. The formulae involved in building the index are described for the discrete function states because of widespread use of discrete measures in classifying functional states in social programs. For building the vocational skills improvement, a set of possible function states for vocational skill are poor, fair, good and excellent. A set of well defined ranges for reading levels and scores of aptitude tests could be used as function states for developing the educational improvement index. For the index to measure physical injury caused by crime, the states defined by Fanshel and Bush for health status index: Well-being; Dissatisfaction; Discomfort; Disability-minor; Disability-major; Disabled; Confined; Confined-bedridden; Isolated; Coma; and Death could be used. In establishing the value of being in a functional state, the relative values rather than the absolute values that are important, so the lowest and highest functional states could be assigned 0 and 1 and some appropriate values between 0 and 1 could be assigned for other functional states. The magnitudes of value of being in a functional state are important only among the states to reflect the importance of that state, so the normalized values between 0 and 1 can be used for all states as long as the same values are used for all programs. The impact of normalization will be same on
all programs and the ranking or comparison of the programs is not affected by the normalization or relative values.

\[ j = 1, 2, 3, \ldots, n \] represent discrete function states (levels),

\[ h_j \] is the value in State Value Units (SVU's) for function state \( j \),

\( t = 0, 1, \ldots \) represent discrete points in time,

\( S(it) \) is the functional state of individual \( i \) at time \( t \).

A point in time state value index measures the instantaneous state value of all individuals \( (m) \) in the population at single point in time and averages these to give a group index. It can be calculated as

\[ H_t = \frac{1}{m} \sum_{i=1}^{m} h_s(it) \]

A period of time state value index averages the state value of each individual over a specified period of time and averages these over all the individuals in the group to give a group index. The period of time index for the time interval between \( t_1 \) and \( t_2 \) can be

\[ H_{t_1, t_2} = \frac{1}{m} \sum_{i=1}^{m} \sum_{t=t_1}^{t_2} h_s(it) \]

For operational ease and for developing the equation for program effects, this equation can be re-stated in a different form as

\[ H_{t_1, t_2} = \frac{1}{m} \sum_{i=1}^{m} \sum_{j=1}^{n} h_j f_{ij} \]

where \( f_{ij} \) is the fraction of time period \( (t_2 - t_1) \) during which individual \( i \) is in state \( j \).

The total amount of improvement created by the program in State Value Units for the time interval between \( t_1 \) and \( t_2 \) is individual
improvements summed over all individuals in the program. It can be calculated as

\[ H_{t_1, t_2}^P = \sum_{i=1}^{m} \sum_{j=1}^{n} h_j (f'_{ij} - f''_{ij}) \]

where \( f'_{ij} \) represents the fraction of time interval between \( t_1 \) and \( t_2 \) spent by individual \( i \) in state \( j \) when there is a program and \( f''_{ij} \) is similarly defined fraction when there is no program. Several health status index models have been used in the health program evaluation studies, but Torrance has shown that most of them are special cases of his model. Several other schemes of building an index for social program evaluation can be shown as special cases of the method described here.

**SELECTION OF IMPLEMENTABLE PERFORMANCE MEASURES**

The final selection of the meaningful performance measures for use in routine evaluation and decision making in the organization depends very heavily on the factors unique to the organizational setting. The most relevant measures that truly measure the achievement toward ultimate goals and the overall performance of the organization could be either too difficult to quantify or only remotely related to the output of the organization or the specific decisions of the policy makers in the organization. The Figure 4 - 2 shows some of the factors influencing the selection of performance measures.

The data collection procedures and the availability of historic data for comparison have to be considered in the final selection along with the need for defining the most comprehensive set of measures. The
<table>
<thead>
<tr>
<th>Resources</th>
<th>Program Participants</th>
<th>Environmental Factors</th>
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<tbody>
<tr>
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<td></td>
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<tr>
<td><strong>Input Measures</strong></td>
<td><strong>Output Measures</strong></td>
<td><strong>Outcome Measures</strong></td>
</tr>
<tr>
<td>Relevance of Goals</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Ease of Establishing Relationships (Cause - Effect)</td>
<td>Easy</td>
<td>Moderate</td>
</tr>
<tr>
<td>Measurability</td>
<td>Easy</td>
<td>Moderate</td>
</tr>
<tr>
<td>Ease of Quantifying</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Follow up Period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control of Administrator</td>
<td>High</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Figure 4-2. Factors Influencing Selection of Performance Measures
clarity of the performance measures selected is important to avoid misinterpretation by an average member of the organization in perceiving the objectives he should be working towards. The directly linked and more specific performance measures are helpful in avoiding misinterpretation and improving consistency in applying the performance measure. The proximity of the performance measure to the events it is evaluating is an important factor in selecting between two performance measures.

The success of the implemented performance measures depends very heavily on the involvement of the decision makers in defining the measures and their commitment in using them in the day-to-day operation and evaluation of programs. The cost of measurement in using the performance measures has to be justified by the improvement in effectiveness of the operations through better decisions and better programs. Golovin's (1969) call for an "evaluative branch" of government indicates the necessity for enhanced measurement of performance in social programs.
The existence and need for defining multiple performance measures in evaluating the criminal justice programs and allocating resources to them is clear from the discussion of the performance measures in the previous chapter. The importance of the performance measurement in the CJS is very well demonstrated by the criminal justice research solicitation by the NILECJ, Performance Measurement Theory. The articles in the NILECJ (1976) Publication, Performance Measurement and the Criminal Justice System: Four Conceptual Approaches, which are the basis for planning the research solicitation, discuss the need for multiple measures and call for the use of several measures. In this chapter, the criminal justice resource allocation problem is formulated as Multiple Objective Linear Programming (MOLP) model to aid the decision maker in resolving the conflicts between noncommensurable objectives and establishing the trade-offs among objectives. The model cannot generate the trade-offs, but it can provide information helpful in the process of clarifying the trade-offs and can make the trade-offs explicit so an informed evaluation of the past decision can be made in retrospect. The discussion of past decisions can address the validity of the trade-offs and other assumptions to improve the learning process of decision making in the organization.

The proposed and continuing programs have varying impact on
different subsystems of the CJS, so it is necessary for any model to consider the interactions among the subsystems: police, corrections, courts and other crime prevention activities, and treat the CJS as a whole. Becker's Theoretical model discussed in the chapter, Current Evaluation Methods, treats the CJS as a whole by using a single objective of minimizing the total social loss. Most of the criticism of Becker's model by Block and Hienieke (1975) concerns the transformation of an inherently multiattribute decision problem into a single criterion model of wealth only without much consideration of the underlying multiattributed structure of the individual's preference. The unidimensional concept of utility in the economic approach has drawn the criticism from Firey (1969) in terms of its applicability to crime and punishment where a crime is expected by its perpetrator to serve his private interest and the punishment is expected by its executor to serve the social interest. A multidimensional concept of utility which can adequately represent the complexity of relationships between private interest and social interest is suggested by Firey. Arrow (1965) cautions about the proper treatment of social and private benefits in developing criteria and measurement of benefits for social interest.

The selection of the preferred package of programs or the decisions on the levels of resources to be allocated for different components cannot be accomplished even using MOLP model without assuming that the decision maker's preference and value structure can be represented by a single value function with all the multiple objectives as arguments and that the trade-offs between the competing and complementary objectives can be quantified in some
form. The use of MOLP model or any other analysis is put in proper perspective by Schlesinger (October 1968) in the following sentences: "Analysis cannot bridge a gap between irreconcilable objectives. At its best, analysis can shed some light on the costs of accepting one objective at the expense of other."

The resource allocation decision in criminal justice system is faced at several levels of Government, Federal, State and Local, and in different subsystems, Police, Corrections, Courts, etc. The MOLP model can be implemented in all cases, however the actual objectives and the decision variables used will have to be selected to match the objectives of the organization allocating the resources. For the successful implementation of the model, it is very important that the administrators and decision makers be involved in the actual definition of the objectives. The objectives discussed in this chapter are presented as an example or a set of objectives that could be used for starting the discussion and development of the objectives. The total expenditures in the CJS published for 1976 by the United States Department of Justice, et al., (1978) are analyzed using the MOLP model to determine if some other alternative resource allocation would have improved the effectiveness. The major emphasis in formulating and solving the model is the development of methodology and illustration of implementation details rather than the derivation of conclusions on the alternative resource allocation strategy. Implementation of the model in the organization responsible for the resource allocation would vastly improve the credibility and impact for the conclusion drawn from the analysis. In formulating the model, it had to be kept
small so the coefficients of the model could be estimated from the available data in the published literature and the computer processing costs would not be too excessive. On the other hand, some detail had to be included to show the capabilities of the methodology and the feasibility of implementation.

DETAILS OF THE MOLP MODEL

The details of the MOLP model are developed starting with the decision variables. The expenditures in the different subsystems of the CJS are the decision variables.

\[ x_i = \text{Expenditures in Subsystem} \ i \]

The subsystems identified in the published 1976 expenditure data and the decision variables used in representing them are shown below:

\[ x_1 = \text{Police Protection Expenditures} \]
\[ x_2 = \text{Corrections Expenditures} \]
\[ x_3 = \text{Legal Services and Prosecution Expenditures} \]
\[ x_4 = \text{Public Defense Expenditures} \]
\[ x_5 = \text{Judicial Expenditures} \]

Another category of Expenditures, Other Criminal Justice, is identified in the 1976 Expenditure data, however, the estimation of the impact on objectives for different levels of expenditures in this category is very difficult without the proper identification of the category. So this category is not included in the model. It is subtracted from the total expenditures to get the total amount of budget available for allocation.

The most important step in the successful use of the model is
the selection of proper objectives and the performance measures. All
the points presented in the chapter on Performance Measures apply to
the definition of objective functions used in the model. The primary
goal of the CJS is crime reduction. A performance measure that can
identify the fulfillment of this crime reduction goal should be
included as one of the objective functions of the model. The possible
measures are Crime Seriousness Index as proposed in the previous
chapter, damages from offenses to the society used by Becker in his
model or simply the total number of offenses. The Crime Seriousness
Index defined as a vector measure would be the ideal choice, however,
the estimation of objective function coefficients for different
components of the Crime Seriousness Index would be a major research
study by itself at the present level of data availability and the
understanding of functional relationship between inputs and outputs
in CJS. The work done as a result of the research solicitation in
Performance Measurement Theory can produce some advancements in this
area. Most of the economic studies used the total number of felonies
to measure the effectiveness of law enforcement expenditures, mostly
because of the availability of the UCR data and the lack of
comprehensive data on damages to the society. So in the demonstration
example, number of offenses is used as a measure fully acknowledging
the short-comings discussed in the earlier chapter.

Several analyses to test the Theory of Deterrence have identified
the probability of conviction as an important factor in deterring
crime. The modeling advances and the improved understanding of the
deterrence mechanism can also be anticipated as a result of the Criminal
The probability of conviction is used as another performance measure and an objective function in the example. The deterrent effect of conviction is related to the probability of conviction as perceived by the offender rather than the actual probability of conviction available only in some research studies. The timeliness of conviction has considerable impact on how the offenders perceive the threat of conviction. Levin (1975) suggests the hypothesis that regardless of the impact of delay on leniency, it is possible that long delay reduces the deterrent effect of the criminal sanction. So the processing time for conviction which is an intermediate output of the CJS is a candidate for one of the performance measures. As better understanding of the deterrence mechanism develops, the interpretation of trade-offs between processing time for conviction and probability of conviction should be possible and the decision makers could be expected to consider these factors in expressing their trade-offs. In the example, probability of filing a case is used as a surrogate measure for time for conviction. It is reasonable to assume that probability of filing a case by the prosecutor will be higher as the schedule of the courts and the prosecutors become less crowded.

All these objectives discussed so far consider the factors favorable to law enforcement. The strict law enforcement and increasing the probability of conviction can probably reduce the amount of crime, but at the expense of punishing some innocent people. Some quality of justice measures should be included in the model to account for the negative aspects of increased law enforcement without due regard to
human rights. Several quality of justice measures can be defined as discussed in earlier chapters, however, a measure for which the data and the relationship between resources and the effectiveness are available had to be selected for the example. The probability of a case terminating without trial is used as a quality of justice measure.

The corrections is a major component of the CJS and the expenditures for corrections are the second highest, only next to police protection. The corrections contributes to reduction of crime through three different phenomena: isolation, deterrence and rehabilitation. The rehabilitation, when it is accomplished in the correctional institutions has several other positive contributions to the society besides reduction of crime. The improvement in vocational skills of the incarcerated offenders is used in the example to represent the positive factors of rehabilitation.

The objectives identified for the example are listed below:

\[
\begin{align*}
\text{Max } z_1 &= \text{ Index Offenses Decreased} \\
\text{Max } z_2 &= \text{ Probability of conviction} \\
\text{Max } z_3 &= \text{ Probability of filing a case} \\
\text{Min } z_4 &= \text{ Probability of terminating a case without trial or Max } - z_4 \\
\text{Max } z_5 &= \text{ Vocational skills improvement}
\end{align*}
\]

Adding the budget constraint for the expenditures in all subsystems, the MOLP model can be summarized as shown in Table 5 - 1.

In formulating the model, there is an implied assumption that the values of objectives can be calculated for different levels of decision variables using the coefficients, \( c_{kj} \), which represent the
Table 5 - 1

Multiple Objective Linear Programming Model

Max $z_1 = c_{11}x_1 + c_{12}x_2 + c_{13}x_3 + c_{14}x_4 + c_{15}x_5$

$z_2 = c_{21}x_1 + c_{22}x_2 + c_{23}x_3 + c_{24}x_4 + c_{25}x_5$

$z_3 = c_{31}x_1 + c_{32}x_2 + c_{33}x_3 + c_{34}x_4 + c_{35}x_5$

$z_4 = c_{41}x_1 + c_{42}x_2 + c_{43}x_3 + c_{44}x_4 + c_{45}x_5$

$z_5 = c_{51}x_1 + c_{52}x_2 + c_{53}x_3 + c_{54}x_4 + c_{55}x_5$

Subject to

$x_1 + x_2 + x_3 + x_4 + x_5 \leq b$

$x_1 \geq 0, x_2 \geq 0, x_3 \geq 0, x_4 \geq 0, x_5 \geq 0$

Where

$b = \text{Total expenditures in CJS to be allocated among the subsystems}$

$c_{kj} = \text{Contribution of objective k by a unit of expenditure in subsystem i}$

$x_j = \text{Expenditures in subsystem i}$

$z_k = \text{Value of objective k}$
contribution to objective $k$ by a unit change in the value of decision variable $j$. This refers to the basic proportionality and additivity assumptions of linear programming model. In CJS resource allocation model, the use of coefficients $c_{kj}$, implies that changing the resources available to the subsystems would proportionately change the effectiveness of the subsystem in achieving the objectives and that the individual contributions of different subsystems can be added to get the overall value of the objectives.

The MOLP model as shown above has the basic structure required to solve the resource allocation problem in CJS. The single objective mathematical programming models have been used in the industry for solving the capital budgeting problem. The MOLP model overcomes the difficulties in applying single objective mathematical programming to CJS by explicitly considering the multidimensional nature of the objectives and the trade-offs among them. In the industry, the measurement problem, that is the estimation of costs and their impacts on objectives have well established procedures. However, the estimation of model coefficients will be a major research undertaking in itself for a full scale MOLP model of CJS.

**ESTIMATION OF THE COEFFICIENTS OF THE MOLP MODEL**

The estimation of the output and its contribution to the objectives of the system is the key issue in evaluating the CJS programs and allocating the resources. The formulation of the MOLP model does not solve this basic measurement problem, it can only provide some structure to the data collection efforts and to the development
of functional relationships between inputs and outputs. For the example, presented here, the coefficients of the objective functions, $c_k$, are estimated from the input-output relationships available in the published literature of empirical investigations on historical data using regression analysis.

All the expenditures in CJS at different levels of Government are published as total dollars spent. The magnitudes of these expenditures are in millions of dollars. To keep all the parameters of the model within reasonable limits so that the computational errors in rounding would not become a significant problem, expenditures and the index offenses are expressed on a per capita basis in the model.

The coefficients of the objective functions for the police protection expenditures, $c_{11}$, $c_{21}$, $c_{31}$, $c_{41}$ and $c_{51}$ are estimated using the relationships developed by Ehrlich (1973) in his empirical investigation of variation of index crimes across all the states of U. S. in 1960, 1950 and 1940 using regression analysis. Ehrlich estimated that "a 1 percent increase in expenditure on direct law enforcement would result in about 3 percent decrease in all felony offenses." This study has created a surge of interest in the empirical investigations of econometric models of crime and punishment and has also become the center of critical discussion on the specification of the model (Ehrlich, 1977). Forst (1976) re-estimated the deterrent effect using 1970 data from the cross section of fifty states, plus the District of Columbia and the same simultaneous equation estimation technique used by Ehrlich. However, Forst concluded that the crime rate is virtually insensitive to cross-state
variation in either the probability or length of incarceration. Panel on Research on Deterrent and Incapacitative Effects, National Research Council, has commissioned a re-analysis of the data used by Ehrlich (Blumstein, Cohen and Nagin, 1978). Vandaele, (1978) after this re-analysis changing the specification of the model, concluded that "With the available data and within the present model, the negative relationship between the crime rate and the probability of imprisonment and between the crime rate and the time served is not spurious".

Some robust estimates of deterrent effects that are widely acceptable will be available only after several corroborating studies are published and in view of the current interest in this topic, this can happen in the near future. In the example, Ehrlich's estimates are used to demonstrate the method.

The coefficient $c_{11}$, the contribution of increased police protection expenditures to reduction in index offenses is calculated from Ehrlich's conclusion that one percent increase in expenditures would decrease three percent in felony offenses.

From Table 2, page 37, of 1976 Uniform Crime Reports (U. S. Federal Bureau of Investigation, 1977):

Index Crime Rate per 1000 population in 1976 = 5.266

Population in 1976 = 214,659,000

From the Table 2, page 23, of Expenditure and Employment Data for the Criminal Justice System 1976.

Police Protection Expenditures by all Governments = $19,681,409,000

All the other criminal justice expenditures used in the example are taken from the same source.
Per Capita Police Protection Expenditures by all Governments = $51.38

\[ c_{11} = \frac{3\% \text{ of Index Crime Rate}}{1\% \text{ of Expenditures}} = 0.3 \]

Using the data for all cities with 100,000 or more residents in 1960, Swimmer (1974) concluded that a one dollar per capita increase in police expenditure is associated with 14 percent less murder, 11 percent less rape, 4 percent less robbery and 3 percent less burglary and larceny. Using Ehrlich's relationship, one dollar increase in per capita police expenditures which is two percent increase in expenditures would result in six percent decrease in all felony offenses. This six percent decrease appears reasonable with reference to the decreases estimated by Swimmer for separate offenses.

The coefficient \( c_{21} \), the contribution of increased police protection expenditures to the improvement in probability of incarceration is calculated from the elasticity of 0.3015 between probability of apprehending and convicting felons and the level of current expenditures on police estimated by Ehrlich (1973, p. 557). In the calculation of probability of conviction, Ehrlich used number of commitments to prisons because no judicial statistics on the number of convictions were available on a state-wide basis. 1976 data for prisoners received from courts are not published at the time of this report writing, so 1975 data are used for calculating the probability of incarceration.

Prisoners received from courts in 1975 by Federal and State Prisons = 129,573

From 1976 UCR, Total Crime Index is 1975 = 11,256,600

Probability of Conviction/Incarceration = 0.0115

\[ c_{21} = \frac{0.3\% \text{ of probability of conviction}}{1\% \text{ of Expenditures}} = 0.000067 \]

The increased police expenditures can be expected to improve the quality of arrests and result in higher percentage of cases filed and lower percent of cases terminated without trial. On the other hand, increased police expenditures could increase the number of arrests without improving the quality of arrests and result in lower percentage of cases filed and higher percent of cases terminated without trial, if the resources of the prosecutors and courts remained at the same level. A study that estimated the relationships between police expenditures and percent of cases filed or percent of cases terminated without trial could not be located, so both the coefficients \( c_{31} \) and \( c_{41} \) are assumed to be zero. The increase in police protection would not really have any impact on vocational skills improvement, so the coefficients \( c_{51} \) is also assumed to be zero.

The coefficient \( c_{12} \), the contribution of increased correctional expenditure to the reduction in index offenses is calculated using the elasticity of crime rate with respect to the average time served in prison. Ehrlich (1973) calculated this elasticity as -1.123 from simultaneous estimation. In estimating this elasticity from historic data, the effect of incapacitation and deterrence are confounded. Nagin (1978) using a theoritical model calculated the
incapacitation elasticity in an attempt to separate the deterrence effect from incapacitation effect. In his model, the incapacitation elasticity is a function of expected number of crimes committed by an active criminal in a single time period, probability of being apprehended and imprisoned for each crime, and average sentence length. From the available data for 1960, Nagin could calculate the values of 0.0315 for the probability of being apprehended and incarcerated, and 2.72 years for the average sentence length, but because of lack of well-documented estimates for expected number of crimes committed by an active criminal for 1960 or for any other year, he used a range of 2.5 to 10 that includes all the estimates. The magnitude of the incapacitation elasticity varies substantially over the range of expected number of crimes committed from -0.179 for 2.5 to .0.466 for 10. The magnitude of incapacitation elasticity is smaller than the elasticity estimated by Ehrlich which includes both incapacitation and deterrence. Because of the heated controversy that the deterrence theory generates, there is justification for using only the incapacitation elasticity in estimating the coefficient $c_{12}$. Due to the lack of single acceptable value for incapacitation elasticity, and due to the fact that Ehrlich's conclusions have been validated by considerable re-analysis, the value of -1.123 for elasticity of crime rate with respect to the average time served in prison, estimated by Ehrlich is used in the calculation of $c_{12}$.

Corrections Expenditures by all Governments in 1976 (U. S. Department of Justice, et al., 1978) is $4,385,512,000. Using the same data for population and index crime rate per 1000 population as
in the calculation of the coefficient $c_{11}$.

Per capita corrections expenditures by all the governments in 1976 = $20.43

$$c_{12} = \frac{1.123\% \text{ of index crime rate}}{1\% \text{ of expenditures}} = 0.289$$

In calculating $c_{12}$ as shown above, the changes in corrections expenditures are assumed to be directly proportional to changes in average sentence length. The increased corrections expenditures could increase the capacity and training facilities of the correctional institutions and could have an impact on sentencing practices and performance of the correctional facilities. However, the simplifying assumption of increase in average time spent in prison with increased correctional expenditures is made to complete the example in the absence of better empirical relationships.

There is a secondary effect on probability of conviction, percent of cases filed and percent of cases terminated without trials from the changes in corrections expenditures. With the current level of difficulties in identifying the relationships of variables with direct impact, the identification of indirect relationships is rather difficult. So for the example, coefficients $c_{22}$, $c_{32}$ and $c_{42}$ are assumed to be zero.

The coefficient $c_{52}$, contribution of increased correctional expenditure to the improvement in vocational skills is calculated using the following conclusions by Singer and Wright (1976, p. 90 and 78):

"...the additional institutional budgetary cost imposed by complying with the standards are offset, at least in part, by benefits to inmates and society at large."
...the income gain nearly justifies the costs of institutional education.

Singer and Wright (1976, p. 76, 82 and 86), estimated the criminal justice system public expenditures required to provide educational services in state and local institutions as shown in Table 5-2.

Table 5-2

<table>
<thead>
<tr>
<th></th>
<th>State</th>
<th>Local</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary Education</td>
<td>181.5</td>
<td>136.3</td>
</tr>
<tr>
<td>Post Secondary Education</td>
<td>6.7</td>
<td>5.1</td>
</tr>
<tr>
<td>Vocational Training</td>
<td>54.5</td>
<td>40.9</td>
</tr>
<tr>
<td>Total</td>
<td>242.7</td>
<td>182.3</td>
</tr>
</tbody>
</table>

State and Local Government Total = $425.0 millions

Assuming that an additional expenditure of $425 million would result in at least that much benefit to the society, the contribution of increased correctional expenditures on improvement in vocational skills is calculated.

Total correctional expenditures in State and Local Government in 1976 = $4129.2 millions

\[
c_{52} = \frac{\text{Educational costs or benefits}}{\text{Total expenditure} + \text{Educational costs}} = 0.0933
\]

The coefficients of the objective functions for the legal
services and prosecution expenditures and the public defense expenditures are calculated using the relationships developed by Rhodes (1976) in his theoretical and empirical investigation using the data from eighty-four of the eighty-nine district courts (the other five were not included because of missing data and extreme cases). Landes (1971) developed a model for individual (micro) decision making in the criminal courts during the plea bargaining process with the assumption that both the prosecutor and the defendant maximize their utility. Rhodes extended Landes' model to clarify the relationship between individual decision making and the overall mechanics of the criminal courts, and to analyze aggregate or macro aspects of criminal justice. Rhodes, in an attempt to test the disposition hypothesis, estimated separate relationships between the dependent variables:

1. Number of cases filed divided by the amount of criminal matter received.
2. Number of trials divided by the amount of criminal matter received.
3. Number of guilty pleas divided by the amount of criminal matter received.
4. The ratio of dispositions other than trials to the number of trials.

and the common set of independent variables:

1. Prosecutors resources: the ratio of the number of lawyers employed by the U. S. Attorney's office to the sum of criminal and civil matter received.
2. The availability and quality of public counsel: the percent of defendants receiving public counsel weighted by the expenditure per indigent case in this district relative to the average expenditure for all federal courts.
3. Delay in disposing of criminal cases and three other variables referring to the age and criminal record of defendant.

The coefficients of these equations estimated by Rhodes using ordinary least squares regression analysis are used in calculating the coefficients $c_{33}$, $c_{43}$, $c_{34}$ and $c_{44}$.

The level of the legal services and prosecution expenditures, and public defense expenditures have an effect on probability of conviction and index offenses per capita. The probability of conviction is more directly related to the percent of cases filed and disposed by trial and is related indirectly through these variables to the prosecution and public defense expenditures. The relationship of per capita index offenses to prosecution and public defense expenditures is much more indirect because its relationship is through probability of conviction. Only a simultaneous equation model can represent these relationships, however there are several difficulties. Rhodes (1976, p. 330) discussed two problems of "identification" and "simultaneous equation bias" in estimating the demand for trials in testing of sentencing hypothesis. Then there is the constant CJS problem of data availability. The coefficients $c_{13}$, $c_{23}$, $c_{14}$, and $c_{24}$ are very important because the resource allocation can be very sensitive to their values. However, the estimation of these coefficients is a major research undertaking in itself and requires some generally accepted deterrence theory. The deterrence hypothesis is drawing considerable resources and is a subject of several research studies, however, there is no well-recognized theory that is not controversial.
So the coefficients $c_{13}$, $c_{23}$, $c_{14}$ and $c_{24}$ are assumed to be zero in the example. This assumption can create credibility problems for the solution of the model. To demonstrate the feasibility of this methodology, the example had to be completed with some questionable coefficients.

The coefficients $c_{33}$, the change in probability of filing a case due to a unit change in the legal services and prosecution expenditures is calculated from the value of coefficient 17.7 estimated by Rhodes in regression equation between ratio of cases filed to received and prosecutor's resources. The ratio of number of lawyers employed by the U. S. Attorney's Office to the sum of criminal and civil matter received is used as the measure of prosecutor's resources in each of the districts.

From the unpublished back up material and print out of multiple regression runs kindly provided by Rhodes in a personal communication:

- Mean value of prosecutor's resources $= 0.0045$
- Mean value of number of cases filed to the amount of criminal matter received $= 0.2645$
- Elasticity of ratio of cases filed to received with respect to prosecutor's resources

$$\frac{\text{Coefficient in Equation} \times \text{Mean of Prosecutor's Resources}}{\text{Mean of ratio of cases filed to received}} = 0.301$$

From the 1976 Annual Report of Attorney General (U. S. Department of Justice, p. 4 and 26):

- Criminal matter received $= 171,518$
- Criminal cases filed $= 44,172$
Ratio of cases filed to received = 0.258
Per capita legal services and prosecution expenditures = $4.88

\[ c_{33} = \frac{0.301\% \text{ of ratio of cases filed to received}}{1\% \text{ of legal services and prosecution expenditures}} = 0.0159 \]

The coefficient \( c_{43} \), the change in probability of terminating a case without trial for a unit change in legal services and prosecution expenditures is calculated from Rhodes estimate of 7.51 for the coefficient of independent variable, prosecutor's resources.

Mean value of ratio of number of cases terminated without trial to the amount of criminal matter = 0.1743 received from Rhodes print out

Elasticity of ratio of cases terminated without trial to cases received with respect to prosecutor's resources = 0.194


Criminal cases terminated without trial = 40,331
Ratio of cases terminated without trial to cases received = 0.235

\[ c_{43} = \frac{0.194\% \text{ of ratio of cases terminated without trial to cases received}}{1\% \text{ of Legal Services and Prosecution expenditures}} = 0.00938 \]

The coefficient \( c_{34} \), the change in probability of filing a case for a unit change in public defense expenditures is calculated from Rhodes estimate of -0.056 for the coefficient of independent variable, the availability and quality of public counsel. Rhodes used the percent of defendants receiving public counsel multiplied by the ratio of expenditure on indigent aid to the national average expenditure on public counsel to represent the quality and availability
of public counsel.

Mean value of the availability and quality of public counsel from Rhodes' printout = 0.5819

Elasticity of ratio of cases filed to received with respect to quality and availability of public counsel = -0.123

Per capita public defense expenditures = $1.54

\[
c_{34} = \frac{-0.123\% \text{ of ratio of cases filed to received}}{1\% \text{ of public defense expenditures}} = -0.0206
\]

The coefficient \( c_{44} \), the change in probability of terminating a case without trial for a unit change in public defense expenditures is calculated from Rhodes estimate of -0.068 for the coefficient of independent variable, availability and quality of public counsel.

Elasticity of ratio of cases terminated without trial to cases received with respect to quality = -0.227 and availability of public counsel

\[
c_{44} = \frac{-0.227\% \text{ of ratio of cases terminated without a trial of cases received}}{1\% \text{ of public defense expenditures}} = -0.0348
\]

The improvement in vocational skills of offenders is not related to the expenditures on legal services and prosecutor or public defense. So the coefficients \( c_{53} \) and \( c_{54} \) are assumed to be zero.

The estimation of coefficients of the objective functions for judicial expenditures could have been done easily on the same lines as for other expenditures. An empirical study that investigated the effect of changes in available resources on the performance of courts could not be identified. Similar to legal services and prosecutors
expenditures, and public defense expenditures, judicial expenditures has an indirect effect on decrease in index offenses and probability of conviction. Because of the lack of available relationships, the coefficients $c_{15}$ and $c_{25}$ are assumed to be zero. The direct effect of changes in judicial expenditures is on percent of cases disposed with trials in courts. Gillespie (1976) formulated a theoretical model for the production of court services and estimated the coefficients of this model using the data from all federal district courts over the period 1968-74. Because of the emphasis of the study on productivity, the dependant variable of his model is average output in equivalent judge years per available judge in each court and percent of criminal cases terminated by trial is one of the independent variables. From his estimates of model coefficients using changes in data over time, he concluded that a 10% increase in percent of trials would reduce court productivity by only around 2%. This conclusion is not based on very robust estimates and the use of inverse relationship of this conclusion is questionable, but it is used in estimating the coefficient $c_{45}$ due to the difficulty in identifying any better relationships. Assuming that increasing resources can account for the decreased productivity, the coefficient $c_{45}$ is estimated from the relationship, 2% increase in resources can increase percent of criminal trials by 10%.

From 1971 Annual Report of the Attorney General (U. S. Department of Justice, p.26) -- the year 1971 is selected because it is in the middle of 1968-74 range used by Gillespie:

Criminal cases filed $= 45,883$
Criminal cases terminated with trial = 5,202

Ratio of cases terminated with trial to cases filed = 0.113

Judicial Expenditures per capita = $11.31

Change of ratio of criminal trials to cases filed for a unit change in judicial resources, \( c_{45} \)

\[
\frac{10\% \text{ of ratio of trials}}{2\% \text{ of judicial expenditures}} = 0.0501
\]

The probability of filing a case depends on the court schedule and is affected by the changes in judicial expenditures. However the coefficient \( c_{35} \) is assumed to be zero due to the lack of any empirically developed relationship that could be used to estimate this coefficient. The changes in judicial expenditures do not have any effect on the vocational skills improvement of the offenders. So the coefficient \( c_{55} \) is assumed to be zero.

All the coefficients of objectives are estimated from the relationships developed in the empirical investigation of historic data using regression analysis. All the estimated relationships are linear and they would be good approximations of the true complex relationships in the neighborhood of the current operating levels. However, extrapolating the relationships for values of independent variables very much different from the current levels could lead to erroneous estimates. So additional constraints are added to the model to limit the changes in allocation of resources to not more than 25 percent of the current level. The value of 25 percent to limit the changes is arbitrarily chosen to complete the example and avoid the rushing of solutions to corners and to eliminate trivial solutions.
representing allocation of all resources to one subsystem. Sensitivity analysis and the analysis of valid range of relationships used in estimating the coefficients could provide a more defendable value for the limit of changes. With these added constraints and the estimated coefficients of objectives the MOLP model can be written as shown in Table 5-3.

The MOLP as formulated is an example and had to be kept simple because the programs developed for solving the model are written for solving small problem. Once a commercially developed software packages such as MPS and other Mathematical Programming packages are available, large problems with hundreds of variables can be formulated and solved as is the case now for linear programming problems.

The resource allocation problem arises at several levels of government and in several departments. Some of the factors that need to be considered in formulating a MOLP model are considered here. In the context of program evaluation and selection, binary decision variables can be used to represent whether a program is to be funded or not. The inter-relationships between programs such as contingent and mutually exclusive programs can be easily incorporated into the model by adding extra constraints to specify these relationships.

In formulating the model for the allocation of resources within an operating agency of a component of CJS, several other constraints besides the operating budget could be involved. For example, the ability of agency to add qualified man power and train them even if the extra funds are available, availability of physical resources such as buildings and equipment and growth limits on them, and
Table 5-3

MOLP Model - Example with Numerical Values

Max \[ 0.3x_1 + 0.289x_2 + 0.000067x_1 \\ 0.0159x_3 - 0.02064x_4 \\ 0.00938x_3 + 0.0348x_4 + 0.0933x_2 \]

Subject to
\[ x_1 + x_2 + x_3 + x_4 + x_5 \leq 22.38 \]
\[ x_1 \leq 25.69 \]
\[ x_2 \leq 10.22 \]
\[ x_3 \leq 2.44 \]
\[ x_4 \leq 0.77 \]
\[ x_5 \leq 5.66 \]

\[ x_1 \geq 0; x_2 \geq 0; x_3 \geq 0; x_4 \geq 0; x_5 \geq 0; \]

The decision variables, \( x_1, \ldots, x_5 \), are changes from the lower 25 percent limit to reduce the size of the model.
availability of technology to solve these problems can be incorpo-
rated easily into the model by adding extra constraints for these
limitations. In case of resource allocation to different geographical
areas in the jurisdiction of the agency, any specific limitations or
requirements of one of the geographical areas also can be specified
in the model. In cases where the benefits or costs are incurred
in different time periods, constraints can be specified separately
for each period or net present values can be calculated using
discounting concepts. The formulation of a linear programming problem
is widely used and the capability to address the problem of multiple
objectives in MOLP model makes this proven LP model available for
social resource allocation problems.
This chapter describes the implementation details of the interactive solution procedures used in this research to solve the MOLP Model formulated in the previous chapter. A Multicriteria Simplex Method, which solves the vector maximization problem to get the nondominated solution set is described first. An interactive approach that successively reduces the cardinality of the nondominated solution set to find a preferred solution acceptable to the decision maker is also described. The information from the model is provided to the decision maker for each of the nondominated solutions to iteratively tighten the range of his value judgements. The Multicriteria Simplex Method is implemented as a batch program which passes a data set of the nondominated solution set and the constraints of the parametric space for each of the solutions to another program running in time sharing environment for interactively selecting the preferred solution. The algorithmic details of the solution procedure are described here while the descriptions of the computer programs developed to implement the computational requirements are presented in Appendix.

The following notation is used in defining relationships between vectors:

For the two \( n \times 1 \) vectors

\[
X = (x_1, \ldots, x_n) \quad \text{and} \quad Y = (y_1, \ldots, y_n)
\]
X > Y if and only if x_j > y_j, j = 1, ..., n
X \geq Y if and only if x_j \geq y_j, j = 1, ..., n
X \preceq Y if and only if X \not\supset Y and Y \not\subset X
X = Y if and only if x_j = y_j, j = 1, ..., n

In presenting the algorithm the following MOLP model is used:

Max CX (6.1)

Subject to

AX = b and X \geq 0

Where

C is 1 x n matrix of objective function coefficients, 
\( c_{kj}, k = 1, \ldots, l; j = 1, \ldots, n \)
\( c_j \) is 1 x 1 vector, \( c_{kj}, k = 1, \ldots, l \)
\( c_k \) is 1 x n vector, \( c_{kj}, j = 1, \ldots, n \)

A is m x n matrix of resource requirements
 coefficients, \( a_{ij}, i = 1, \ldots, m; j = 1, \ldots, n \)
\( a_i \) is m x 1 vector, \( a_{ij}, i = 1, \ldots, m \)
\( a_j \) is 1 x n vector, \( a_{ij}, j = 1, \ldots, n \)

X is n x 1 vector of decision variables,
\( x_j, j = 1, 2, \ldots, n \)

b is m x 1 vector of resource limitations,
\( b_i, i = 1, 2, \ldots, m \)

**FINDING ALL NONDOMINATED SOLUTIONS**

The Multicriteria Simplex Method, a generalized version of the simplex method, derived by Yu and Zeleny (1975) to locate the entire set of all nondominated extreme points is used to solve the vector maximization problem for the model formulated in previous chapter.

A Solution, \( \overline{X} \), is nondominated if there exists no other feasible solution such that \( CX \geq C\overline{X} \) and \( CX \not\geq C\overline{X} \).
The details of the algorithm are described here without presenting the proofs for the properties of the algorithm, which are presented by Yu and Zeleny.

Addition of slack and surplus variables and finding the initial basic feasible solution using phase 1 is same as simplex method. A multicriteria simplex tableau for a basic feasible solution, $\lambda^0$ can be written as shown in Table 6 - 1. There are some differences in this table, because of the multiple criteria functions, from the standard simplex tableau. These are $l$ criteria rows of $c_{kj}$; $k = 1, \ldots, l; j = 1, \ldots, n$; corresponding to $l$ objective functions. The index set of all the $m$ basic variables is denoted by $J$ while $\bar{J}$ denotes the index set of currently nonbasic variables, so that $J \cup \bar{J} = (1, \ldots, n)$. For the case shown in Table 6 - 1, $J = (1, \ldots, m)$ and $\bar{J} = (m+1, \ldots, n)$.

In the Table 6 - 1, $c_{kj} = 0$ for all $j \in J$ and
\[
\begin{align*}
\bar{c}_{kj} &= \sum_{i=1}^{m} c_{ki} \bar{a}_{ij} - c_{kj} \quad \text{for all } j \in \bar{J} \\
\bar{z}_k &= \sum_{i=1}^{k} c_{ki} \bar{b}_i
\end{align*}
\]
(6 - 2)

A composite objective function,
\[
\sum_{j=1}^{m} \left( \frac{c}{\lambda^0} c_{kj} \right) x_j
\]
(6 - 4)
is appended at the end of the tableau to test the nondominance of the current basic feasible solution. The details of the nondominance test are discussed later.

In the simplex method, based on the row selection rule to determine the variables to leave the basis, the value of the entering variable can be defined for each of the nonbasic variables as shown below:
Table 6-1

A Multicriteria Simplex Tableau

<table>
<thead>
<tr>
<th>Basic Variables</th>
<th>Basic Variables</th>
<th>Nonbasic Variables</th>
<th>Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>x_{m+1} ... x_j ... x_n</td>
<td></td>
</tr>
<tr>
<td>x_1</td>
<td>1</td>
<td>\tilde{a}<em>{1(m+1)} ... \tilde{a}</em>{1j} ... \tilde{a}_{1n}</td>
<td>\tilde{b}_1</td>
</tr>
<tr>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
</tr>
<tr>
<td>x_i</td>
<td>0</td>
<td>\tilde{a}<em>{i(m+1)} ... \tilde{a}</em>{ij} ... \tilde{a}_{in}</td>
<td>\tilde{b}_i</td>
</tr>
<tr>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
</tr>
<tr>
<td>x_m</td>
<td>0</td>
<td>\tilde{a}<em>{m(m+1)} ... \tilde{a}</em>{mj} ... \tilde{a}_{mn}</td>
<td>\tilde{b}_m</td>
</tr>
<tr>
<td>x_{m+1}</td>
<td>0</td>
<td>\tilde{c}<em>{1(m+1)} ... \tilde{c}</em>{1j} ... \tilde{c}_{1n}</td>
<td>\tilde{z}_1</td>
</tr>
<tr>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
</tr>
<tr>
<td>x_{m+k}</td>
<td>0</td>
<td>\tilde{c}<em>{k(m+1)} ... \tilde{c}</em>{kj} ... \tilde{c}_{kn}</td>
<td>\tilde{z}_k</td>
</tr>
<tr>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
</tr>
<tr>
<td>x_{m+1}</td>
<td>0</td>
<td>\tilde{c}<em>{1(m+1)} ... \tilde{c}</em>{1j} ... \tilde{c}_{1n}</td>
<td>\tilde{z}_1</td>
</tr>
<tr>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
</tr>
<tr>
<td>x_{m+1}</td>
<td>0</td>
<td>\tilde{c}<em>{1(m+1)} ... \tilde{c}</em>{1j} ... \tilde{c}_{1n}</td>
<td>\tilde{z}_{l+1}</td>
</tr>
</tbody>
</table>

\tilde{c}_{1+1(m+1)} \tilde{c}_{(l+1)j} \tilde{c}_{(l+1)n} \tilde{z}_{l+1}
\[
\theta_j = \min \left\{ \frac{b_{rj}}{a_{rj}} : a_{rj} > 0 \right\} \text{ for } j \in J \quad (6 - 5)
\]

Similar to the optimality test in simplex method, the determination of whether the current basic feasible solution is nondominated or dominated is based on the revised cost coefficients of the nonbasic variables. In the tableau, if \( \bar{c}_{kj} > 0 \) for all \( j \in \mathcal{J} \), then the \( k^{th} \) objective function is at its maximum and there are no alternative solutions that will maximize \( k^{th} \) objective, so the current solution is nondominated. (Test 1)

By entering the nonbasic variable \( j \) into the basis, a new basic solution, say \( X^1 \), can be obtained from the current solution, \( X^0 \). The values \( (Z^1) \) of the objective functions for the new solution, \( X^1 \) will have the following relationship to the objective function values \( (Z^0) \) of the current solution.

\[
Z^1_j = Z^0_k - \theta_j \bar{c}_{kj} \quad \text{for } k = 1, \ldots, 1 \quad (6 - 6)
\]

If the tableau representing current basic feasible solution, assuming \( \theta_j > 0 \) for \( j \in \mathcal{J} \), then the following decision rules derived from equation \( (6 - 6) \) can be used to determine the nondominance of the current solution.

i) The current solution is dominated if \( \bar{c}_{kj} \leq 0 \) for all \( k = 1, \ldots, 1 \) and \( \bar{c}_{kj} < 0 \) for at least one \( k = 1, \ldots, 1 \)
for \( j \in \mathcal{J} \). (Test 2)

ii) The entering of the variable \( j_i \), into basis would lead to a dominated solution, if \( \bar{c}_{kj} \geq 0 \) for all \( k = 1, \ldots, 1 \) and \( \bar{c}_{kj} > 0 \) for at least one \( k = 1, \ldots, 1 \) (Test 3)

iii) If there are columns \( r, s \) such that \( \theta_r \bar{c}_{kr} \leq \theta_s \bar{c}_{ks} \) for all
\[ k = 1, \ldots, 1 \] and \( \theta_r \tilde{c}_{kr} < \theta_s \tilde{c}_{ks} \) for at least one \( k = 1, \ldots, 1 \), for \( r \neq s \) and \( r, s \in J \), then the solution resulting from entering the variable \( s \) is dominated by the solution resulting from entering the variable \( r \). \hspace{1cm} \text{(Test 4)}

These four decision tests considerably trim the number of iterations required in finding all nondominated extreme points. However, in a tableau, for the solution \( x^1 \), it is possible that

i) there is no column with \( \tilde{c}_j \leq 0 \) and \( \tilde{c}_j \neq 0 \)

ii) columns for which \( \theta_r \tilde{c}_{r} \leq \theta_s \tilde{c}_{s} \), \( r \neq s \) and \( r, s \in J \)

cannot be considered

iii) there is no row with \( \tilde{c}_j \geq 0 \) and \( \tilde{c}_j \neq 0 \).

Then the variables to be considered for entering are those with \( \tilde{c}_j \neq 0 \), \( j \in J \) and \( \theta_r \tilde{c}_{r} \cup \theta_s \tilde{c}_{s} \), \( r \neq s \); \( r, s \in J \). It is necessary to determine whether the current solution is dominated or nondominated in these cases before entering a new variable to change the basis. A non-dominance test is developed by considering the following linear programming problem.

\[
\text{Max } V = \sum_{k=1}^{l} e_k
\]

Subject to

\[
AX = b \
CX - e = CX^1 \
e \geq 0, X \geq 0
\]

The current basic feasible solution of the MOLP problem (6 - 1), \( x^1 \), is an initial feasible solution to the LP problem (6 - 7) with \( e = 0 \), implying \( \text{Max } V \geq 0 \). \( \text{Max } V > 0 \) implies that at least one of \( e_k > 0 \) and at least one of \( c_kX > c_kx^1 \). So \( x^1 \) is a dominated
solution. \( \text{Max } V = 0 \) implies that \( e_k = 0 \) and that there is no feasible solution to LP problem (6 - 7) such that \( cX \geq cX^1 \). Thus \( X^1 \) is a nondominated solution.

The following decision rule can be formulated based on the above discussion to determine whether the current solution is nondominated or not.

The current solution is dominated if optimal solution to LP problem (6 - 7), \( \text{Max } V > 0 \) and it is nondominated if

\[ \text{Max } V = 0 \]  

(Test 5)

The composite objective function added to the Table 1 makes the application of the above test efficient and the following simplex tableaus in matrix notation show the derivation of an efficient method for Test 5.

The initial tableau for the MOLP problem (6 - 1), with the constraint \( CX - e = CX^1 \) appended can be written as shown below.

\[
\begin{bmatrix}
A & \begin{bmatrix} I_{mxm} & 0_{mxl} \end{bmatrix} & b \\
C & \begin{bmatrix} 0_{lxm} & -I_{lxl} \end{bmatrix} & CX^1 \\
-C & \begin{bmatrix} 0_{lxm} & 0_{lxl} \end{bmatrix} & 0_{lxl}
\end{bmatrix}
\]

(6 - 8)

(6 - 9)

(6 - 10)

where \( I \) is identity matrix of proper order

\( 0 \) is zero matrix of proper order

The tableau corresponding to the solution, \( X^1 \), can be written with respect to its basis, \( B \), as:
In the above tableau, the right hand side of row (6 - 12) is zero matrix because \( C^T x^1 = C_B B^{-1} b \). \( C_B \) refers to a \( 1 \times m \) matrix of objective function coefficients corresponding to the basic variables in \( x^1 \).

The simplex tableau for the LP problem, 6 - 7, can be constructed by replacing row (6 - 13) with row (6 - 16) as shown below.

\[
\begin{bmatrix}
B^{-1}A & B^{-1} & 0 & B^{-1}b \\
C - C_B B^{-1}A & -C_B B^{-1} & -I & 0 \\
0 & 0 & -I_{1x1} & 0
\end{bmatrix} \quad (6 - 14)
\]

The basic feasible solution can be obtained by the Phase 1 and the tableau can be constructed as shown below:

\[
\begin{bmatrix}
B^{-1}A & B^{-1} & 0 & B^{-1}b \\
C_B B^{-1}A - C_B B^{-1} & C_B B^{-1} & I & 0 \\
-I_{1x1} B & I_{1x1} B & 0 & 0
\end{bmatrix} \quad (6 - 17)
\]

In the above tableau, a basic feasible solution to the LP problem (6 - 7) is available and row (6 - 19) corresponds to the composite function introduced in Table 6 - 1. From this row optimality of LP problem (6 - 7) and the nondominance of the current basic feasible solution in the MOLP problem (6 - 1) can be checked. If there is
an element of composite objective function, which is negative, say $j^{th}$, and all the elements of the $j^{th}$ column in row $(6 - 18)$ are negative, then for $\theta_j > 0$, it can be concluded that $\text{Max } V > 0$ and the corresponding solution $X^1$ is dominated. This property is used in one of the subroutines of the computer program to check for nondominance.

Using one or more of the five tests described, the nondominance of a solution can be determined and hence it is easy to find the initial nondominated solution from the basic feasible solution found using Phase 1. However, it is necessary to explore other bases in an orderly manner to find all the nondominated extreme points. Zeleny (1974) employed an adjusted version of the incomplete investigation of adjacent vertices. In the computer program this method amounts to keeping two lists of bases, one for the bases that would result in dominated solutions and the bases corresponding to the nondominated solutions already identified, and the second for the bases that need to be explored.

At each iteration, any of the nonbasic columns could be entered, to get a new basis, but entering some of the nonbasic columns would result in a dominated basis. The tests defined could be used to test for nondominance. All such bases that are known to yield a dominated solution are added to the first list, while the other bases that need to be explored are added to the second list. As the traversing continues from one basis to other, the bases that are already traversed are added to the first list and are taken out of the second list, if it is present in that list. The search for the nondominated
Table 6 - 2.

Major Steps in the Algorithm for Multicriteria
Simplex Method

1. Find the initial feasible solution using Phase I procedure of Simplex Method. If it does not exist, stop.

2. Compute revised coefficients for criterial rows and composite objective function using (6 - 2).

3. If $c_{kj} > 0$ for all $j \in \bar{J}$ for at least one $k$ then the current solution uniquely maximizes one objective and it is nondominated, go to step 6.

4. If there are any $j \in \bar{J}$ such that $c_{ij} \geq 0$ the current solution is dominated, consider all $j$ such $j$, go to step 11.

5. Check the nondominance by solving the LP problem to find $\max V$. If $\max V > 0$ then go to step 7.

6. The current solution is a nondominated extreme point. Save it.

7. If there is any $j \in \bar{J}$ such that $\theta c_{s} < 0$ for all $s \in J$ then go to step 11.

8. Look for columns which would lead to solutions noncomparable to current solution. If there are no $j \in \bar{J}$ such that $c_{ij} < 0$ go to step 10.

9. If the current solution is nondominated some of the noncomparable solutions could potentially be nondominated, so store them in the list of unexplored bases.

10. If there are unexplored bases in stored list, select the nearest basis and go to step 12, otherwise stop.

11. Search the list of bases already explored. If the introduction of $j^{th}$ column results in an already explored basis, go to step 10.

12. Introduce $j^{th}$ column. Calculate new $\bar{a}_{ij}$. Go to step 2.
extreme points is stopped when the second list of unexplored bases becomes empty. Some of the main steps in the algorithm for finding all the nondominated extreme points are summarized in Table 6-2.

NUMERICAL EXAMPLE OF SOME STEPS IN MULTICRITERIA SIMPLEX METHOD

The initial tableau for the example shown in Table 5-3, after adding slack variables and calculating the revised cost coefficients, objective values and composite objective function using equations (6-2 thru 6-4) is shown in Table 6-3. For this example addition of slack variables provides an initial basic feasible solution without any need for Phase I procedure. In Table 6-3, it can be seen that none of the objectives are at their unique maximum. So Test 1 cannot be conclusive to show that the current solution is nondominated. In column 2, all revised cost coefficients are non-positive. So using Test 2, the current solution is decided to be dominated. Column 2 is entered into the basis to replace slack variable, $x_8$, from the basis. The tableau resulting from pivoting on $\bar{a}_{32}$ is shown in Table 6-4.

None of the objectives are at their unique maximum in Table 6-4. The Test 2 shows that the solution represented in Table 6-4 is dominated and the column 1 can be entered to replace slack variable, $x_6$, in the basis. After pivoting on $\bar{a}_{11}$, the resulting tableau is as shown in Table 6-5. The objective
Table 6 - 3

Initial Multicriteria Simplex Tableau

<table>
<thead>
<tr>
<th>Basic Var.</th>
<th>x₁</th>
<th>x₂</th>
<th>x₃</th>
<th>x₄</th>
<th>x₅</th>
<th>x₆</th>
<th>x₇</th>
<th>x₈</th>
<th>x₉</th>
<th>x₁₀</th>
<th>x₁₁</th>
<th>Const.</th>
</tr>
</thead>
<tbody>
<tr>
<td>x₆</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>22.38</td>
</tr>
<tr>
<td>x₇</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25.69</td>
</tr>
<tr>
<td>x₈</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10.22</td>
</tr>
<tr>
<td>x₉</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2.44</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.77</td>
</tr>
<tr>
<td>x₁₁</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>5.66</td>
</tr>
<tr>
<td>-0.3</td>
<td>-0.289</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-0.000067</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
</tr>
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<td>0</td>
<td>-0.0159</td>
<td>0.0206</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
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<td>0</td>
<td>0.00938</td>
<td>-0.0348</td>
<td>-0.0501</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-0.0933</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>-0.300067</td>
<td>-0.3823</td>
<td>-0.00652</td>
<td>-0.0142</td>
<td>-0.0501</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 6 - 4
Multicriteria Simplex Tableau after One Pivot Operation

<table>
<thead>
<tr>
<th>Basic Var.</th>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$x_4$</th>
<th>$x_5$</th>
<th>$x_6$</th>
<th>$x_7$</th>
<th>$x_8$</th>
<th>$x_9$</th>
<th>$x_{10}$</th>
<th>$x_{11}$</th>
<th>Const.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_6$</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12.16</td>
</tr>
<tr>
<td>$x_7$</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25.69</td>
</tr>
<tr>
<td>$x_2$</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10.22</td>
</tr>
<tr>
<td>$x_9$</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2.44</td>
</tr>
<tr>
<td>$x_{10}$</td>
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<td>0</td>
<td>1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.77</td>
</tr>
<tr>
<td>$x_{11}$</td>
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<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>5.66</td>
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<tr>
<td>$-0.3$</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.954</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>-0.0159</td>
<td>.0206</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>.00938</td>
<td>-.0348</td>
<td>-.0501</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.0933</td>
<td>0</td>
<td>.9535</td>
</tr>
<tr>
<td>$-0.300067$</td>
<td>0</td>
<td>-.00652</td>
<td>-.0142</td>
<td>-.0501</td>
<td>0</td>
<td>0</td>
<td>.3823</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3.907</td>
</tr>
</tbody>
</table>
Table 6 - 5
Multicriteria Simplex Tableau after Two Pivot Operations

<table>
<thead>
<tr>
<th>Basic Var.</th>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$x_4$</th>
<th>$x_5$</th>
<th>$x_6$</th>
<th>$x_7$</th>
<th>$x_8$</th>
<th>$x_9$</th>
<th>$x_{10}$</th>
<th>$x_{11}$</th>
<th>Const.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12.16</td>
</tr>
<tr>
<td>$x_7$</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13.53</td>
</tr>
<tr>
<td>$x_2$</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10.22</td>
</tr>
<tr>
<td>$x_9$</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2.44</td>
</tr>
<tr>
<td>$x_{10}$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.77</td>
</tr>
<tr>
<td>$x_{11}$</td>
<td>0</td>
<td>0</td>
<td>-0.315</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5.66</td>
</tr>
</tbody>
</table>

| | 0    | 0    | 0.000067 | 0.000067 | 0.000067 | 0.000067 | 0    | -0.000067 | 0    | 0      | 0      | 6.602  |
| | 0    | 0    | -0.0159 | 0.0206 | 0    | 0    | 0    | 0    | 0    | 0      | 0      | 0.90815 |
| | 0    | 0    | 0.00938 | -0.0348 | -0.0501 | 0    | 0    | 0    | 0    | 0      | 0      | 0      |
| | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0      | 0      | 0      |
| | 0    | 0    | 0.2935 | 0.2859 | 0.25  | 0.300067 | 0    | 0.0822 | 0    | 0      | 0      | 7.556   |

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function 5 is at its maximum but there are alternative maxima. There is no column $j$, with $c_j \leq 0$ in Table 6-5 to show that it is dominated. The calculations for Test 4 are shown in Table 6-6. The nonbasic variable $x_6$ is not considered in Table 6-6, because entering this variable into the basis would result in the basis $6, 7, 2, 9, 10, 11$ which was already considered and determined to be a dominated solution. It can also be seen from Table 6-6 that there are no columns for which $\theta_i c_{ir} \leq \theta_s c_{is}, r \neq s$ and $r, s \in J$.

All the nonbasic columns that can be considered for entry into the basis, 3, 4, 5 and 8 generate solutions neither dominating the current solution nor dominated by the current solution. So it is necessary to establish whether the current solution is nondominated by using Test 5. The simplex tables to find out Max $V$ of Test 5 are shown in Table 6-7. All the coefficients in composite objective functions, which is the objective row for the simplex tableau to find Max $V$, are nonnegative. So the solution represented in Table 6-7 is optimal and $\text{Max } V = 0$. Using the Test 5, it can be determined that the solution represented by Table 6-5 is nondominated because $\text{Max } V = 0$.

One of the nonbasic columns, 3, 4, 5 or 8 is entered into the basis to continue the search for next nondominated solution, while bases formed by entering the other nonbasic columns are entered into the list of bases to be explored further. Continuing the calculations yields twelve nondominated solutions shown in Table A-2.
Table 6 - 6

Test 4 Calculations for Solution of Table 6 - 5

<table>
<thead>
<tr>
<th>Nonbasic Variables</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row with Min Ratio, r</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Min Ratio, θ_j</td>
<td>2.44</td>
<td>.77</td>
<td>5.66</td>
<td>10.22</td>
</tr>
<tr>
<td>θ_j c_{1j}</td>
<td>.732</td>
<td>.231</td>
<td>1.698</td>
<td>-.1124</td>
</tr>
<tr>
<td>θ_j c_{2j}</td>
<td>.00016</td>
<td>.00005</td>
<td>.00038</td>
<td>-.00068</td>
</tr>
<tr>
<td>θ_j c_{3j}</td>
<td>-.0388</td>
<td>.0159</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>θ_j c_{4j}</td>
<td>.0229</td>
<td>-.0268</td>
<td>-.284</td>
<td>0</td>
</tr>
<tr>
<td>θ_j c_{5j}</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.9535</td>
</tr>
</tbody>
</table>
Table 6 - 7

Simplex Tables to find Max V of Test 5

<table>
<thead>
<tr>
<th>.3</th>
<th>.3</th>
<th>.3</th>
<th>.3</th>
<th>-.011</th>
<th>1</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>.000067</td>
<td>.000067</td>
<td>.000067</td>
<td>.000067</td>
<td>-.000067</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-.0159</td>
<td>.0206</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>.00938</td>
<td>-.0348</td>
<td>-.0501</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.0933</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>.2935</td>
<td>.2859</td>
<td>.25</td>
<td>.300067</td>
<td>.0822</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

All revised cost coefficients are > 0, so the initial solution is the optimal solution with Max V = 0.
as they are printed out by the vector optimization program. The values of decision variables shown in Table A - 2 are the expenditures in different components of the CJS above the lower 25% limit. The twelve nondominated solutions are shown in Table 6 - 8 as changes from the current levels along with the current levels of expenditures and objective functions. For example the first nondominated solution indicates that:

- Reduction of police expenditures by $0.68 per capita from the current level of $51.38;
- Increase of corrections expenditures by $5.11 per capita above the current level of $20.43;
- Reduction of prosecution and legal services expenditures by $1.22 per capita from the current level of $4.88;
- Reduction of public defense expenditures by $0.38 per capita from the current level of $1.54;
- Reduction of judicial expenditures by $2.83 per capita from the current level of $11.31;

would result in:

- Drop of index offenses per 1000 population by 1.273 below the current level of 5.266;
- Drop of incarceration probability by 0.000045 below the current level of .0115;
- Drop of cases filed fraction by 0.01155 below the current level of .258;
- Increase no trial fraction by 0.1436 above the current level of 0.238;
- and improvement of vocational skills of incarcerated offenders by 0.4767 above the current level of 1.9799.

Table A - 2 also shows the lower and upper limits for the preferences of objectives for each of the nondominated solutions.
<table>
<thead>
<tr>
<th>Nondominated Solution Number</th>
<th>Current Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Police Protection</td>
<td>51.38</td>
</tr>
<tr>
<td>Corrections</td>
<td>20.43</td>
</tr>
<tr>
<td>Prosec. &amp; Legal</td>
<td>4.88</td>
</tr>
<tr>
<td>Public Defense</td>
<td>1.54</td>
</tr>
<tr>
<td>Judicial</td>
<td>11.31</td>
</tr>
<tr>
<td>Offenses Decrsd.</td>
<td>5.266</td>
</tr>
<tr>
<td>Incarc. Prob.</td>
<td>0.0115</td>
</tr>
<tr>
<td>Cases Filed Frac.</td>
<td>0.258</td>
</tr>
<tr>
<td>No Trial Frac.</td>
<td>0.238</td>
</tr>
<tr>
<td>Vocational Skills</td>
<td>1.9799</td>
</tr>
</tbody>
</table>

Table 6 - 8
Nondominated Solutions as Changes from Current Levels
REDUCTION OF NONDOMINATED SOLUTION SET TO SELECT PREFERRED SOLUTION

The solution of vector maximization problem of MOLP model using Multicriteria Simplex Method does not provide a single solution except in some special cases. The nondominated solution set obtained is usually much smaller than the set of all feasible solutions, however, it may not be small enough for the decision maker to select a preferred solution. An interactive approach in which the decision maker is provided with information from the model and is expected to express his preferences for the multiple objectives is described here. Single point estimates of weighting factors or values are not expected from the decision maker, but only a range within which his weighting factors could fall is extracted. In successive iterations, by narrowing the range of decision makers trade-offs, the nondominated solution set is reduced to a single preferred solution. In this interactive approach, there is a good division of labor with decision maker expressing his decisions on the range of weighting factors and the machine computing to reduce the cardinality of nondominated solution set.

In solving the vector maximization problem and in this interactive procedure, it is assumed that there exists the implicit or unknown function that expresses the overall merit of each of the feasible solutions and it could be used in ordering the alternatives. It is also assumed that this overall merit which is a function of values of all the objectives, \( U(C_1 X, C_2 X, \ldots, C_k X) \) is monotonically increasing with respect to all its arguments. Let us define an
additive weight problem, $P_W$

$$\text{Max } \sum_{k=1}^{\infty} w_k c_k x$$

Subject to

$$AX=b; \quad X \geq 0$$

Where $W$ is a weight vector and without loss of any generality it can be normalized and defined as

$$\sum_{k=1}^{\infty} w_k = 1, \quad w_k \geq 0, \quad k = 1, \ldots, 1$$

Zeleny stated a theorem (1973, p. 275, Theorem 2.1) according to which, there is a weight vector $W$ such that at least one solution, $X$, maximizing $P_W$ also maximizes $U(CX)$. In this interactive approach, a subpolyhedra of weights $W(X^n)$ is calculated for each of the non-dominated solutions, $X^i$, such that

$$\text{Max } W.CX = W CX^i \quad \text{for all } W \in \tilde{W}(X^i)$$

$$AX=b, X \geq 0$$

Zeleny has also stated another theorem (1973, p. 275, Theorem 2.5) that defines the subpolyhedra of weights for a nondominated solution $X^i$ as

$$\tilde{W}(X^i) = \left\{ W \mid w_{\cdot, j} \geq 0; \quad j \in \tilde{J}\right\}$$

Where

$$w_{\cdot, j} = \sum_{k=1}^{\infty} w_k \bar{c}_{kj}$$

and $\sum_{k=1}^{\infty} w_k = 1; \quad w_k \geq 0; \quad k = 1, \ldots, 1$

An interpretation for this definition for subpolyhedra of weights can be as follows. If $W^*$ is the weight vector chosen and a LP problem
\( P_w^* \), is written with it as
\[
\text{Max } \ W^* CX
\]
Subject to
\[
AX = b; X \geq 0
\]
then the optimality condition is that \( W^* \bar{c} \geq 0 \). So for the non-dominated solution, \( x^i \) to be preferred solution, \( x^i \) must be the optimal solution for the LP problem \( P_w \).

From this definition of \( \bar{W}(x^i) \), the equations that define it can be written from the multiple criteria simplex tableau as
\[
\frac{\bar{a}}{\sum_{k=2}^{n} w_k} w_k \bar{c}_{kj} \geq 0, \ j \in \bar{J}
\]
(6 - 23)

The dimensionality of \( \bar{W}(x^i) \) can be reduced by one, when the substitution of \( (1 - \frac{\bar{a}}{\sum_{k=2}^{n} w_k}) \) is made for \( w_1 \)

\[
(1 - \frac{\bar{a}}{\sum_{k=2}^{n} w_k}) \bar{c}_{ij} + \frac{\bar{a}}{\sum_{k=2}^{n} w_k} w_k \bar{c}_{kj} \geq 0, \ j \in J
\]

\[
\bar{c}_{ij} + \frac{\bar{a}}{\sum_{k=2}^{n} w_k} w_k (\bar{c}_{kj} - \bar{c}_{ij}) \geq 0, \ j \in \bar{J}
\]

\[
\sum_{k=2}^{n} w_k (\bar{c}_{ij} - \bar{c}_{kj}) \leq \bar{c}_{ij}, \ j \in \bar{J}
\]
(6 - 24)

An additional equation
\[
\frac{\bar{a}}{\sum_{k=2}^{n} w_k} w_k \leq 1
\]
needs to be added because of the substitution to reduce dimensionality.
The reduction of dimensionality and addition of this equation are essential to avoid unbounded objectives in the linear programs formulated to provide information to the decision maker from these equations. The details of these linear programs are decribed later.
in this chapter. The subpolyhedra of weighting factors will be cones without this limiting constraint and bounds for these weighting factors cannot be calculated. The equations defining the subpolyhedra of weights for the nondominated solution represented in the Table 6 - 5 are shown in Table 6 - 9.

Table 6 - 9
Equations that Weighting Factors should Satisfy for Nondominated Solution of Table 6 - 5 to be Preferred Solution

\[
\begin{align*}
0.2993w_2 + 0.3159w_3 + 0.29062w_4 + 0.3w_5 &\leq 0.3 \\
0.2993w_2 + 0.2794w_3 + 0.3348w_4 + 0.3w_5 &\leq 0.3 \\
0.2993w_2 + 0.3w_3 + 0.3501w_4 + 0.3w_5 &\leq 0.3 \\
0.2993w_2 + 0.3w_3 + 0.3w_4 + 0.3w_5 &\leq 0.3 \\
-0.010033w_2 - 0.011w_3 - 0.011w_4 - 0.1043w_5 &\leq -0.011 \\
w_2 + w_3 + w_4 + w_5 &\leq 1
\end{align*}
\]
In practice, the equations that define the subpolyhedra of the weights contain several redundant equations. The following procedure suggested by Zeleny (1974) is used to discard inessential constraints.

1. Consider all constraints with \( c_{ij} \neq 0 \), \( j \in \bar{J} \). Divide each of these constraints by the corresponding \( c_{ij} \) to get new coefficients, \( f_{kj} = (\bar{c}_{ij} - \bar{c}_{kj})/\bar{c}_{ij} \), \( k = 2, \ldots, l \); \( j \in \bar{J} \) and \( f_{1j} = 1 \); \( j \in \bar{J} \).

2. These constraints with \( \bar{c}_{ij} \neq 0 \) can be divided into two groups, \( \bar{c}_{ij} > 0 \) and \( \bar{c}_{ij} < 0 \).
   a. Group \( \bar{c}_{ij} > 0 \): if for any two constraints, say \( r \) and \( s \), \( f_{rj} < f_{sj}, j \in \bar{J} \), then the constraint \( r \) is redundant and can be deleted.
   b. Group \( \bar{c}_{ij} < 0 \): If for any two constraints, say \( r \) and \( s \), \( f_{rj} > f_{sj}, j \in \bar{J} \), then the constraint \( r \) is redundant and can be deleted.

We are left with constraints having \( \bar{c}_{ij} = 0 \) and the constraints not deleted in step 2 of the above procedure. All these can be represented as

\[
\sum_{k=2}^{l} \bar{x} f_{kj} \leq \bar{f}_{1j}, \quad j \in \bar{J} \tag{6-25}
\]

where \( \bar{f}_{1j} = 1 \), \( \bar{f}_{kj} = f_{kj} \), \( k = 2, \ldots, l \); \( j \in \bar{J} \) and \( \bar{f}_{1j} > 0 \);

\( \bar{f}_{1j} = 0 \); \( \bar{f}_{kj} = -\bar{c}_{kj} \), \( k = 2, \ldots, l \); \( j \in \bar{J} \) and \( \bar{f}_{1j} = 0 \);

\( \bar{f}_{1j} = -1 \); \( \bar{f}_{kj} = -\bar{f}_{kj} \), \( k = 2, \ldots, l \); \( j \in \bar{J} \) and \( \bar{f}_{1j} < 0 \).

and \( \bar{J} \) is a subset of \( \bar{J} \) representing all the equations not deleted.

The equations of Table 6-9 with the above transformations are shown in Table 6-10.
Table 6 - 10

Essential Equations of Table 6-9 with Some Transformations

\[
\begin{align*}
0.9998w_2 + 1.053w_3 + 0.9687w_4 & \quad w_5 \leq 1 \\
0.9998w_2 & \quad w_3 + 1.167w_4 + w_5 \leq 1 \\
0.9939w_2 & \quad w_3 + w_4 + 9.482w_5 \geq 1 \\
w_2 & \quad w_3 + w_4 + w_5 \leq 1
\end{align*}
\]

It can be seen from the Table 6 - 10 that the second and fourth equations of the Table 6 - 9 are deleted through the tests for redundancy defined so far. To eliminate any further inessential constraints the following LP problem is solved for each of the constraints.

\[
\begin{align*}
\text{Max} & \quad -y_r \\
\text{subject to} & \\
\sum_{k=2}^{l} w_k \bar{f}_{kr} + y_r & = \bar{f}_{1r} \\
\sum_{k=2}^{l} w_k \bar{f}_{kj} & \leq \bar{f}_{1j}, \quad j \in \bar{J} \text{ and } j \neq r.
\end{align*}
\]

If Max \(-y_r\) is zero then the constraint \(r\) is essential otherwise the constraint \(r\) can be eliminated. \(\bar{J}\) a subst of \(\bar{J}\) is used to denote all the essential equations after this step.
All these steps to eliminate redundant equations are included in the batch computer program that solves the vector maximization problem to find all nondominated extreme points. This batch program saves the coefficients of essential equations that define the subpolyhedra of weights, along with the values of decision variables and objective functions for each of the nondominated solutions. All these saved data are passed from the batch program to interactive program as a data set on disk.

Now that we have obtained all the essential equations that define the subpolyhedra of weights for each of the nondominated solutions, the problem is how to present the information to the decision maker. Zeleny used for his example a problem with three objectives. With the reduction of dimensions by one due to substitution, the equations have only two unknown weights and Zeleny used graphic presentation. The graphic approach is not practical for the problems with more than three objectives. So the projections of the subpolyhedra of weights on the axes are used to provide information to the decision maker. To compare this approach to the Zeleny's graphical presentation a two dimensional case is made up from the equations in Table 6 - 9 by substituting zero for $w_2$ and $w_3$. The resulting equations and their graphic representation are shown in Figure 6 - 1. $\tilde{w}(x^1)$ which is actually a triangle ABC is approximated as rectangle ADCE and the decision maker is provided with the range AD for $w_5$ and AE for $w_4$. The projections of the subpolyhedra of weights are calculated by solving the following linear programs for $r = 2, \ldots, 1$. 

```math
\begin{align*}
\end{align*}
```
.9687w_4 + w_5 \leq 1 \quad (1)

1.167w_4 + w_5 \leq 1 \quad (2)

w_4 + 9.482w_5 \geq 1 \quad (3)

w_4 + w_5 \leq 1 \quad (4)

Figure 6-1. Graphic Representation of Subpolyhedra of Weights
Max \( w_r \)
Subject to
\[
\sum_{k=2}^{l} w_k f_{kj} \leq \bar{f}_{kj}, \quad j \in \mathcal{J} \tag{6-27}
\]
\[
w_k \geq 0, \quad k = 2, \ldots, l
\]
Min \( w_r \)
Subject to
\[
\sum_{k=2}^{l} w_k f_{kj} \geq \bar{f}_{kj}, \quad j \in \mathcal{J} \tag{6-28}
\]
\[
w_k \geq 0, \quad k = 2, \ldots, l
\]

These LP problems are solved in the interactive program in conjunction with the input from the decision maker. The decision maker's estimate for \( w_k \) is obtained as range \( l_k \) to \( h_k \). The two constraints \( w_k \leq h_k \) and \( w_k \geq l_k \) can be added to the other equations that define the subpolyhedra of weights, and written as

Max \( w_r \), \quad r = 2, \ldots, l
Subject to
\[
\sum_{k=2}^{l} w_k f_{kj} \leq \bar{f}_{kj}, \quad j \in \mathcal{J} \tag{6-29}
\]
\[
w_k \leq h_k, \quad k = 2, \ldots, l
\]
\[
w_k \geq l_k, \quad k = 2, \ldots, l
\]
\[
w_k \geq 0, \quad k = 2, \ldots, l
\]
Min \( w_r \) \( r = 2, \ldots, 1 \)

Subject to

\[
\sum_{k=2}^{\ell} w_k f_{kj} \leq f_{ij} \quad ; \quad j \in J
\]

\( w_k \leq h_k \), \( k = 2, \ldots, 1 \)

\( w_k \leq l_k \), \( k = 2, \ldots, 1 \) \( (6 - 30) \)

\( w_k \geq 0 \), \( k = 2, \ldots, 1 \)

At each interaction \( h_k \) and \( l_k \) are tightened and the new projection on to the axes for subpolyhedra are calculated. The nondominated solution for which the problem (6 - 29) or (6 - 30) does not have a feasible solution is dropped from further consideration. This is the basic procedure for reducing the nondominated solution set.

The problems (6 - 29) and (6 - 30) can be solved by the standard simplex, however, the size of the problem and the computer time are considerably increased. So the optimality conditions defined by Luenberger (1973, pp. 48 - 53) for upper bounded variables are used to minimize the size of the problem.

The Interactive Preferred Solution Selection Program SETRED, solves the problems (6 - 29) and (6 - 30) using the optimality conditions for upper bounded variables and provides information to the decision maker in terms of lower and upper limits for weights of objectives, for each of the nondominated solutions still under consideration. The interactive program gets the data for the problems (6 - 29) and (6 - 30) from the data set saved on disc by the vector optimization program. So the decision maker can interact with the model with minimal amount of input. The print out of a short session
with the interactive program is shown in Table B-1 in Appendix. The value ranges input as the preferences of the decision maker at the final iteration are as shown below.

- Above 0.4495 for incarceration probability;
- Above 0.45 for cases filed fraction;
- Above 0.1 for vocational skills.

For these range of values, the second nondominated solution shown in Table 6-8 becomes the preferred solution.

The interactive program also provides the explicit range of values that make the selected nondominated solution the preferred solution. These ranges of values are always narrower than the value ranges expressed by the decision maker as can be seen from the value ranges shown below. The value ranges implied in selecting the second nondominated solution as the preferred solution are shown below:

- Between 0.4495 and 0.45 for incarceration probability;
- Between 0.45 and 0.4505 for cases filed fraction;
- Between 0.0 and 0.0005 for no trial fraction;
- Between 0.1 and 0.1005 for vocational skills.

The value ranges available explicitly for the solution selected as the preferred solution are useful in evaluating the past decisions. The discussion of past decisions can concentrate on discrepancies in the specific values or the measurement errors rather than vague subjective arguments.
CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

This study has concentrated on the development of a decision aiding method for resource allocation and program evaluation in the public sector using the Criminal Justice System (CJS) as an example. The resource allocation decisions in the public sector are characterized by noncommensurable outputs and are more complex than in the profit making organizations of private sector. The resource allocation problem is formulated as a Multiple Objective Linear Programming Model to emphasize the need for explicit treatment of multiple objectives. The methodology developed in this study highlighted the two distinctly different aspects of resource allocation: the measurement problem of estimating the impact on outputs for varying amounts of inputs; and the decision problem of selecting proper trade-offs between conflicting and complementing objectives.

The Current Evaluation Methods reviewed in the second chapter concentrate mostly on the measurement problems. Cost-Benefit and Cost-Effectiveness Analysis, and Econometric Methods consider the decision problem, but there is no explicit treatment of multiple objectives or the value clarification and extraction. The Multiple Criteria Decision Making Methods, which consider the multiple objectives explicitly and address the value system were presented in the third chapter. MOLP model was selected for providing the
basic structure to the data collection and analysis effort of the methodology developed in this study. The MOLP model identifies the measurement problem and the decision problem separately and provides very good division of labor between the analyst and the decision maker. The formulation of the model addressed and highlighted the major steps in the measurement problem: Identifying the Objectives; Defining the Performance Measures to gauge the achievement towards the objectives; Estimating the Resource Requirements; and Establishing the Relationship between Resources and Objectives. The solution of the model concentrates on the decision problem of choosing the trade offs between conflicting and complementary objectives and aids the decision maker in expressing his value structure through narrowing ranges for the value of each objective.

The measurement problem in the CJS is very complex because of the fragmentation of the system into Courts, Police and Corrections etc. Because of the checks and balances in the Constitution, there is no single executive responsible for all of the CJS. The measurement problem needs to be addressed from two aspects. The first is understanding of physical relationships which is best addressed by very well planned and conducted experimental studies. The second is routinizing the evaluation and implementation of procedures to collect data on a continuing basis to estimate the specific relationships between resources and achievement of objectives at several organizational levels. This study concentrated on routinizing the evaluation, so some of the problems in identifying the performance measures, and using the available data sources in estimating the
performance measures are discussed in the fourth chapter. The selection of appropriate performance measures is the key to the successful implementation of the methodology developed in this study. The participation of the decision makers in the selection of performance measures is crucial and the actual performance measures used in the model have to be selected in the organizational context by the decision makers in the organization. To aid in the selection, several characteristics of performance measures and some factors affecting the selection were also presented. Several performance measures are described for initial consideration in selecting the final measures to be used in the organization implementing the study.

Two computer programs were developed to perform the computations of the algorithms in solving the formulated MOLP model. These programs were designed to permit the decision makers to interact with the model and the computer in expressing their value structure. The programs provide information to the decision maker on the range of weighting factors that should include his values of the objectives for each of the nondominated solution to become the preferred solution. The range of weighting factors expressed by the decision maker are used to reduce the cardinality of nondominated solution set in selecting the preferred solution. The programs were also designed to be general in nature to allow their use in wide variety of resource allocation problems where the need exists for treating the multiple objectives explicitly.
CONCLUSIONS

The specific conclusions that can be drawn from the conduct of this research are related more to the methodology and the development of decision aids for the resource allocation decisions than to the actual allocation of resources in the criminal justice system used as an example. However, the formulation of the model identified several missing relationships between inputs and outputs of the CJS. These are discussed in the next section on recommendations.

The development of the methodology in this study concentrated on the need to address the decision problem and considering the value system of multiple objectives. In public sector, because of the nature of objectives, it is important that the development of decision aiding methods consider and treat the existence of multiple objectives. However, with reference to the CJS, the concentration on the multiple objectives and the value system does not imply that the measurement problem is not an important issue or that it has received the attention it deserves. The valid measurement of performance on each of the defined objectives is essential for proper clarification and extraction of the values of decision making authorities toward multiple objectives. The recent literature indicates that considerable resources are spent in addressing the measurement problem in the CJS. This research is concentrated on the use of multiple measures in selecting the preferred package of resource allocation schemes.

Widely accepted estimates of the relationships between the
resources allocated and the achievement of objectives is the basic requirement for the successful implementation of the MOLP model. The information systems being developed in the CJS are collecting and reporting considerable amounts of data for the day to day operational needs of the organizations which are components of the CJS. The analysis of data from several information systems in the different components of the CJS and resolution of differences and standards of reporting in summarizing the data are required for the use of these statistics in system wide resource allocation decisions. The empirical relationships estimated must be verified in different geographical areas and in different levels of government to avoid spurious results and questionable application of conclusions from specific conditions to system wide use.

In the model formulated, most of the coefficients are estimated from the empirical investigations of historic data. However, some coefficients are assumed to be zero and some of the conclusions of empirical investigations may be controversial. So the results of the analysis need to be considered with some caution. The solution of the vector maximization problem generated twelve nondominated solutions. For the decision maker's input value ranges shown in Table 7-1, eleven of the twelve nondominated solutions are dropped, so the remaining nondominated solution is the preferred solution of the model. This solution is shown in Table 7-1. The value ranges input as the decision maker's are only examples made up to show
Table 7 – 1

Preferred Solution and the Value Ranges

Specified by the Decision Maker

For values ranges expressed by the decision maker which are shown below:

Above .4495 for incarceration probability;
Above .45 for the cases filed fraction;
Above .1 for vocational skills index ——

The preferred solution is to:

Decrease police protection expenditures by $3.12 per capita from 1976 level of $51.38;

Increase corrections expenditures by $5.11 per capita above 1976 level of $20.43;

Increase Prosecution and legal services expenditures by $1.22 above 1976 level of $4.88 per capita;

Decrease public defense expenditure by $0.38 from 1976 level of $1.54 per capita;

Decrease judicial expenditures by $2.83 from 1976 level of $11.31 per capita ——

to result in:

Drop of .541 in index offenses per 1000 population below 5.256 for 1976;

Drop of incarceration probability by 0.00021 below 1976 level of 0.0115;

Improvement of cases filed fraction by 0.0272 above 1976 level of 0.258;

Increase of no trial fraction of 0.1665 above 1976 level of 0.238;

and improvement of vocational skills of incarcerated offenders by .4767 above 1976 level of 1.9799.
that the methodology works. The value range for the second objective, probability of incarceration had to be input at a four digit level to select one preferred solution. For the value ranges of: Above .44 for incarceration probability; above .44 for cases filed fraction; and above .1 for vocational skills index — only the second and seventh nondominated solutions are left for consideration. The decision maker can select one of these two as the preferred solution. In the run shown in Table A - 1, the value ranges are narrowed further to the level shown in Table 7 - 1 to drop all nondominated solutions except the preferred solution.

For different value ranges of the decision maker's preferences shown in Table 7 - 2, the eighth nondominated solution of Table 6 - 8 becomes the preferred solution. This preferred solution is also interpreted in Table 7 - 2. The value ranges in Table 7 - 1 can be interpreted as law enforcement oriented while the value ranges in Table 7 - 2 are for increased civil rights. The preference for no trial fraction is different in the two set of weights causing the shift in resources in judicial expenditures and public defense expenditures. The preferred solution is dependent on the decision maker's choice of preferences. The methodology makes the decision maker's preferences explicit and shows the range of values which are implied in selecting the particular nondominated solution as the preferred solution.

Some of the coefficients of the model were assumed to be zero because no empirical relationship could be located in the published
Table 7 - 2
Preferred Solution and the Value Ranges
Specified by the Decision Maker

For value ranges input by the decision maker:

Above .427 for incarceration probability;
Between .22 and 0.3 for cases filed fraction;
Between .25 and 0.3 for no trial fraction;
Between .1 and 0.3 for vocational skills---

The preferred solution is to:

Decrease police protection expenditures by $9.55 per capita from 1976 level of $51.38;
Increase corrections expenditures by $5.11 per capita above 1976 level of $20.43;
Increase prosecution and legal services expenditures by $1.22 above 1976 expenditures of $4.88 per capita;
Increase public defense expenditure by $.39 above 1976 level of $1.54 per capita;
Increase judicial expenditures by $2.83 above 1976 level of $11.31 per capita---

to result in:

Increase in index offenses of 1.389 per 1000 population above the current level of 5.266;
Drop of incarceration probability by 0.000064 below the current level of 0.0115;
Improvement of cases filed fraction by 0.0114 above the current level of 0.258;
Drop of no trial fraction by 0.1439 below the current level of 0.238;
and improvement of vocational skills of incarcerated offenders by .4767 above the current level of 1.9799.
literature. To analyze the impact of these assumptions, the problem is solved by assuming some values for the coefficients $c_{13}$, the impact of increased police expenditures on fraction of cases filed and the coefficient $c_{53}$, the impact of increased judicial expenditures on cases filed fraction. Using a value of 0.01 for $c_{13}$ and solving the model results in ten nondominated solutions. For the value ranges shown in Table 7-2, the preferred solution is different. The difference between this preferred solution and the preferred solution of the original problem is that $1.22$ per capita is shifted from prosecution and legal services expenditures to the police protection expenditures. This appears reasonable because the specification of 0.01 for the coefficient $c_{13}$ implies that the police expenditures improve the cases filed fraction which was influenced by prosecution and legal services expenditures positively and public defense expenditures negatively. For the value ranges shown in Table 7-1, there is no change in preferred solution for the change in the value of coefficient $c_{13}$.

The MOLP model is solved for another case using 0.01 for $c_{13}$ and $c_{53}$. The solution of vector maximization problem yields the same ten nondominated solutions as for the case of $c_{53} = 0$ and $c_{13} = .01$. The third objective function values are different for the nondominated solutions because of the coefficient $c_{53}$, but value of the decision variables are same. The decomposition of value space for the ten nondominated solutions is also different from the case with $c_{53} = 0$. However, for the value ranges of the decision maker's preferences
shown in both Table 7-1 and Table 7-2, the preferred solution is the same whether $c_{53} = 0$ or $c_{53} = 0.01$.

These examples show that the sensitivity analysis on the model could be used to understand the behavior of the system. Several values of a coefficient could be tried for the cases where the conclusions of the empirical investigations used in estimating the coefficients are controversial. As the state of the art of the estimated empirical relationships improve in the CJS, recommendations for resource allocation can be made with confidence on the basis of the MOLP model solution.

RECOMMENDATIONS FOR FURTHER RESEARCH

The formulation of the MOLP model and its solution have shown several research areas that need in depth study in resource allocation decision aid development. These recommendations are with reference to both the formulation of the model and the solution of the model. In the formulation of the model, the lack of established functional relationships between inputs and outputs stands out ahead of all other items.

For the estimation of all the coefficients in the simple model formulated in this research, estimation of several functional relationships listed below would be helpful.

- Impact of changes in police expenditures on the quality and quantity of arrests, prosecutors work load, probability of filing a case, and probability of a case being terminated without trial.
Simultaneous relationships between changes in police and corrections expenditures on index offenses decreased and probability of conviction.

Impact of changes in legal services and prosecution expenditures, and public defense expenditures on index offenses decreased and probability of conviction.

Direct relationship between changes in judicial expenditures and probability of filing a case, and probability of terminating a case without trial.

Impact of changes in judicial expenditures on index offenses decreased and probability of conviction.

Simultaneous relationships between changes in police expenditures, corrections expenditures and judicial expenditures on index offenses decreased.

Impact of changes in corrections expenditures on vocational skills improvement and rehabilitation of offenders.

In addition to the better estimation of the coefficients of the model using some of the relationships mentioned above, the objectives used in the model can be improved to suit the organizational needs of the CJS component in which the model is being implemented. An index developed on the lines described in the fourth chapter can be used for the vocational skills improvement and rehabilitation of the offenders in the correctional institutions. The index offenses objective can be replaced by a vector measure of crime seriousness index as the data to estimate the coefficients are available.

Some improvement in the constraints used in the model would enhance the credibility of the nondominated solution set obtained by solving the vector maximization problem. The sensitivity analysis of the relationships between inputs and outputs to establish the range
over which the established relationship holds is an important improvement in formulating the constraints.

An important area of further research in solving the formulated model is in the information provided to the decision maker from the model in extracting his values of objectives. The dual of the formulated MOLP model can be investigated further to use its solution in providing information to decision maker. The concept of shadow prices can be used to better interpret the information provided to the decision maker. In extracting the ranges for the weights attached to each objectives by the decision maker, it is very important that the relative magnitude of the objectives at the current operating levels be considered. Some form of normalization procedure or selection of proper units for the objectives could improve the interpretation of the information provided from the model by the decision maker. With some of the improvements and the advancements in the accepted functional relationships between inputs and outputs in the CJS, the implementation of a MOLP model can result in better decisions in allocating resources.
APPENDIX A
MULTICRITERIA SIMPLEX METHOD BATCH PROGRAM

The batch program, VOPTIM, developed for solving vector optimization problem using Multicriteria Simplex Method is described here. Zeleny (1974) published the listing of the FORTRAN Program based on Multicriteria Simplex Method and included a revised version that works in his later publication (Zeleny, 1976). The program used in this study is independent revision of the first version to make it work and to add the coding to save constraints of the parametric space for each of the nondominated solutions. The procedures described in Chapter 6 to eliminate redundant constraints are included in this program. Only the nonredundant constraints of the parametric space are saved by this program as a data set on disc to pass to the interactive program described in Appendix B. The calculation of limits of the parametric space for each of the nondominated solutions is also added to the program to provide this information to the decision maker in expressing his initial value judgements.

This program uses the FORTRAN statements common to at least three manufacturers' compilers and it can be compiled and executed by just adding the proper Job Control Cards. The input card deck set up for the problem defined in Table 5-3 is shown in Table A-1. The Job Control Cards vary from installation to installation, so only the data cards are shown. The first card defining the size of the problem
Table A - 1

Input Card Deck Setup for VOPTIM Program

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 65</td>
<td>POLICE PROTECTION</td>
</tr>
<tr>
<td>CORRECTIONS</td>
<td></td>
</tr>
<tr>
<td>PROSECUTION &amp; LEGAL</td>
<td></td>
</tr>
<tr>
<td>PUBLIC DEFENSE</td>
<td></td>
</tr>
<tr>
<td>JUDICIAL EXPEN.</td>
<td></td>
</tr>
<tr>
<td>OFFENSES DECREASED</td>
<td></td>
</tr>
<tr>
<td>INCARCERATION PROB.</td>
<td></td>
</tr>
<tr>
<td>CASES FILED FRACT.</td>
<td></td>
</tr>
<tr>
<td>NO TRIAL FRACT. DEC.</td>
<td></td>
</tr>
<tr>
<td>VOCATIONAL SKILLS</td>
<td></td>
</tr>
<tr>
<td>000000</td>
<td></td>
</tr>
<tr>
<td>(8F10.4)</td>
<td></td>
</tr>
<tr>
<td>1. 1. 1. 1. 1.</td>
<td>22.38.</td>
</tr>
<tr>
<td>1. 0. 0. 0. 0.</td>
<td>25.69</td>
</tr>
<tr>
<td>1. 0. 0. 0. 0.</td>
<td>10.22</td>
</tr>
<tr>
<td>0. 0. 1. 0. 0.</td>
<td>2.44</td>
</tr>
<tr>
<td>0. 0. 0. 1. 0.</td>
<td>0.77</td>
</tr>
<tr>
<td>0. 0. 0. 0. 1.</td>
<td>5.66</td>
</tr>
<tr>
<td>0.3 0.289 0. 0. 0.0</td>
<td></td>
</tr>
<tr>
<td>0.000067</td>
<td>0.0159 -0.0206</td>
</tr>
<tr>
<td></td>
<td>-0.00938 0.0348 0.0501</td>
</tr>
<tr>
<td>0.0933</td>
<td></td>
</tr>
</tbody>
</table>
has to be prepared in the format shown below:

<table>
<thead>
<tr>
<th>Column</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>I2</td>
<td>Number of variables excluding slack, surplus or artificial</td>
</tr>
<tr>
<td>3-4</td>
<td>I2</td>
<td>Number of constraints</td>
</tr>
<tr>
<td>5</td>
<td>I1</td>
<td>Number of objective functions</td>
</tr>
</tbody>
</table>

Following the first card, there should be one card with name of the variable or identifier for the objective functions for each of the variables and objective functions in the format shown here.

<table>
<thead>
<tr>
<th>Column</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-20</td>
<td>5A4</td>
<td>Descriptor for variable or objective</td>
</tr>
</tbody>
</table>

Following the cards with descriptors, there should be a card to define the relationships of the constraints as shown here.

<table>
<thead>
<tr>
<th>Column</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I1</td>
<td>For 1st constraint, 0 if &lt;=, 1 if =, or 2 if &gt;=</td>
</tr>
<tr>
<td>i</td>
<td></td>
<td>For ith constraint</td>
</tr>
</tbody>
</table>

After the card describing the relationships of the constraints, there should be a card defining the formats of the following cards.

The format should be in a format statement acceptable for execution in FORTRAN statement. The data of the problem should be punched in format described on format definition card on the following cards. The
data is first read for the coefficients of constraints with right-hand side expected as the last data item of the constraint. The data for the coefficients of the objective functions is read after reading data for the constraint.

The printout of the program is very large to include here. So the last part of the printout showing all the nondominated solutions is shown in Table A - 2. The listing of the program is shown in Table A - 3. The description of some of the key variables is shown in the listing with the use of the comment cards. The algorithmic details of the Multicriteria Simplex Method used in this program are described in Chapter 6. The major steps of the algorithm are shown in Table 6 - 2.
Table A - 2

Example of VOPTIM Program Output

<table>
<thead>
<tr>
<th>SOLUTION NO.</th>
<th>BASIS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>POLICE PROTECTION</td>
<td>12.1600046</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>13.5299978</td>
</tr>
<tr>
<td></td>
<td>CORRECTIONS</td>
<td>10.2200003</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>2.43999958</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>0.76999988</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>5.65999985</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>OBJ.VALUES</th>
<th>LOWER LIMIT</th>
<th>UPPER LIMIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offenses Decreased</td>
<td>6.60157967</td>
<td>0.0</td>
<td>0.99928617</td>
</tr>
<tr>
<td>Incarceration Prob.</td>
<td>0.00081472</td>
<td>0.0</td>
<td>0.99928242</td>
</tr>
<tr>
<td>Cases Filed FRACT.</td>
<td>0.0</td>
<td>0.0</td>
<td>0.94406587</td>
</tr>
<tr>
<td>No Trial FRACT. Dec.</td>
<td>0.0</td>
<td>0.0</td>
<td>0.84268260</td>
</tr>
<tr>
<td>Vocational Skills</td>
<td>0.95352584</td>
<td>0.00071387</td>
<td>0.99999917</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SOLUTION NO.</th>
<th>BASIS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>POLICE PROTECTION</td>
<td>9.72000504</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>15.9699974</td>
</tr>
<tr>
<td></td>
<td>CORRECTIONS</td>
<td>10.2200003</td>
</tr>
<tr>
<td></td>
<td>PROSECUTION &amp; LEGAL</td>
<td>2.43999958</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>0.76999988</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>5.65999985</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>OBJ.VALUES</th>
<th>LOWER LIMIT</th>
<th>UPPER LIMIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offenses Decreased</td>
<td>5.86958027</td>
<td>0.0</td>
<td>0.99998826</td>
</tr>
<tr>
<td>Incarceration Prob.</td>
<td>0.00065124</td>
<td>0.0</td>
<td>0.99508882</td>
</tr>
<tr>
<td>Cases Filed FRACT.</td>
<td>0.00879599</td>
<td>0.00001178</td>
<td>0.99999911</td>
</tr>
<tr>
<td>No Trial FRACT. Dec.</td>
<td>0.02288720</td>
<td>0.0</td>
<td>0.20293105</td>
</tr>
<tr>
<td>Vocational Skills</td>
<td>0.95352584</td>
<td>0.0</td>
<td>0.99998713</td>
</tr>
</tbody>
</table>
Table A - 2 (Contd.)

Example of VOPTIM Program Output

<table>
<thead>
<tr>
<th>SOLUTION NO.</th>
<th>BASIS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>POLICE PROTECTION</td>
<td>22.3799896</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>3.30998993</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>10.2200003</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>2.43999958</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>0.76999998</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>5.65999985</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OBJ. VALUES</th>
<th>LOWER LIMIT</th>
<th>UPPER LIMIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.71399689</td>
<td>0.0</td>
<td>1.00000000</td>
</tr>
<tr>
<td>0.00149946</td>
<td>0.0</td>
<td>1.00000000</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.94966799</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.85689819</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.10546458</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SOLUTION NO.</th>
<th>BASIS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>POLICE PROTECTION</td>
<td>19.9399872</td>
</tr>
<tr>
<td></td>
<td>SLACK/SURPLUS</td>
<td>5.74998951</td>
</tr>
<tr>
<td></td>
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### Table A - 2 (Contd.)

Example of VOPTIM Program Output

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Table A - 2 (Contd.)

Example of VOPTIM Program Output

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Table A - 2 (contd.)

Example of VOPTIM Program Output

SOLUTION NO. 9

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Table A - 2 (Contd.)

Example of VOPTIM Program Output

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Table A – 3. Listing of VOPTIM Program

**THIS IS THE MAIN PROGRAM FOR A MULTIOBJECTIVE LINEAR PROGRAMMING PROBLEM.**

THE NUMBER OF CONSTRAINTS IS LIMITED TO 12, THE NUMBER OF OBJECTIVE FUNCTIONS TO 7, AND THE NUMBER OF VARIABLES INCLUDING ALL SLACK AND ARTIFICIAL VARIABLES TO 40

NOV= NUMBER OF VARIABLES

NOC= NUMBER OF CONSTRAINTS

NOB= NUMBER OF OBJECTIVE FUNCTIONS

NOBZ= COMPOSITE OBJECTIVE FUNCTION NUMBER=NOB + 1

KUSE= NUMBER OF BASES USED

KAUX= NUMBER OF AUXILIARY BASES STORED

NOV1= NUMBER OF VARIABLES INCLUDING ARTIFICIAL

WHEN THE CONSTRAINT IS LESS THAN OR EQUAL, IEQ(J) = 0

WHEN THE CONSTRAINT IS EQUAL, IEQ(J) = 1

WHEN THE CONSTRAINT IS GREATER THAN OR EQUAL, IEQ(J) = 2

**IB= STATUS ARRAY OF VARIABLES**

0 = OUT OF BASIS

1 = IN BASIS

2 = SEARCH FOR NEW VEC. AFTER NOND. SOLN.

3 = ARTIFICIAL VARIABLE AND SEARCHING FOR NEW VECTOR AFTER NOND. SOLN.

C = WHEN THE BASIS FORMED BY ENTERING THIS VARIABLE HAS ALREADY BEEN USED

**ID= LIST OF BASIC VECTORS**

**TAB= TABLEAU ARRAY**

**C= OBJECTIVE FUNCTIONS ARRAY - INITIAL**

**Z= OBJECTIVE FUNCTIONS ARRAY**

**X= VALUE OF BASIC VECTORS**

**INN= LIST OF BASES PREVIOUSLY SEARCHED**

**IM= LIST OF ROW NUMBERS WHERE MIN RATIOS OCCUR**

**IAUX= LIST OF AUXILIARY BASES**

**COMMON NOV, NOC, NOB, KUSE, NOBZ, NOV1, TAB(12,40), Y(12),**

**IC(8,40), J(6,40), X(8), ID(12), IB(40), IEQ(12), T(12,40),**

**INN(300,3), IAUX(200,3), FMT(12)**

**COMMON /PARSP2/ ZTAB(40,8), ZRHS(40), IZE(40), SL(8), SH(8)**

**DIMENSION VC(8)**

**DIMENSION IM(40)**

**DIMENSION COLNAM(5,40), OBJNAM(5,8), SLSUR(5)**

**DATA SPACE/4H**

**DATA SLSUR/4HSLAC, 4HK/SU, 4HRPLU, 4HS , 4H /**

**REWIND 9**
Table A - 3. (contd.). Listing of VOPTIM Program

902 FORMAT(18A4)
   WRITE (6,993) FMT
993 FORMAT(5X,18A4)
   DO 9 I=1,NOC
     READ (5,FMT) (TAB(I,J),J=1,NOV),V(I)
9 WRITE (6,992) (TAB(I,J),J=1,NOV),V(I)
992 FORMAT (5X,8F10.5)
   DO 10 I=1,NOB
     READ (5,FMT) (C(I,J),J=1,NOV)
10 WRITE (6,992) (C(I,J),J=1,NOV) -
   DO 11 I=1,NOV
     DO 11 J=1,NOB
       C(NOVZ,I)=C(NOVZ,I)+C(J,I)
11 CONTINUE
   C ADDING SURPLUS AND SLACK VARIABLES
   IF(IEQ(0).EQ.1) GO TO 15
   NOV =NOV +1
   IF(IEQ(J).EQ.0) GO TO 13
   TAB(J,NOV)=-1.0
   GO TO 15
13 TAB(J,NOV)=1.0
   IB(NOV)=1
   ID(J)=NOV
15 CONTINUE
   NOV1=NOV
   CALL PHASE1(TAB,12,V,NOC,NOV1,IEQ,IB,IFLAG)
   IF (IFLAG .EQ. 0) GO TO 66
   WRITE (6,904)
904 FORMAT (5X,30H THERE IS NO FEASIBLE SOLUTION)
   STOP
66 CONTINUE
   NOV1=NOV
   CALL OBJCAL (C,8,V,NOC,ID,NOBZ,X)
   CALL CHCALC(TAB,12,C,8,ID,NOBZ,NOV1,NOC,Z)
   CALL PRINIT
   C SELECTING THE COL WITH MIN NEGATIVE REV. COEFF.
   C IN COMPOSITE OBJ AND CHECKING IF ALL
   C OBJECTIVES HAVE NEGITIVE COEFF. FOR
   C THAT COL SO IT COULD BE BROUGHT IN
   67 CONTINUE
     ICOL=0
     AMIN=0.0
     DO 75 J=1,NOV
       IF (IB(J).GE.1) GO TO 75
       IF(Z(NOBZ,1),GE.-0.1E-4) GO TO 75
       IF (Z(NOBZ,1),GE.AMIN) GO TO 75
       DO 70 J=1,NOB
         IF (Z(J,1),CT>0.0) GO TO 75
60 CONTINUE
     AMIN=Z(NOBZ,1)
     ICOL=I
85 IF (ICOL .EQ. 0) GO TO 85
   CALL ROWSEL(TAB(1,ICOL),V,ID,NOC,IROW)
   IF (IROW) 81,81,82
81 WRITE (6,905)
905 FORMAT (//5X,19H UNBOUNDED SOLUTION)
   STOP
82 CALL TEST2(IROW,ICOL)
   IF (IB(1),EQ,5) GO TO 67
   CALL PIVOT(TAB,12,V,NOV1,NOC,IROW)
   GO TO 66
85 IF (NOBZ,1) STOP
   GO TO 186
86 CONTINUE
   C AT THIS POINT THERE IS NO VECTOR THAT IMPROVES
   C ALL OBJ. FUNC. FIND THE ROW WITH MIN RATIO
   C AND SET STATUS OF VECTOR TO 2 IF THE RATIO
   C CANNOT BE CALCULATED
   DO 110 I=1,NOV
     IF (IB(I).EQ.1) GO TO 110
     CALL ROWSEL(TAB(1,I),V,ID,NOC,IROW)
     IF (IROW.EQ.0) IB(I)=2
110 IM(I)=IROW
   C SET STATUS FOR VECTOR TO 3 IF ALL OF THE REV.
   C OBJ. COEFF. ARE NONNEGATIVE
   C TEST 3 OF ALGORITHM IN CHAPTER 6
   DO 115 I=1,NOV
     IF (IB(I).EQ.1) GO TO 115
     IF (Z(I,1),LE.0.0) GO TO 115
114 CONTINUE
     IB(I)=3
115 CONTINUE
   C SET THE STATUS OF VECTORS TO 3 IF VC FOR ALL
   C OBJECTIVES IS OF SAME SIGN
   C TEST 4 OF ALGORITHM IN CHAPTER 6
   NOV=NOV-1

88 CONTINUE
Table A - 3 (Contd.). Listing of VOPTIM Program

DO 150 I=1,NOV
IF (IB(I).NE.0) GO TO 150
I2=I+1
DO 140 J=I2,NOV
IF (IB(I).NE.0.OR. IB(J).NE.0) GO TO 140
J1=IM(I)
J2=IM(J)
TH1=V(J1)/TAB(J1,I)
IF(ABS(TH1) .GT. 0.1E-4) GO TO 118
IB(I)=3
GO TO 140
118 TH2=V(J2)/TAB(J2,J)
IF(ABS(TH2) .GT. 0.1E-4) GO TO 119
IB(J)=3
GO TO 140
119 DO 120 K=1,NOB
120 VC(K)=Z(K,I)*TH1-Z(K,J)*TH2
IJ=0
IK=0
DO 125 K=1,NOB
IF(VC(K) .GT. 0.1E-4) IJ=1
IF(VC(K) .LT. -0.1E-4) IK=1
125 CONTINUE
IF (IJ.EQ.0.AND.IK.EQ.1) IB(J)=3
IF (IJ.EQ.1.AND.IK.EQ.0) IB(I)=3
140 CONTINUE
C ADD THE BASES NOT USED PREVIOUSLY TO THE LIST
DO 151 I=1,NOV
IF (IB(I).EQ.3) CALL TEST2 (IM(I),I,2)
151 CONTINUE
C TEST IF THE BASES HAVE BEEN USED PREVIOUSLY
155 DO 165 I=1,NOV
IF (IB(I).EQ.0) CALL TEST2 (IM(I),I,1)
165 CONTINUE
C STORE THE CANDIDATE BASES IF THEY HAVE NOT
C BEEN STORED
J1=0
DO 175 I=1,NOV
IF (IB(I).GT.0) GO TO 175
IF (J1.EQ.0) GO TO 170
CALL TEST3 (IM(I),I)
GO TO 175
170 IROW=IM(I)
Table A - 3 (Contd.). Listing of VOPTIM Program

1020 FORMAT(I2)
   DO 250 J = 1, IROW
   READ (9,1025) (ZTAB(J,K), K=1, I1), ZRHS(J)
1025 FORMAT(8E15.8)
   READ (9,1020) IZE(J)
250 CONTINUE
   READ (9,1025) (SL(J), SH(J), J=1, I1)
   TH1 = 1.
   TH2 = 1.
   J = II -
252 IF (J .LT. 1) GO TO 255
   J1 = J +1
   SL(J1) = SL(J)
   SH(J1) = SH(J)
   TH1 = TH1 - SL(J1)
   TH2 = TH2 - SH(J1)
   J = J - 1
   GO TO 252
255 CONTINUE
   IF (TH1 .LT. 0.) TH1 = 0.
   IF (TH2 .LT. 0.) TH2 = 0.
   SL(1) = TH2
   SH(1) = TH1
   WRITE (6,1007) I
1007 FORMAT( ///9X,12HSOLUTION NO.,I5,///9X,5HBASIS,
         130X,5HVALUE)
   DO 230 J=1, NOC
   IJ = ID(J)
230 WRITE (6,1008) ID(J), (COLNAM(K,IJ), K=1, 5), V(J)
1008 FORMAT(5X,15,2X,5A4,F20.8)
1010 FORMAT(5X,5E20.8)
   WRITE (6,1027)
1027 FORMAT( ///35X,10HOBJ.VALUE,9X,11HLOWER LIMIT,9X,
         11HUPPER LIMIT)
   DO 235 J = 1, NOB
   WRITE (6,1028) (OBJNAM(K,J), K=1, 5), X(J), SL(J), SH(J)
235 CONTINUE
290 CONTINUE
999 STOP

SUBROUTINE RONSEL(TABCOL,RHS,IB,NOC,IROW)
   ------
   THIS SUBROUTINE SELECTS THE ROW WITH MIN RATIO
   IN CASE OF TIE SELECTS THE ROW WITH HIGHER
   COLUMN NO. IN BASIS
   DIMENSION TABCOL(NOC), RHS(NOC), IB(NOC)
   IRW=0
   AMIN=100000000.
   DO 43 K=1,NOC
   IF(TABCOL(K).LE.0.1E-4) GO TO 43
   IF(TABCOL(K).LT.0.1E-5.AND.RHS(K).LT.0.1E-5) GO TO 43
   RATIO = RHS(K) / TABCOL(K)
   IF(ABS(RATIO - AMIN) .LT. 0.1E-4) GO TO 20
   IF (RATIO - AMIN) 30,20,43
20 IF (IB(K) .LT. IB(IROW)) GO TO 43
30 AMIN=RATIO
   IRW = K
43 CONTINUE
   RETURN
   END

SUBROUTINE PIVOT(TAB,NTD,V,NV,NC,IROW,ICOL)
   ------
   THIS SUBROUTINE TRANSFORMS THE TABLEAUS AND
   ENTERS THE ICOL ELEMENT IN PLACE OF THE IRW
   ELEMENT IN THE BASIS
   DIMENSION TAB(NTD,NV), V(NC)
   DI = TAB(IROW,ICOL)
   DO 10 I=1,NV
   10 TAB(IROW,I)=TAB(IROW,I)/DI
      V(IROW)=V(IROW)/DI
   DO 30 I=1,NC
   IF(1.EQ.IROW) GO TO 30
   DI = TAB(I,ICOL)
   V(I) = V(I) - V(IROW)*DI
   IF (ABS(V(I)) .LT. 0.1E-5) V(I) = 0.
   DO 25 J=1,NV
   TEMP = TAB(I,J) - DI * TAB(IROW,J)
   IF (0 .EQ. ICOL) TEMP = 0.
   IF(ABS(TEMP) .LT. 0.1E-4) TEMP = 0.
Table A – 3 (Contd.). Listing of VOPTIM Program

```
TAB(I,J) = TEMP
25 CONTINUE
30 CONTINUE
RETURN
END

SUBROUTINE OBJCAL (C,NCD,V,N0C,ID,N0BZ,X)

THIS SUBROUTINE COMPUTES THE VALUE OF EACH OBJECTIVE FUNCTION

DIMENSION C(NCD,1),V(N0C),ID(N0C),X(N0BZ)
C - OBJECTIVE FUNCTIONS ARRAY
V - VALUE OF BASIC VECTORS
ID - LIST OF BASIC VECTORS
X - VALUE OF OBJECTIVE FUNCTIONS
NCD - DIMENSION OF C, NO. OF ROWS IN C
NOC - NO. OF CONSTRAINTS
NOBZ - NO. OF OBJECTIVE FUNCTIONS
DO 20 I=1,NOBZ
   SUM=0.0
   DO 15 J=1,N0C
      ID1=ID(J)
      15 SUM=SUM+C(I,ID1)*V(J)
   20 X(I)=SUM
RETURN
END

SUBROUTINE CHCALC(TAB,NTD,C,NCD,ID,NOBZ,NOVI,NOC,Z)

THIS SUBROUTINE COMPUTES THE VALUE OF EACH ELEMENT OF THE OBJECTIVE FUNCTION ARRAY

DIMENSION TAB(NTD,NOVI),C(NCD,NOVI),Z(NCD,NOVI)
C NOC - NO. OF CONSTRAINTS
C Z - OBJECTIVE FUNCTIONS ARRAY - REVISED
C DIMENSION TAB(NTD,NOVI),C(NCD,NOVI),Z(NCD,NOVI)
C DIMENSION ID(NOC)
C DO 20 J=1,NOVI
C DO 15 K=1,NOC
C ID1=ID(K)
C 15 SUM=SUN+TAB(K,J)*C(I,ID1)
C SUM = SUM - C(I,J)
C IF(ABS(SUM) .LT. 0.1E-4) SUM = 0.
C Z(I,J) = SUM
C 20 CONTINUE
RETURN
END

SUBROUTINE DROPR(IAUX,IIAD, JIAD,NAUX,NDROP)

DIMENSION IAUX(IIAD,JIAD)
C THIS SUBROUTINE DROPS THE ROW KU FROM ARRAY IAUX
C IAUX - ARRAY IN WHICH ROW IS TO BE DROPPED
C IIAD - NO. OF ROWS IN DIMENSION OF IAUX
C JIAD - NO. OF COLUMNS IN DIMENSION OF IAUX
C NAUX - NO. OF ROWS FILLED
C NDROP - NO. OF ROW TO BE DROPPED
C N1 = NAUX - 1
C IF (NDROP .GT. N1) GO TO 155
C DO 140 I = NDROP,N1
C IP1 = I + 1
C DO 130 J = 1,JIAD
C 130 IAUX(I,J) = IAUX(IP1,J)
C 140 CONTINUE
C DO 170 J = 1,JIAD
C 170 IAUX(NAUX,J) = 0
C NAUX = N1
RETURN
END
```

---

| C | NOC - NO. OF CONSTRAINTS |
| C | Z - OBJECTIVE FUNCTIONS ARRAY - REVISED |
| C | DIMENSION TAB(NTD,NOVI),C(NCD,NOVI),Z(NCD,NOVI) |
| C | DIMENSION ID(NOC) |
| C | DO 20 J=1,NOVI |
| C | DO 15 K=1,NOC |
| C | ID1=ID(K) |
| C | 15 SUM=SUN+TAB(K,J)*C(I,ID1) |
| C | SUM = SUM - C(I,J) |
| C | IF(ABS(SUM) .LT. 0.1E-4) SUM = 0. |
| C | Z(I,J) = SUM |
| C | 20 CONTINUE |
| C | RETURN |
| C | END |

---

| C | SUBROUTINE CHCALC(TAB,NTD,C,NCD,ID,NOBZ,NOVI,NOC,Z) |
| C | ----- |
| C | DIMENSION TAB(NTD,NOVI),C(NCD,NOVI),Z(NCD,NOVI) |
| C | DIMENSION ID(NOC) |
| C | DO 20 J=1,NOVI |
| C | DO 15 K=1,NOC |
| C | ID1=ID(K) |
| C | 15 SUM=SUN+TAB(K,J)*C(I,ID1) |
| C | SUM = SUM - C(I,J) |
| C | IF(ABS(SUM) .LT. 0.1E-4) SUM = 0. |
| C | Z(I,J) = SUM |
| C | 20 CONTINUE |
| C | RETURN |
| C | END |

---

| C | SUBROUTINE DROPR(IAUX,IIAD, JIAD,NAUX,NDROP) |
| C | ----- |
| C | DIMENSION IAUX(IIAD,JIAD) |
| C | THIS SUBROUTINE DROPS THE ROW KU FROM ARRAY IAUX |
| C | IAUX - ARRAY IN WHICH ROW IS TO BE DROPPED |
| C | IIAD - NO. OF ROWS IN DIMENSION OF IAUX |
| C | JIAD - NO. OF COLUMNS IN DIMENSION OF IAUX |
| C | NAUX - NO. OF ROWS FILLED |
| C | NDROP - NO. OF ROW TO BE DROPPED |
| C | N1 = NAUX - 1 |
| C | IF (NDROP .GT. N1) GO TO 155 |
| C | DO 140 I = NDROP,N1 |
| C | IP1 = I + 1 |
| C | DO 130 J = 1,JIAD |
| C | 130 IAUX(I,J) = IAUX(IP1,J) |
| C | 140 CONTINUE |
| C | DO 170 J = 1,JIAD |
| C | 170 IAUX(NAUX,J) = 0 |
| C | NAUX = N1 |
| C | RETURN |
| C | END |
Table A – 3 (Cont.). Listing of VOPTIM Program

SUBROUTINE PRINIT
---
THIS SUBROUTINE PRINTS OUT THE SIMPLEX TABLEAU INCLUDING OBJECTIVES
COMMON NOV,NOC,NOB,KAUX,KUSE,NOBZ,NOVI,TAB(12,40),V(12),
1C(8,40),Z(8,40),X(8),ID(12),IB(40),IEQ(12),T(12,40),
2INN(300,3),IAUX(200,3),FMT(12)
WRITE (6,900)
900 FORMAT(///5X,16H SIMPLEX TABLEAU/)
WRITE (6,901)
901 FORMAT (IX,6H BASIS,2X,6H VALUE,7X,10H VARIABLES )
DO 100 I=1,NOVI,7
IL=I+6
IF (IL.GT.NOV1) IL=NOV1
DO J=1,NOC
90 WRITE (6,902) ID(J),V(J),(TAB(J,K),K=I,IL)
902 FORMAT (1X,I6,8E15.6)
WRITE (6,903)
100 CONTINUE
WRITE (6,904)
904 FORMAT (///5X,15H OBJECTIVE FUNCTIONS )
WRITE (6,905)
905 FORMAT (IX,7OBJ, F.,2X,6H VALUE,7X,10H VARIABLES )
DO 200 I=1,NOVI,7
IL=I+6
IF (IL.GT.NOVI) IL=NOVI
DO J=1,NOB
90 WRITE (6,902) ID(J),V(J),(TAB(J,K),K=I,IL)
WRITE (6,903)
200 CONTINUE
WRITE (6,906)
906 FORMAT (///5X,15H COMPOSITE FUNCTION)
DO 210 I=1,NOVI,7
IL=I+6
IF (IL.GT.NOVI) IL=NOVI
210 WRITE (6,902) NOBZ,X(NOBZ), (Z(NOBZ,K),K=I,IL)
WRITE (6,907) KAUX,KUSE
907 FORMAT(5X,5K,5K,HEKUSE=,I8)
IF (KUXAU.EQ.0) GO TO 250
WRITE (6,955) (IAUX(I,1),IAUX(I,2),I=1,KAUX)
955 FORMAT (7(2X,2I8))
250 CONTINUE

IF (KUSE .EQ. 0) GO TO 260
WRITE (6,955) (INN(I,1), INN(I,2),I=1,KUSE)
260 CONTINUE
RETURN
END

SUBROUTINE TEST2 (IROW,ICOL,IK)
---
THIS SUBROUTINE TESTS TO SEE IF THE PROPOSED BASIS HAS BEEN USED PREVIOUSLY
STATUS ARRAY ELEMENT IS SET TO 5 IF BASIS IS USED
IK=0 IF NOT USED ADD TO THE USED LIST INN AND CHANGE ARRAY IB
IK=1 IF NOT USED RETURN WITHOUT SETTING ARRAY ELEMENT TO 5
IK=2 IF NOT USED ADD TO THE USED LIST INN
COMMON NOV,NOC,NOB,KAUX,KUSE,NOBZ,NOVI,TAB(12,40),V(12),
1C(8,40),Z(8,40),X(8),ID(12),IB(40),IEQ(12),T(12,40),
2INN(300,3),IAUX(200,3),FMT(12)
IF (IK.NE.0) GO TO 6
DO 5 I=1,NOV
IF (IB(I).EQ.5) IB(I)=0
5 CONTINUE
IF (IK.NE.0) GO TO 6
CALL COMPB(IR0W,ICOL,1,1)
IF (KUSE.EQ.0) GO TO 60
DO 50 1=1,KUSE
IF (I.EQ.INN(I,1).AND.12.EQ.INN(I,2)) GO TO 75
50 CONTINUE
IF (IK.NE.1).AND.12.EQ.INN(I,2)) GO TO 75
50 CONTINUE
60 IF (IK.EQ.1) GO TO 99
75 IB(icol)=5
99 RETURN

IF (IK.EQ.1) GO TO 99
KUXAU=KUSE+1
INN(KUXAU,1)=I1
INN(KUXAU,2)=I2
IF (IK.EQ.0) GO TO 99
IB(icol)=1
I1=ID(IRow)
IB(icol)=I1
ID(IRow)=icol
GO TO 99
75 IB(icol)=5
99 RETURN
Table A - 3 (Contd.). Listing of VOPTIM Program

SUBROUTINE COMPB(IR0W, ICOL, I1, I2)
!
THIS SUBROUTINE SORTS AND COMPresses THE LIST OF
BASIC VECTORS INTO TWO WORDS I1 AND I2
!
COMMON NOV, NOC, NOB, Kaux, KUSE, NOBZ, NOV1, TAB(12, 40), V(12),
IC(8, 40), Z(8, 40), X(8), ID(12), IB(40), IEQ(12), T(12, 40),
2INN(300, 3), IAUX(200, 3), FMT(12)

DIMENSION IT(12)
DO 10 I = 1, NOC
IT(I) = ID(I)
10 CONTINUE
IT(IR0W) = ICOL
N0CM1 = NOC - 1
DO 30 J = I1, NOC
IF (IT(J).LE.0) GO TO 25
IF (IT(I).LE.0) GO TO 20
IF (IT(J).GE. IT(I)) GO TO 25
20 MOVE = IT(I)
IT(I) = IT(J)
IT(J) = MOVE
25 CONTINUE
30 CONTINUE
I1 = 0
I2 = 0
MULTF = 1000000
DO 40 I = 1, NOC
IF (I-5) 35, 36, 37
35 I1 = I1 + IT(I)*MULTF
GO TO 38
36 MULTF = 1000000
37 I2 = I2 + IT(I)*MULTF
38 MULTF = MULTF / 100
40 CONTINUE
RETURN
END

SUBROUTINE TEST3 (IROW, ICOL)
!
THIS SUBROUTINE TESTS TO SEE IF A BASIS HAS BEEN
STORED FOR FUTURE USE AND STORES IF IT HAS NOT
BEEN STORED PREVIOUSLY
!
COMMON NOV, NOC, NOB, Kaux, KUSE, NOBZ, NOV1, TAB(12, 40), V(12),
IC(8, 40), Z(8, 40), X(8), ID(12), IB(40), IEQ(12), T(12, 40),
2INN(300, 3), IAUX(200, 3), FMT(12)
CALL COMPB(IROW, ICOL, I1, I2)
IF (KAUX.EQ.0) GO TO 60
DO 50 J = 1, KAUX
IF (II.EQ. IAUX(I, 1).AND.I2.EQ. IAUX(I, 2)) GO TO 99
50 CONTINUE
60 KAUX = KAUX + 1
IAUX(KAUX,1) = II
IAUX(KAUX,2) = I2
99 RETURN
END

SUBROUTINE FORBAS (KKU)
!
THIS SUBROUTINE SELECTS A BASIS THAT HAS BEEN
STORED EARLIER AND IS CLOSER TO THE CURRENT BASIS
THAN ANY OTHER STORED BASIS AND FORCES THAT BASIS
INTO THE SOLUTION
!
COMMON NOV, NOC, NOB, Kaux, KUSE, NOBZ, NOV1, TAB(12, 40), V(12),
IC(8, 40), Z(8, 40), X(8), ID(12), IB(40), IEQ(12), T(12, 40),
2INN(300, 3), IAUX(200, 3), FMT(12)
COMMON /LOCAL/ IKa(12), IOUT(12), NOER, INA(12), IADD(200)
DO 3 I = 1, KAUX
IADD(I) = 1
4 IA1 = IAUX(I, 1)
IA2 = IAUX(I, 2)
DO 1 J = 1, KUSE
IF (IA1.EQ. INN(J, 1).AND.IA2.EQ. INN(J, 2)) GO TO 2
1 CONTINUE
GO TO 3
2 CALL DROP(IAUX, 200, 2, KAUX, 1)
GO TO 4
CONTINUE
IF (KAUX.EQ.0) GO TO 98
WRITE (6,8)
CALL CHOS1(KU)
IF (KU.EQ.0) GO TO 98
IADD(KU)=0
10
DO 25 II=1,NOER
IROW = 0
ICOL = 0
DO 20 I=1,NOER
IF (IOUT(I).EQ.0) GO TO 20
IC=IOUT(I)
DO 19 J=1,NOER
J1=INA(J)
CALL ROWSEL(TAB(I,J1),V,ID,NOC,JJ)
IF (ID(JJ).NE.IC) GO TO 19
INA(J)=0
IROW=JJ
ICOL=J1
GO TO 22
19
CONTINUE
20
IF(IROW .EQ. 0 .OR. ICOL .EQ. 0) GO TO 25
IOUT(I)=0
22
CALL PIVOT(TAB,12,V,NOV1,NOC,IROW,ICOL)
IDI=ID(1,IROW)
IB(IDI)=0
IB(ICOL)=1
ID(1,IROW)=ICOL
IKK=IKK+1
CALL OBJCAL(C,8,V,NOC,NOBZ,X)
CALL CHCALC(TAB,12,C,8,NOC,NOBZ,NOV1,NOC,Z)
CALL PRINIT
25
CONTINUE
IF (IKK.EQ.NOER) GO TO 97
WRITE (6,92)
92 FORMAT (/5X,23HBASIS CANNOT BE ENTERED )
GO TO 5
97
CALL DROP1(IAUX,200,Z,KAUX,KU)
GO TO 99
98
KUU=1
99
RETURN
END

SUBROUTINE CHOS1(KU)

THIS SUBROUTINE CHOOSES THE AUXILLARY BASIS THAT IS
CLOSEST TO THE CURRENT BASIS

COMMON NOV,NOC,NOB,KAUX,KUSE,NOBZ,NOV1,TAB(12,40),V(12),
1C(8,40),Z(8,40),X(8),ID(12),IB(40),IEQ(12),T(12,40),
2INN(300,3),IAUX(200,3),FMT(12)
COMMON /LOCAL/ IKA(12),IOUT(12),NOER,INA(12),IADD(200)
DIMENSION IOU(40),IN(40)
DO 5 I=1,12
IKA(I)=0
IOUT(I)=0
5
MIN=9
KU=0
DO 100 I1=1,KAUX
111
I11=I1-1
I1=KAUX-I11
II=I1
J1=INA(J)
CALL ROWSEL(TAB(1,J1),V,ID,NOC,JJ)
IF (ID(JJ).NE.IC) GO TO 10
INA(J)=0
IROW=JJ
ICOL=J1
GO TO 22
19
CONTINUE
20
IF(IROW .EQ. 0 .OR. ICOL .EQ. 0) GO TO 25
IOUT(I)=0
22
CALL PIVOT(TAB,12,V,NOV1,NOC,IROW,ICOL)
IDI=ID(1,IROW)
IB(IDI)=0
IB(ICOL)=1
ID(1,IROW)=ICOL
IKK=IKK+1
CALL OBJCAL(C,8,V,NOC,NOBZ,X)
CALL CHCALC(TAB,12,C,8,NOC,NOBZ,NOV1,NOC,Z)
CALL PRINIT
25
CONTINUE
IF (IKK.EQ.NOER) GO TO 100
MULTF = 1000000
DO 10 I=1,NOC
14=I2/MULTF
IKA(I)=I4
II2=I2-I4*MULTF
MULTF = MULTF / 100
10
I2=I2-MULTF
IKA(I)=I2
12=I2-I4*MULTF
MULTF = MULTF / 100
20
CONTINUE
COUNT IO, NUMBER OF VECTORS NOT IN CURRENT BASIS
IO=0
DO 30 I=1,NOC
30 CONTINUE
Table A - 3 (Contd.). Listing of VOPTIM Program

```
30 CONTINUE
C COUNT INI, NUMBER OF VECTORS IN CURRENT BASIS THAT
C ARE NOT IN THE PROPOSED BASIS
INI=0
DO 40 I=1,NOC
DO 35 J=1,NOC
IF (IKA(I).EQ.ID(J)) GO TO 40
35 CONTINUE
INI=INI+1
IN(INI)=IKA(I)
40 CONTINUE
IF (IO.EQ.O) GO TO 100
IF (10.GE.MIN) GO TO 100
C SAVE THE CLOSEST BASIS
MIN=IO
KU=I1
DO 50 1=1,10
IOUT(I)=I0U(I)
50 INA(I)=IN(I)
100 CONTINUE
IF (MIN.EQ.9) GO TO 99
NOER=MIN
IF (KU.EQ.O) GO TO 99
KUSE = KUSE+1
INN(KUSE,1)=IAUX(KU,1)
INN(KUSE,2)=IAUX(KU,2)
WRITE (6,90) IAUX(KU,1),IAUX(KU,2)
90 FORMAT (5X, 9HAUXILLARY ,5X,3I8)
99 RETURN
C
C SUBROUTINE NONDOM (K,NOND) ------
C THIS SUBROUTINE TESTS IF THE CURRENT BASIS IS
C NODOMINATED AND IF IT IS , STORES IT IN
C THE FILE OF NONDOMINATED BASES
C ATAB= TABLEAU OF SUBPROBLEM
C IC= LIST OF BASIC VECTORS
C IG= STATUS VECTOR OF VARIABLES FOR SUBPROBLEM
C ZI= OBJECTIVE ROW OF SUBPROBLEM

```
THE BASIS IS NON-DOMINATED IF \( \text{II}=0 \)

CONTINUE

CALL ROWSEL(ATAB(1,II),AV,IC,NOB,III)

THE BASIS IS DOMINATED IF \( \text{II}=0 \)

IF (III.EQ.0) GO TO 51

CALL PIVOT(ATAB,8,AV,NV,NOB,III,11)

I=IC(III)

IC(III)=II

IG(I)=0

IG(II)=1

DO 50 J=1,NV

SUM=0.0

DO 45 J=1,NOB

II = IC(J)

45 SUM = SUM + CI(II)*ATAB(J,I)

SUM = SUM - CI(I)

IF(ABS(SUM).LT.0.1E-4) SUM = 0.

ZI(I) = SUM

CONTINUE

GO TO 31

51 CONTINUE

DO 60 J=1,NOC

IF (TAB(J,II).GT.0.0) GO TO 61

CONTINUE

WRITE (6,900)

900 FORMAT (//5X,30H ORIGINAL PROBLEM IS UNBOUNDED //)

GO TO 99

901 FORMAT (5X,34H SUBPROBLEM IS UNBOUNDED FOR BASIS,1213)

GO TO 99

70 NOND+NONDP+1

K=1

WRITE (9,911) (ID(J),J=1,NOC)

911 FORMAT (8I2)

WRITE (9,912) (V(J),J=1,NOC)

912 FORMAT (8E15.8)

WRITE (9,912) (X(J),J=1,NOBZ)

CALL PARSPC

99 RETURN

SUBROUTINE PARSPC

This subroutine writes the nonredundant constraints of the parametric space for current nondominated solution on permanent file.

COMMON NOV,NOC,NOB,KAUX,KUSE,NOBZ,NOV1,TAB(12,40),V(12),
CI(8,40),Z(8,40),X(8),ID(12),IB(40),IEQ(12),T(12,40),
ZINV(300,3),IAUX(200,3),FMT(12)

COMMON /PARSP2/ ZTAB(40,8),ZRHS(40),IZE(40),SL(8),SH(8)

DIMENSION TZ(41,40),IZB(40),ZR(40)

NODBP = NOB - 1

NRW = 0

DO 140 I = 1,NOV1

IF(ID(I).EQ.1) GO TO 140

NRW = NRW + 1

TEMP = Z(I,1)

IF(ABS(TEMP).LT.0.1E-4) TEMP = 0.

ZRHS(NRW) = TEMP

IZE(NRW) = 0

IF (TEMP.LT.0.) IZE(NRW) = 2

DO 130 J = 1,NOB1

130 ZTAB(NRW,J) = ZTAB(NRW,J)/TEMP

CONTINUE

IF(ABS(TEMP).LT.0.1E-4) GO TO 140

ZRHS(NRW) = 1

DO 135 J = 1,NOB1

135 ZTAB(NRW,J) = ZTAB(NRW,J)/TEMP

CONTINUE

ADDING NORMALIZING CONSTRAINT

NRW = NRW + 1

DO 145 J = 1,NOB1

145 ZTAB(NRW,J) = ZTAB(NRW,J)/TEMP

CONTINUE

DO LOOPS ARE SIMULATED USING CODING DUE TO PROBLEMS

WITH DO LOOPS WHEN LIMITS ARE CHANGED WITHIN LOOP

II = 0

151 II = II + 1

152 IF (II.GT.0) GO TO 205

IZEII = IZE(II)

ZRHSII = ZRHS(II)

I = II

153 I = I + 1

239
Table A - 3 (Contd.). Listing of VOPTIM Program

154 IF (I .GT. NROW) GO TO 151
   IF (IZE(I) .NE. IZEII) GO TO 153
   IF (ABS(ZRHS(I) - ZRHSII) .GT. 0.1E-4) GO TO 153
   IG = 0
   IIG = 0
   DO 160 J = 1,NOBM1
      IF (ABS(ZTAB(I,J) - ZTAB(I,J)) .LT. 0.1E-4) GO TO 160
   IF (ZTAB(I,J) - ZTAB(I,J)) 155,160,157
   155 IG = 1
   GO TO 160
   157 IIG = 1
   CONTINUE
   IF (IG*IG .EQ. 1) GO TO 153
   IF (IZEII .EQ. 0 .AND. IIG .EQ. 1) GO TO 165
   IF (IZEII .EQ. 2 .AND. IG .EQ. 1) GO TO 165
   CALL DROPC(ZTAB,ZRHS,IZE,40,NOBM1,NROW,I)
   GO TO 152
   165 CALL DROPC(ZTAB,ZRHS,IZE,40,NOBM1,NROW,1)
   GO TO 154
   205 CONTINUE
   II = 0
   207 II = II + 1
   208 IF (II .GT. NROW) GO TO 295
   NCOL = NOBM1
   DO 220 I = 1,NROW
      IZB(I) = NCOL
   DO 210 J = 1,NOBM1
      ZT(I,J) = ZTAB(I,J)
   210 ZT(I,J) = ZTAB(I,J)
      IF (I .EQ. 11) GO TO 215
   NCOL = NCOL + 1
   DO 212 J = 1,NROW
      ZT(I,J) = ZTAB(I,J)
      ZT(I,J) = 0
   212 ZT(I,J) = ZTAB(I,J)
      IF (IZE(I) .EQ. 1) GO TO 220
   ZT(I,J) = ZTAB(I,J)
   IZB(I) = NCOL
   GO TO 220
   215 IZB = IZE(I)
   IZE(I) = 1
   CONTINUE
   CALL PHASEI(ZT,41,ZR,NROW,NCOL,IZE,IZB,IFLAG)
   IZE(I) = IZEII
   IF (IFLAG .NE. 1) GO TO 207
   CALL DROPC(ZTAB,ZRHS,IZE,40,NOBM1,NROW,II)
   CONTINUE
   DO 295 I = 1,NROW
      ZR(I) = ZRHS(I)
   CONTINUE
   CALL PSLIMT(ZT,41,N0BM1,NROW,ZR,IZE,SL,SH)
   WRITE (9,901) NROW
   901 FORMAT(I2)
   WRITE (6,911) (ZTAB(I,J),J=1,N0BM1), ZRHS(I)
   911 FORMAT(8E15.8)
   WRITE (6,913) IZE(I), (ZTAB(I,J),J=1,N0BM1), ZRHS(I)
   913 FORMAT(8X,I2,2X,8E15.8)
   WRITE (9,911) (SL(I),SH(I),I=1,N0BM1)
   WRITE (6,923) (SL(I),I=1,N0BM1)
   923 FORMAT(12H LOWER LIMIT,8E15.8)
   WRITE (6,925) (SH(I),I=1,N0BM1)
   925 FORMAT(12H UPPER LIMIT,8E15.8)
   RETURN

SUBROUTINE DROPC(ZTAB,ZRHS,IZE,ID,JCOL,NROW,NDROP) -----

THIS SUBROUTINE DROPS A CONSTRAINT BY DROPPING ROW
IN ZTAB MATRIX AND ELEMENT IN ZRHS AND IZE VECTORS
ZTAB - ARRAY CONTAINING THE MATRIX
ZRHS - ARRAY CONTAINING THE VECTOR FOR RHS
IZE ARRAY CONTAINING THE ROW RELATIONSHIPS
ID - NO. OF ROWS IN DIMENSION OF ZTAB
JCOL - NO. OF COL. TO BE PROCESSED IN MOVING ROW
NROW - NO. OF ROWS PRESENT IN MATRIX
NDROP - NO. OF CONSTRAINT TO BE Dropped
DIMENSION ZTAB(ID,JCOL),ZRHS(ID),IZE(ID)
N1 = NROW - 1
IF (NDROP .GT. N1) GO TO 155
DO 150 I = NDROP,N1
   150 I1 = I + 1

200
Table A - 3 (Contd.). Listing of VOPTIM Program

DO 130 J = 1, JCOL
130 ZTAB(I,J) = ZTAB(IP1,I,J)
ZRHS(I) = ZRHS(IP1)
IZE(I) = IZE(IP1)
150 CONTINUE
DO 170 J = 1, JCOL
170 ZTAB(NROW,J) = 0.
ZRHS(NROW) = 0.
IZE(NROW) = 0
NROW = N1
RETURN
END

SUBROUTINE PHASE1(STAB, NTD, RHS, NROW, NCOL, ISE, IB, IFLAG)
IFLAG = 0 FEASIBLE SOLUTION EXISTS
1 NO FEASIBLE SOLUTION
2 UNBOUNDED OBJECTIVE
DIMENSION STAB(NTD, NCOL), RHS(NTD), ISE(NTD), IB(NTD)
NRP1 = NROW + 1
IFLAG = 0
NVAR = NCOL
DO 105 I = 1, NCOL
105 STAB(NRP1,I) = 0.
RHS(NRP1) = 0.
DO 195 I = 1, NROW
IF (ISE(I) .EQ. 0) GO TO 195
NVAR = NVAR + 1
IB(I) = NVAR
DO 180 J = 1, NCOL
180 STAB(NRP1,J) = STAB(NRP1,J) - STAB(I,J)
RHS(NRP1) = RHS(NRP1) - RHS(I)
DO 190 J = 1, NRP1
190 STAB(J,NVAR) = 0.
STAB(J,NVAR) = 1.
195 CONTINUE
IF (NVAR .EQ. NCOL) GO TO 900
205 CONTINUE
RMIN = 99999.
ICOL = 0
DO 220 J = 1, NVAR
220 CONTINUE
IF (STAB(NRP1,J) .GE. RMIN) GO TO 220
RMIN = STAB(NRP1,J)
ICOL = J
CALL ROWSEL(STAB(I, ICOL), RHS, IB, NROW, IROW)
IF (RMIN .LE. 0) GO TO 270
CALL PIVOT(STAB, NTD, RHS, NVAR, NRP1, IROW, ICOL)
IF (ICOL) = ICOL
GO TO 205
250 CONTINUE
IF (ABS(RHS(NRP1)) .LT. 0.1E-4) GO TO 900
IFLAG = 1
GO TO 900
270 CONTINUE
WRITE (6, 275)
275 FORMAT(//, 5X, 20HSUBROUTINE PHASE1 - , 20H UNBOUNDED OBJECTIVE, //)
IFLAG = 2
900 CONTINUE
RETURN
END

SUBROUTINE PSLIMT(ATAB, IAD, NCOL, NROW, ARHS, IAE, SL, SH)
DIMENSION ATAB(IAD, NCOL), ARHS(NROW), IAE(NROW)
DIMENSION SL(NCOL), SH(NCOL)

THIS SUBROUTINE SOLVES LP PROBLEMS TO GET LIMITS
OF PARAMETRIC SPACE
ATAB = TABLEAU OF LP, A MATRIX
IAD = NO. OF ROWS IN DIMENSION OF ATAB
NCOL = NO. OF VARIABLES IN A MATRIX OF LP
NROW = NO. OF ROWS IN A MATRIX OF LP
ARHS = RIGHT HAND SIDE OF LP
IAE = RELATIONSHIPS(GLE) OF CONSTRAINTS
SL = LOWER LIMIT OF PARAMETRIC SPACE
SH = UPPER LIMIT OF PARAMETRIC SPACE
DIMENSION ATAB(IAD, NCOL), ARHS(NROW), IAE(NROW)
DIMENSION SL(NCOL), SH(NCOL)
Table A - 3 (Contd.). Listing of VOPTIM Program

```
DIMENSION AZ(48), IAB(40), AC(48)
NVAR = NCOL
DO 145 I = 1, NROW
    IF (IAE(I) .EQ. 1) GO TO 145
    NVAR = NVAR + 1
    DO 140 J = 1, NROW
        ATAB(J, NVAR) = 0.
        ATAB(I, NVAR) = -1.
    IF (IAE(I) .EQ. 2) GO TO 145
    IAB(I) = NVAR
    ATAB(I, NVAR) = 1.
145 CONTINUE
CALL PHASE1(ATAB, IAD, ARHS, NROW, NVAR, IAE, IAB, IFLAG)
IF (IFLAG .EQ. 0) GO TO 205
    DO 175 I = 1, NCOL
        SL(I) = -1.
    175 SH(I) = -1.
RETURN
205 CONTINUE
DO 210 J = 1, NVAR
    AC(J) = 0.
    DO 295 II = 1, NCOL
        AC(II) = 1
        AMIN = 999999.
        ICOL = 0
        DO 222 J = 1, NVAR
            SUM = 0.
            DO 220 I = 1, NROW
                IAB1 = IAB(I)
                SUM = SUM + ATAB(I, J)*AC(IAB1)
                AZ(J) = SUM - AC(J)
                IF (AZ(J) .GE. AMIN) GO TO 225
                AMIN = AZ(J)
                ICOL = J
            220 CONTINUE
            IF (AZ(ICOL) .GT. -0.1E-4) GO TO 245
            CALL ROWSEL(ATAB(1, ICOL), ARHS, IAB, NROW, IROW)
            IF (IROW .NE. 0) GO TO 235
            OBJ = 999 * AC(II)
            GO TO 255
        225 CONTINUE
        CALL PIVOT(ATAB, IAD, ARHS, NVAR, NROW, IROW, ICOL)
        IAB(IROW) = ICOL
        GO TO 215
    235 CALL PIVOT(ATAB, IAD, ARHS, NVAR, NROW, IROW, ICOL)
    IAB(IROW) = ICOL
    GO TO 215
245 OBJ = 0.
DO 250 I = 1, NROW
    IAB1 = IAB(I)
250 OBJ = OBJ + AC(IAB1) * ARHS(I)
255 IF (AC(II) .EQ. -1.) GO TO 275
    SH(II) = OBJ
    AC(II) = -1.
    GO TO 215
275 SL(II) = -OBJ
    AC(II) = 0.
295 CONTINUE
RETURN
END
```
APPENDIX B

INTERACTIVE PREFERRED SOLUTION SELECTION PROGRAM

The interactive program, SETRED, developed for interactively reducing the nondominated solution set to select the preferred solution of the decision maker is described here. This program is written so it could be run with a terminal in decision maker's office. This program uses the constraints of the parametric space saved on disc as a data set by the batch program described in Appendix A, as input besides the decision makers value judgements input from the terminal for the lead through questions typed on the terminal.

This program solves linear programs to calculate the limits of the parametric space for each of the nondominated solutions. At each iteration the range of the value judgements input from the terminal are added as extra constraints to the constraints defining the parametric space of the nondominated solution. The nondominated solution is dropped from further consideration when there is no feasible solution to all the constraints defining the parametric space. The program stops when there is only one nondominated solution left for further consideration or when "99" is entered for the objective number from the terminal keyboard.

The procedure to start the program vary from installation to installation, so it is not described here. It is the standard installation procedure to execute a FORTRAN program in time sharing.

233
environment. The prompting for input stops when "00" is entered for the objective number from the terminal keyboard. The computations to solve the linear programs are started after "00" input with the decision makers' input for ranges of value judgements added as constraints. All the nondominated solutions not dropped from consideration are re-examined with all the input so far before prompting for additional input.

A typical run could take several iterations. A special after the fact run that trimmed the nondominated solution set to a single preferred solution is shown in Table B - 1. The listing of the program is shown in Table B - 2. The details of the algorithms used in interactive procedure are described in Chapter 6.
Table B.1 Example of SETRED Program Output

ENTER 0 FOR OBJ. # TO PROCESS WITH VALUES INPUT
9 FOR OBJ. # TO TERMINATE THE RUN
ENTER 0 FOR UPPER OR LOWER LIMITS FOR NO CHANGE

ENTER OBJECTIVE NUMBER
2
ENTER LOWER LIMIT FOR INCARCERATION PROB.
.4
ENTER UPPER LIMIT FOR INCARCERATION PROB.

ENTER OBJECTIVE NUMBER
3
ENTER LOWER LIMIT FOR CASES FILED FRACT.
.4
ENTER UPPER LIMIT FOR CASES FILED FRACT.

ENTER OBJECTIVE NUMBER
5
ENTER LOWER LIMIT FOR VOCATIONAL SKILLS
.1
ENTER UPPER LIMIT FOR VOCATIONAL SKILLS

<table>
<thead>
<tr>
<th>OBJECTIVE NUMBER</th>
<th>LOWER LIMIT</th>
<th>UPPER LIMIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

VALUES INPUT SO FAR - AS USED IN THIS ITERATION

<table>
<thead>
<tr>
<th>LOWER LIMIT</th>
<th>0.0</th>
<th>0.10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPPER LIMIT</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

SOLUTION NO. 1

<table>
<thead>
<tr>
<th>LOWER LIMIT</th>
<th>0.0</th>
<th>0.40000</th>
<th>0.47891</th>
<th>0.10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPPER LIMIT</td>
<td>0.10000</td>
<td>0.47891</td>
<td>0.08144</td>
<td>0.17889</td>
</tr>
</tbody>
</table>

SOLUTION NO. 2

<table>
<thead>
<tr>
<th>LOWER LIMIT</th>
<th>0.0</th>
<th>0.40000</th>
<th>0.50000</th>
<th>0.10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPPER LIMIT</td>
<td>0.10000</td>
<td>0.50000</td>
<td>0.08577</td>
<td>0.20000</td>
</tr>
</tbody>
</table>
Table B-1 (Contd.) Example of SETRED Program Output

SOLUTION NO. 3
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION

SOLUTION NO. 4
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION

SOLUTION NO. 5
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION

SOLUTION NO. 6
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION

SOLUTION NO. 7
LOWER LIMIT  0.0  0.40000  0.40000  0.00054  0.10000
UPPER LIMIT  0.09946  0.49933  0.49946  0.10000  0.19946

SOLUTION NO. 8
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION

SOLUTION NO. 9
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION

SOLUTION NO. 10
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION

SOLUTION NO. 11
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION

SOLUTION NO. 12
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION
Table B - 1 (Contd.)

Example of SETRED Program Output

ENTER OBJECTIVE NUMBER
2
ENTER LOWER LIMIT FOR INCARCERATION PROB.
.44
ENTER UPPER LIMIT FOR INCARCERATION PROB.

ENTER OBJECTIVE NUMBER
3
ENTER LOWER LIMIT FOR CASES FILED FRACT.
.44
ENTER UPPER LIMIT FOR CASES FILED FRACT.

ENTER OBJECTIVE NUMBER

<table>
<thead>
<tr>
<th>OFFENSES</th>
<th>INCARCER</th>
<th>CASES FI</th>
<th>NO TRIAL</th>
<th>VOCATION</th>
<th>DECREASED</th>
<th>ATION PROB.</th>
<th>LED FRACT.</th>
<th>FRAC. DEC.</th>
<th>AL SKILLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALUES INPUT SO FAR - AS USED IN THIS ITERATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOWER LIMIT</td>
<td>0.0</td>
<td>0.44000</td>
<td>0.44000</td>
<td>0.0</td>
<td>0.10000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPPER LIMIT</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SOLUTION NO. 1
AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED SOLUTION
DROPPED FROM FURTHER CONSIDERATION

SOLUTION NO. 2

| LOWER LIMIT | 0.0 | 0.44000 | 0.44000 | 0.0 | 0.10000 |
| UPPER LIMIT | 0.02000 | 0.46000 | 0.46000 | 0.01722 | 0.12000 |

SOLUTION NO. 7

| LOWER LIMIT | 0.0 | 0.44000 | 0.44000 | 0.00059 | 0.10000 |
| UPPER LIMIT | 0.01941 | 0.45939 | 0.45941 | 0.02000 | 0.11941 |
Table B - 1 (Contd.)

Example of SETRED Program Output

**ENTER OBJECTIVE NUMBER**

2

**ENTER LOWER LIMIT FOR INCARCERATION PROB.**

.4495

**ENTER UPPER LIMIT FOR INCARCERATION PROB.**

3

**ENTER LOWER LIMIT FOR CASES FILED FRACT.**

.45

**ENTER UPPER LIMIT FOR CASES FILED FRACT.**

**ENTER OBJECTIVE NUMBER**


<table>
<thead>
<tr>
<th>OFFENSES IN CAR CER A TION PROB.</th>
<th>CASES FI NED FRACT.</th>
<th>NO TRIAL</th>
<th>VOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECREASED</td>
<td>LED FRACT.</td>
<td>FRAC. DEC.</td>
<td>AL SKILLS</td>
</tr>
<tr>
<td>VALUES INPUT SO FAR - AS USED IN THIS ITERATION</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| LOWER LIMIT | 0.0 | 0.44950 | 0.45000 | 0.0 | 0.10000 |
| UPPER LIMIT | 1.00000 | 1.00000 | 1.00000 | 1.00000 | 1.00000 |

**SOLUTION NO. 2**

| LOWER LIMIT | 0.0 | 0.44950 | 0.45000 | 0.0 | 0.10000 |
| UPPER LIMIT | 0.00050 | 0.45000 | 0.45050 | 0.00050 | 0.10050 |

**SOLUTION NO. 7**

AT CURRENT LEVEL OF VALUE STRUCTURE, THIS CANNOT BE PREFERRED. SOLUTION DROPPED FROM FURTHER CONSIDERATION.
Table B - 2. Listing of SETRED Program

COMMON COLNAM(5,40), OBJNAM(5,8), NOV, NOC, NOB, ID(12),
1   V(12), X(8), NROW, ZTAB(40,48), ZRHS(40), IEQ(40),
2   SL(8), SH(8), SLI(8), SHI(8), SU1(48), ZRHS(40), IEQ(40),
3   CR(40), TAB(40,8), RHS(40), IEQ(40)
IUW = 10
IUR = 9
READ (IUR, 105) NOV, NOC, NOB
105 FORMAT (8I2)
NOBZ = NOB + 1
NOBM1 = NOB - 1
DO 120 I = 1, NOV
   115 FORMAT (5A4)
   120 CONTINUE
DO 130 I = 1, NOB
   130 CONTINUE
DO 160 I = 1, NOB
   160 SLI(I) = 0.
   160 CONTINUE
WRITE (6, 190)
190 FORMAT (/5X, 19H ENTER 0 FOR OBJ. # ,
   1   28HTO PROCESS WITH VALUES INPUT ,/IIX,
   2   33H TO TERMINATE THE RUN ,/IIX,
   3  41H FOR UPPER OR LOWER LIMITS FOR NO CHANGE ,///)
210 CONTINUE
WRITE (6, 211)
211 FORMAT (I1X, 22H ENTER OBJECTIVE NUMBER)
   214 FORMAT (11)
   214 IF ( I .EQ. 9) GO TO 655
   214 IF ( I .EQ. 0) GO TO 255
   214 IF ( I .GT. NOB .OR. I .LT. 2) GO TO 230
   216 FORMAT (I1X, 22H ENTER LOWER LIMIT FOR ,5A4)
   216 READ (5, 217) SLIR
   217 FORMAT (5I1)
   218 FORMAT (1X, 22H ENTER UPPER LIMIT FOR ,5A4)
   218 READ (5, 217) SHIR
220 IF (SHIR .NE. 0 .AND. SHIR .LT. SHI(I)) SHI(I) = SHIR
   220 CONTINUE
WRITE (6, 230)
230 FORMAT (6, 240) I
240 FORMAT (1X, 29H OBJECTIVE NUMBER IS INCORRECT ,18)
   240 CONTINUE
255 NSC = 0
   255 NSOL = 0
   255 WRITE (6, 256) ((OBJNAM(I, J), I = 1, NOB), J = 1, NOB)
   256 FORMAT (6, 257) ((OBJNAM(I, J), I = 3, 5), J = 1, NOB)
   257 FORMAT (6, 258) ((TAB(I, J), I = 1, NOB), J = 1, NOB)
   258 CONTINUE
WRITE (6, 259) (SHI(I), I = 1, NOB)
   259 CONTINUE
WRITE (6, 260)
260 NSOL = NSOL + 1
   260 IF (IUR .NE. 9) GO TO 267
   260 READ (IUR, 105) (ID(I), I = 1, NOC)
   260 IF (ID(1) .EQ. 99 .AND. ID(2) .EQ. 99) GO TO 605
   260 READ (IUR, 265) (V(I), I = 1, NOC)
   265 FORMAT (8E15.8)
   265 READ (IUR, 265) (X(I), I = 1, NOBZ)
   265 CONTINUE
   267 READ (IUR, 270) NSOL
   270 CONTINUE
READ (IUR, 105) NROW
   275 CONTINUE
READ (IUR, 105) NROW
   275 IF (NSOL .EQ. 99 .AND. NROW .EQ. 99) GO TO 605
   275 IF (NSOL .EQ. 99 .AND. NROW .EQ. 99) GO TO 605
   275 DO 280 I = 1, NROW
   275 READ (IUR, 265) (ZTAB(I, J), J = 1, NOBM1), ZRHS(I)
   275 DO 277 J = 1, NOBM1
   277 TAB(I, J) = ZTAB(I, J)
   277 RHS(I) = ZRHS(I)
   277 READ (IUR, 105) IZE(I)
   277 IEQ(I) = IZE(I)
   277 CONTINUE
   280 CONTINUE
IF (IUR .NE. 9) GO TO 290
   290 CONTINUE
READ (IUR, 265) (SL1(I), SH1(I), I = 1, NOBM1)
   290 CONTINUE
WRITE (6, 295) NSOL
   295 FORMAT (5X, 12H SOLUTION NO., 14)
   295 NVAR = NOBM1
   295 DO 315 I = 1, NOBM1
   295 IF (I .EQ. 1) IPI = 1 + 1
   295 IF (I .EQ. 1) SUI(I) = SH1(IPI) - SL1(IPI)
Table B - 2 (Contd.). Listing of SETRED Program

<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>IF (SL(I) .EQ. 0.) GO TO 315</td>
</tr>
<tr>
<td>310</td>
<td>ZRHS(J) = ZRHS(J) - SL(I) * ZTAB(J,I)</td>
</tr>
<tr>
<td>315</td>
<td>CONTINUE</td>
</tr>
<tr>
<td>320</td>
<td>ZTAB(J,I) = -ZTAB(J,I)</td>
</tr>
<tr>
<td>325</td>
<td>IZE(I) = 2</td>
</tr>
<tr>
<td>330</td>
<td>IZE(I) = 0</td>
</tr>
<tr>
<td>335</td>
<td>IF (IZE(I) .EQ. 1) GO TO 350</td>
</tr>
<tr>
<td>340</td>
<td>ZTAB(J,NVAR) = 0.</td>
</tr>
<tr>
<td>345</td>
<td>CALL BPHAS(ZTAB,40,ZRHS,NROW,NVAR,IZE,IE,SUI,IFLAG)</td>
</tr>
<tr>
<td>350</td>
<td>CONTINUE</td>
</tr>
<tr>
<td>370</td>
<td>CO(I) = 0.</td>
</tr>
<tr>
<td>405</td>
<td>AMIN = 999999.</td>
</tr>
<tr>
<td>410</td>
<td>SUM = SUM + ZTAB(I,J) * CO(I)</td>
</tr>
<tr>
<td>415</td>
<td>CONTINUE</td>
</tr>
</tbody>
</table>

The code snippet is a listing of the SETRED program, which appears to be for solving linear equations. The code involves operations such as initializing variables, handling conditions, and calling subroutines to perform operations like solving systems of equations. The listing includes detailed logic for manipulating arrays and variables to achieve the desired mathematical operations.
OBJ = OBJ + SH(IPI)
I = I - 1
GO TO 477
480 CONTINUE
SL(1) = 1. - OBJ
IF (SL(1) .LT. 0.) SL(1) = 0.
SH(I) = 1. - SUM
WRITE (6,485) (SL(I),I=1,NOB)
485 FORMAT(IX,11HL0WER LIMIT,7(5X,F7.5))
WRITE (6,490) (SH(I),I=1,NOB)
490 FORMAT(1X,11HUPPER LIMIT,7(5X,F7.5))
NSC = NSC + 1
GO TO 555
505 WRITE (6,510)
510 FORMAT(1X,36HAT CURRENT LEVEL OF VALUE STRUCTURE,,
1 IX,34HTHIS CANNOT BE PREFERRED SOLUTION,,,
2 IX,34HDROPPED FROM FURTHER CONSIDERATION )
555 GO TO 260
605 J = 99
WRITE (IUW,270) J
WRITE (IUW,105) J
IF (NSC .EQ. 0) GO TO 655
IF (IUR .EQ. 9) GOTO 615
REWIND IUR
615 REWIND IUW
IUR = IUW
IUW = IUW + 1
IF (IUW .GT. 11) IUW = 10
WRITE (6,640)
640 FORMAT(/,1X)
GO TO 210
STOP
END
SUBROUTINE BPHAS1(STAB,NTD,RHS,NRP1,IB,IE,ISE,IB,
1  IE,SUI,IFLAG)
-------
IFLAG = 0 FEASIBLE SOLUTION EXISTS
1 NO FEASIBLE SOLUTION
2 UNBOUNDED OBJECTIVE

DIMENSION STAB(NTD,NCOL),RHS(NROW),ISE(NROW)
DIMENSION IE(NC0L),IB(NROW),SUI(NCOL)
NRP1 = NROW + 1
IFLAG = 0
NVAR = NCOL
DO 105 I = 1,NCOL
105 STAB(NRP1,I) = 0.
RHS(NRP1) = 0.
DO 195 I = 1,NROW
IF (ISE(I) .EQ. 0) GO TO 195
NVAR = NVAR + 1
DO 180 J = 1,NCOL
180 STAB(NRP1,J) = STAB(NRP1,I) - STAB(I,J)
RHS(NRP1) = RHS(NRP1) - RHS(I)
DO 190 J = 1,NCOL
190 STAB(J,NVAR) = 0.
SUI(1,NVAR) = 1.
IE(NVAR) = 0.
IB(I) = NVAR
195 CONTINUE
IF (NVAR .EQ. NCOL) GO TO 990
205 CONTINUE
RMIN = 99999.
ICOL = 0.
DO 210 J = 1,NCOL
IF (STAB(NRP1,J) .GE. RMIN) GO TO 210
RMIN = STAB(NRP1,J)
ICOL = J
220 CONTINUE
IF (ICOL .EQ. 0 .OR. STAB(NRP1,ICOL) .LT. -0.1E-5) GO TO 255
CALL BSELR(STAB(1,ICOL),RHS,NROW,SUI,IB,ICOL,IFLAG)
IF (IROW .EQ. 0 .AND. IFLG .NE. 1) GO TO 910
CALL BPIV0T(STAB,NTD,RHS,NVAR,NRP1,IB,IE,SUI,
1  IROW,ICOL,IFLAG)
GO TO 205
255 IF (ABS(RHS(NRP1)) .LT. 0.1E-5) GO TO 990
905 IFLAG = 1
RETURN
910 IFLAG = 2
WRITE (6,915)
915 FORMAT(/,1X)
20HUNBOUNDED OBJECTIVE ,//)
990 RETURN
Table B - 2 (Contd.). Listing of SETRED Program

SUBROUTINE BPIVOT(STAB, NTD, RHS, NVAR, NC, IB, IE, SUI, IROW, ICOL, IFLAG)

THIS SUBROUTINE UPDATES THE TABLEAU BASED ON FLAG SET BY BSELR FOR BOUNDED SIMPLEX

DIMENSION STAB(NTD, NVAR), RHS(NTD), IB(NTD), IE(NVAR)
DIMENSION SUI(NVAR)

IF (IFLG - 2) 205, 305, 405

205 IE(ICOL) = - IE(ICOL)

TU = SUI(ICOL)
DO 220 I = 1, NC
RHS(I) = RHS(I) - TU * STAB(I, ICOL)
IF (ABS(RHS(I)) .LT. 0.1E-4) RHS(I) = 0.
STAB(I, ICOL) = - STAB(I, ICOL)
220 CONTINUE
RETURN

305 CONTINUE
CALL PIVOT(STAB, NTD, RHS, NVAR, NC, IROW, ICOL)
IB(IROW) = ICOL
RETURN

405 CONTINUE
I = IB(IROW)
RHS(IROW) = RHS(IROW) - SUI(I)
IF (ABS(RHS(IROW)) .LT. 0.1E-4) RHS(IROW) = 0.
STAB(IROW, I) = -STAB(IROW, I)
IE(I) = -IE(I)
GO TO 305
END

SUBROUTINE BSELR(TABCOL, RHS, NOC, SUI, IB, ICOL, IROW, IFLAG)

THIS SUBROUTINE SELECTS THE ROW FOR PIVOTTING AND SETS THE FLAG FOR NEXT OPERATION TO BE PERFORMED FOR BOUNDED SIMPLEX

DIMENSION TABCOL(NOC), RHS(NOC), IB(NOC), SUI(NOC)
IROW = 0

AMIN2 = 999999.
AMIN3 = AMIN2
IRON2 = 0
IRON3 = 0
DO 150 I = 1, NOC
IF (ABS(TABCOL(I)) .LT. 0.1E-4) GO TO 150
IF (ABS(TABCOL(I)) .LT. 0.1E-4) GO TO 150
IF (TABCOL(I)) 115, 135, 145
115 II = IB(I)
IF (SUI(II) .EQ. 0.) GO TO 150
IF (ABS(RATIO-AMIN2) .LT. 0.1E-4) GO TO 120
IF (RATIO - AMIN2) 125, 120, 150
120 IF (IB(I) .GT. IB(IROW3)) GO TO 150
125 AMIN2 = RATIO
IRON2 = I
GO TO 150
135 RATIO = RHS(I)/TABCOL(I)
IF (ABS(RATIO-AMIN2) .LT. 0.1E-4) GO TO 140
IF (RATIO - AMIN2) 145, 140, 150
140 IF (IB(I) .LT. IB(IROW2)) GO TO 150
145 AMIN2 = RATIO
IRON2 = I
150 CONTINUE
IFLAG = 1
155 IF (AMIN2 .GT. AMIN3) GO TO 170
160 IFLAG = 2
IRON = IROW2
GO TO 190
170 IFLAG = 3
IRON = IROW3
190 RETURN
END

SUBROUTINE PIVOT(TAB, NTD, V, NV, NC, IROW, ICOL)

THIS SUBROUTINE TRANSFORMS THE TABLEAUS
Table B - 2 (Contd.). Listing of SETRED Program

```
C AND ENTERS THE ICOL ELEMENT IN PLACE OF
C THE IROW ELEMENT IN THE BASIS
DIMENSION TAB(NTD,NV), V(NC)
DI = TAB(IROW,ICOL)
DO 10 I=1,NV
10 TAB(IROW,I)=TAB(IROW,I)/DI
   V(IROW)=V(IROW)/DI
   DO 30 J=1,NC
      IF (I.EQ.IROW) GO TO 30
      DI = TAB(I,ICOL)
      V(I)=V(I)-V(IROW)*DI
      IF (ABS(V(I)) .LT. 0.1E-5) V(I)=0.
   DO 25 J=1,NC
      TEMP = TAB(I,J) - DI * TAB(IROW,J)
      IF (J .EQ. ICOL) TEMP = 0.
      IF (ABS(TEMP) .LT. 0.1E-4) TEMP = 0.
      TAB(I,J) = TEMP
   25 CONTINUE
30 CONTINUE
RETURN
END
```
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