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Hossein, Mohamad Seyed

THE MATHEMATICAL MACROSCOPIC OPTIMIZATION PROCEDURES FOR TRANSPORTATION SAFETY RESOURCE ALLOCATION IN LOCAL URBAN JURISDICTIONS

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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

# THE MATHEMATICAL MACROSCOPIC OPTIMIZATION PROCEDURES FOR TRANSPORTATION SAFETY RESOURCE ALLOCATION IN LOCAL URBAN JURISDICTIONS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

MOHAMAD SEYED HOSSEIN

NORMAN, OKLAHOMA

1982

THE MATHEMATICAL MACROSCOPIC OPTIMIZATION PROCEDURES FOR TRANSPORTATION SAFETY RESOURCE ALLOCATION IN LOCAL URBAN JURISDICTIONS

APPROVED BY:

Leonard B. West (Chairman)

Allen R. Cook

Robert A. Shapiro

Robert L. Lehr

Vadi Veloo

## ABSTRACT


With decreasing growth in revenues, and increasing competition for scarce funds, there is an urgent need to carefully access safety project priorities and improve local traffic program management. This dissertation is a response to this important issue.

Two mathematical programming models, named the Feasibility Assessment Technique and the Optimality Assessment procedure, are developed in this dissertation to select, analyze and allocate safety countermeasures that result in saving more human lives and to insure that the capital funds are used effectively.

The Optimality Assessment Technique develops a goal programming model to the multi-objective decision problem of highway funds safety allocation The model allows the decision maker to review critically the priority structure for goals in view of a solution derived by the model. In addition, the proposed procedure includes a variety of computer programming to aid the local, state and federal government decision makers in analyzing and allocating financial resources for traffic safety improvement programs.

Utilization of the proposed methodology is recommended to state and local decision makers and is necessary not only because substantial sums of money are involved in safety improvement programs, but also, and more importantly, because lives might be lost if highly effective countermeasures are underestimated as the result of the subjective judgment commonly used in local urban traffic agencies.

## ACKNOWLEDGEMENTS

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J. F. Caraway Chief, Design Bureau and lastly C. E. Alexander from the Alabama Highway Department. Mr. Alexander contributed extensive data for model calibration. Gratitude is expressed to the Department of Transportation and especially to Mr. Mueller for his assistance during the early stages of the research, especially with the literature review and preparation of the research proposal. My sincere appreciation is also extended to Mrs. Nancy Johnson for her excellent editorial work.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# THE MATHEMATICAL MACROSCOPIC OPTIMIZATION PROCEDURE FOR TRANSPORTATION SAFETY RESOURCE ALLOCATION IN LOCAL URBAN JURISDICTIONS

## CHAPTER I

## INTRODUCTION AND NEED STUDY

Background of the study:

Today's transportation officials have exhibited considerable concern for the loss of life and the injuries associated with transportation accidents. With the enactment of congressional legislation in 1966, the problem of highway safety was officially acknowledged as serious on a nationwide basis (4). Vigorous programs were initiated by the Federal and State governments and the private sector alike to define and to better understand transportation safety problems.

National highway accident statistics indicate that the annual number and rate of traffic accident deaths has declined to its lowest levels since mid 60's. This, together with the fact that annual vehicle miles of travel have generally increased throughout the same period, indicates that positive gains are being achieved from recent highway safety efforts.

To create a hazard-free environment, especially in the highway system, Federal Highway Administration (FHWA) has developed a collection of highway-safety programs that consists of a full range of projects and types of improvements for various countermeasures (115). On an aggregate basis, these projects have definitely affected the number and severity of traffic accidents. However, the extent to which improvement and programs have been effective, and the application of the required system used in local areas have not been fully investigated and documented.

In response to the FHWA, nearly all states have developed and implemented special processes to analyze, select and prioritize safety improvement projects. In this regard, in 1976 about 60 percent of the states can correlate highway inventory data with accident data for state highways and an additional 30 percent of the states are developing this capability. Only half the states have this correlation capability on local roads (114). This can be attributed to the lack of interest, inadequate funds, appropriate procedures, suitable and convenience methodology in which to aid the local transportation agencies to identify, analyze, implement, and more importantly, represent the needs of the community for safety programs with a quantitative figures to convince the state authority to receive safety funds.

Currently, most traffic safety programs that have been designed are too complex, too advanced, and obviously too costly and time consuming to be implemented in such limited financial areas. Such programs need a great deal of input data, several experts, and require high expenditures which are not practical nor efficient enough to be used . One of the main objectives of this research study is to propose a feasible methodology which will be practical and efficient in allocating the limited resources for improving potential traffic-accident areas and that enables the local government or state to quantify and estimate the real needs for improving traffic safety in their jurisdictions. The methodology will help them to analyze and estimate a set of basic needs in which would be used as a yardstick for allocating the safety resources by higher level decision-makers.

## (1-1) NEED STUDY

With decreasing growth in revenues, and increasing competition for scarce funds there is an urgent need to carefully assess project priorities and improve the local traffic program management.

A desirable technique is one that , (1) is responsive to the major policy issues, (2) is capable of handling multiple objectives and community goals, (3) is inexpensive and simple, (4) has minimal data requirement, (5) can be applied efficiently as a manual technique for allocating the safety resources in small-system planning but, if need be, can be computerized to simplify complex processes for repetitive or larger-system application.

In order to focus special attention on critical traffic safety needs, the Federal Highway Administrator annually develops a list of program emphasis areas. For example, the following emphasis areas were included in highway and urban safety for fiscal year 1978 (115):

> Encourage the improvement of state highway safety program management and increased program activities in the following areas: (1) complete processes to establish priorities and evaluate program effectiveness, (2) accelerate installation of appropriate warning devices at all railroad crossings, and (3) establish method for ensuring the safety of motorists driving through construction and maintenance zones.

The following summarizes accomplishments toward meeting the emphasis area objectives in establishing priorities and evaluation effectiveness procedures by the states and local authorities in the United States (116).

> Nearly all states have developed and implemented special processes to analyze, select and prioritize safety improvement projects in accordance with FHWA regulations. About 60 percent of the States can correlate highway inventory data with accident data for state highways and an additional 30 percent of the states are developing this

> capability. On local roads only half the states have this correlation capability. States with significant accomplishments in this area include Alabama, California, Florida, Michigan, and Texas.

Considering the above facts, local urban areas always suffer from a lack of practical procedures to use for the establishment of project priorities and traffic resource allocation.

An effective methodology for traffic accident improvement is needed not only because substantial sums of money are involved, but also, and more importantly, because lives might be lost if highly effective countermeasures are underestimated while relatively less effective countermeasures receive substantial support.

Thus, the principal product of this research will be the development of a cost/effectiveness procedure that is applicable to the analysis of the activities collectively referred to as "resource allocation for traffic safety improvement programs". The proposed methodology should be suitable for management use at all levels federal and state Agency Administrator especially for use at the level of local decision maker(s).

In summary, the primary goal of this research study is to fulfill the needs for an applicable and effective procedure for allocating local resources to reduce traffic accidents, a vital and important issue of public interest as well as of interest to local and state government.

## (1-2) LOCAL JURISDICTION CHARACTERISTICS

As mentioned, the proposed methodology can be used by any level of government authority (local, state, and federal) to formulate safety needs for their jurisdictions based on the proposed optimal safety projects and safety program according to the recommended procedure. However, because of the complexity of the higher level decision-making (usually, federal government) in allocating safety funds, and the methodology for further verification, the proposed methodology is recommended as an alternative to be considered by the federal government in allocating safety resources. But in a lower level of decision-making, the procedure is capable of being used by the local jurisdiction as well as the states as an effective tool for their safety improvement programs. Various steps have been recognized and fully described in this dissertation to aid local governments who wants to start to build a safety system regardless of the size and government structures.

### (1-2.1) TRANSPORTATION SAFETY SYSTEM IN SMALL URBAN JURISDICTION

A Quick Review:

Usually there are significant differences exist among the jurisdictions (under 50,000 population). These differences are attributed to government structure, social values, economical and political disadvantages. Because of this, it is very hard to systematic plan for their traffic safety programs. However, planners should be aware of these differences when they propose general planning tools for transportation systems. Here, an attempt is made to demonstrate some of these differences, especially when a traffic safety program has to be implemented in a small jurisdiction.

Formal traffic improvement programs are generally utilized in municipalities and urbanized counties over 50,000 population, but smaller communities (which account for about 85 percent of the total number of local governments in the United States) have been ignored or under estimated, since they do not have formal procedures for implementing any traffic safety programs. Implementing any traffic safety program requires a certain process and procedure which a local agency should follow, for example, how should the project be financed?, how should human and technological resources be developed?, how should the project be implemented?, who is in charge of its maintenance and future expenses?, what kind of external and internal funds should be provided?, and many other parameters which the decision maker should seek in order to implement a certain program.

The following paragraph addresses the first question: what possible funding resources exist for small jurisdictions?.

Local governments usually obtain highway revenue from two basic sources as follows:

(1) Locally raised revenues,

(2) Grant-in-aid from state and federal government.

A 1979 survey indicates that locally raised revenue (both urban and rural) totaled $ 8.4 billion or about 23 percent of all highway revenue generated by all units of government (47). Comparing this figure with local revenue in 1970, which was about 18 percent of total revenue then, it can be concluded that local revenue has grown faster than the federal and state sources. The reason is that local government relies less on road-user tax revenue than do the states or the federal government and it is less subjected to the uncertainty due to energy crises and more importantly, inflation. The major part of the local revenue is from property taxes and usually, property tax keeps pace with inflation. Statistics show that in 1979, the local governments obtained only 8 percent of tax revenue directly from users.

## (1-2.2) SOURCE OF FUNDING IN LOCAL URBAN JURISDICTION (INTERNAL)

Source of funding for local traffic safety improvement generally include: Federal 401,402 and 403 funds, automobile associations, service clubs, and fund from the local jurisdictions themselves (46). Local funds may be raised through special assessment and utility districts, such as those taxes paid to a municipality for street lighting, parking, and street improvement (47).

An interesting point is that even when funds may be available for programs intended to improve traffic safety from sources external to the small jurisdictions, there may a hesitancy in accepting such a fund. A 1979 American Public Works Association (APWA) survey questionnaire indicated a very negative attitude by many local transportation agencies in accepting such funds. They rejected such temporary assistance, realizing that the program probably will not be continued and would be without further secured funds (49). Thus, even though such funds can be used to support the salary of a traffic engineer, the grant is usually available only for a specific period of time, so many small jurisdictions feel that without that support they will not be able to maintain such a program. Some communities also doubt their ability to use their own funds to continue to maintain a traffic safety program that initially resulted from the utilization of outside funding. Sometimes, when a community receives a federal grant assistance, it may not have enough of its own funds to implement the recommended traffic improvement.

States also play a significant role in allocating the resources in small urban areas, and enforcing priorities for available external funding. The following example should clarify such a state's influence on resource allocation in the small urban areas. The basic formulation for the traffic safety funds usually is changed according to the state's interest. For example, rather than promote and exercise the traffic safety planning proposed by the local jurisdiction, it may assign higher priorities to other programs or countermeasures considering the national interest instead of the community safety needs. Thus, emphasis on providing traffic safety improvement in a local community is significantly affected by state-established priorities.

The role of state government assistance to local government also is considered here as a significant difference which exists in small areas. Governmental assistance to the local government is generally administered directly through state agencies, such as State Highway agencies, or the Departments of Transportation, and the Office of Governor's safety representative. So, the personal effectiveness of the agency's representative has a direct effect on the success of state-administered traffic safety programs. Thus, regardless of what the policy or legal guidelines may be concerning official contacts, the success of the operation is a direct function of the people who implement the program (47, p. 38).

Sharing technologies, experts, and costs of traffic safety programs with other neighbors can be considered as a sound alternative for the small jurisdictions. Unfortunately, however, as the 1979 survey indicated, there may be a hesitancy for a small urban area to share those expenses with either a neighboring community or with any other related agency. This again may be based on traditions or experiences which have not proved fruitful. Although it could be technically feasible to share traffic engineering resources such as manpower, administration, or experts on either a regional, county, or multijurisdictional basis, it is infrequently done (47, p. 35).

The other important main difficulty in implementing any traffic safety program in small urban areas is a lack of manpower and resources. The question of providing or implementing any safety program involves the funding necessary for the technical staff , capital, research, and its logistical support. Again, as the APWA survey indicated, most communities which have undertaken any type of traffic safety program have done so with the 402 funding, leaving unanswered the problem as to what will be done with the staff and maintenance costs on termination of the federal grant. Funding support available only during the specific period of time leaves the local jurisdiction with a huge problem afterward. In some cases the local government could exercise one of two options as follows :

(a) Terminate the program at the end of the period, or

(b) Continue the program with 100 percent local funding.

These two options, or the combination of the two, generate a great complexity for the decision maker(s) which should compromise the uncertainty of the situation with the logical needs of the community.

The decision-making process in a small urban area is a very complex and difficult task. The decision maker is limited by so many constraints. He/she has to sometimes ignore many "good and feasible" solutions because they may be "too-good", or "too advanced", or too complicated for immediate or short-term application. For example, this might include the use of computers for inventories, comprehensive origin-destination studies, major geometric street improvements, and related technologies. In conclusion the approach considered in this thesis is in a "macro-level". It is beyond the scope of this dissertation to investigate the characteristic of the small urban jurisdictions, but a warning is given if the planner intends to develop a safety program: he/she should aware of these differences.

## (1-3) UNCERTAINTY AND SAFETY PROGRAMS

It must be conceded that there are always uncertainties in every transportation analysis, or other related systems which are dealing with the social and real world parameters. Uncertainties in safety planning programs which are considered in this thesis can be classified as follows :

(1) NEEDS
(2) TECHNOLOGY
(3) GOALS AND OBJECTIVES

No matter how elaborate a needs model can be , or how accurately the data can support the model, there will always be an uncertainty about our predictions of future needs for transportation safety or other related modeling approaches. It is very hard to understand the internal dynamics of social and economic systems which are simulated in the modeling approaches.

In addition to the uncertainty about the safety problems related to future needs is the uncertainty about technology; not only about the life or technique used in the systems, but about the different safety devices which will be available a few years from now.

The community's goals and objectives are also uncertain. For example, in designing a safety device or planning a safety program, a decision should always be made with regard to someone's point of view. But, whose point of view? An individual's or a group's?, do they fully express the real objectives? In fact attempts always are made to identify the real goals and objectives, but inevitably, the goals are uncertain.

## (1-4) SAFETY OBJECTIVES

The main purpose of this research is to consider the safety objectives as a backbone of all computational analysis. Safety objectives can be defined as follows:

(a) Reduction of traffic and highway accidents,

(b) Reduction of injuries resulting from traffic accidents,

(c) Reduction of deaths due to traffic accidents,

(d) Reduction of property losses due to traffic accidents.

These main objectives are considered as dependent variables in all computational aspect of this thesis.

## (1-5) PROBLEM STATEMENT AND OVERALL OBJECTIVES AND TASKS

Eight objectives and tasks have been established in this thesis as follows :

(1) Develop a procedure that can be used to model the influence of different countermeasures on accident reduction, and thereby estimate the effectiveness and cost of each countermeasure.

(2) Design a program structure that displays alternative countermeasures for each hazardous location with cost, benefit, and effectiveness.

(3) Develop a model to allocate the local resources for traffic improvement so that a set of local, and state objectives are to be satisfied.

(4) Calibrate and evaluate the model under different budgets in a limited manner to ensure that when the program is implemented, it will be functional.

(5) Demonstrate the effectiveness of the methodology in the analysis of typical problems and its ability to provide desirable output.

(6) Introduce a new optimization technique and demonstrate its application in traffic safety programs.

(7) Develop a procedural manual and appropriate computer program.

(8) Conduct a sensitivity analysis for evaluating the effect of factors, such as different budgets or resources, objectives and goals, rates of return, policy issues, etc.

## (1-6) MACRO APPROACH TO DEVELOP A PROCEDURE FOR A TRAFFIC SAFETY RESOURCE ALLOCATION PROGRAM IN URBAN AREAS

The problem of urban accidents is a multi-dimensional one involving a system comprised of man, machine and environment as well as the complex interrelationships that are possible between these variables. It is obvious that there can be no single solution. Indeed, suggested improvements have been numerous such as report forms, accident investigation, specific data needs, data use, methodologies and modifications in system operations.

Planning and analysis for urban safety projects have been approached in a variety of ways by state transportation agencies. These approaches have shortcomings in the areas of quantitative precision, speed in turnaround, level of detail and applicability to small and poor areas. However, this thesis represents a mathematical procedure which a decision maker may choose in order to present his goals and objectives and other considerations. State-of-the-art in transportation safety economic analysis usually suffers from the lack of a powerful mechanism that can translate theory into practices which can be understood by a city manager for decision making in allocating resources for traffic improvement projects. This methodology enables the local decision maker(s) to determine how much improvements can be accomplished with the available resources.

In some statewide planning procedures a group of high-ranking professional and political officials meet an annually to allocate highway safety funds based upon an intuitive, factual, or limited definition of need, geographical distribution, political influence and many other subjective judgments. An alternative to this largely judgmental approach is sufficiency, or adequacy rating where existing transportation facilities are scored based on some measurable factors. Both of the above processes can not be implemented in a small local jurisdiction, since most of the small cities suffer from a lack of manpower and money.

The optimization procedure presented here is a "macro-approach". Safety analysis is a very complex problem, but under several logical assumptions with the help of this technique this complexity can be relieved or improved.

A powerful operation research methodology has been selected and developed to model this complex problem. Two step mathematical programming enables the decision maker to use either or both steps depending on the complexity, scale and structural components of the transportation agency, safety problem and the scale of the investigation. The first step is recommended for small urban jurisdictions and the second step can be used by either local or state government. In the second step, the concept of optimization technique is used with the new technique of multiple objective which is developed for traffic safety resource allocation. The capability of the proposed model in solving the problems having multiple objectives can be represented by the following examples:

(a) Allocate limited resources, budget constraints,

(b) Minimize the accident severity by types (fatal, nonfatal and total accidents),

(c) Maintain the "national critical accident rate" for each location under study,

(d) Allocate the specific percentage of available resources for any specific improvement. For example, allocate 45 percent of total resources for intersection safety improvement projects,

(e) Impose the local and state's priorities.

As mentioned, the model is offered as a new approach in safety programming especially for allocation of limited resources by local, state, or federal governments. A dual capability of the proposed procedure in quantifying the basic safety needs of a local community or state would permit the higher level of decision maker to optimize the allocation of safety resources.

The accuracy and reliability of the proposed model is dependent upon the accuracy of the input data. Usually in-depth field investigations are needed to provide systematic identification procedures; however a sound and effective system for investigation requires a significant amount of investment which most small-cities are not willing to allocate. A powerful model covers this deficiency by estimating the required data. Efforts also have been made to estimate the effectiveness of many safety countermeasures with the help of available and sound literatures. In this regard, significant quantities of data have been gathered from more than 120 studies which have been done around the United States and European countries. The only local data needed is related to the identification of high-hazard locations. This historical data may indicate common accidents at particular locations. This should be obtained through local police accident records, or state and local transportation agencies. Nevertheless, the judgment of the experienced safety analyst is the most important ingredient in hazard and countermeasures identification.

## (1-7) TECHNIQUES DESCRIPTION

Two mathematical techniques have been used in this dissertation as follows:

(1) Feasibility Assessment Technique,

(2) Optimality Assessment Technique.

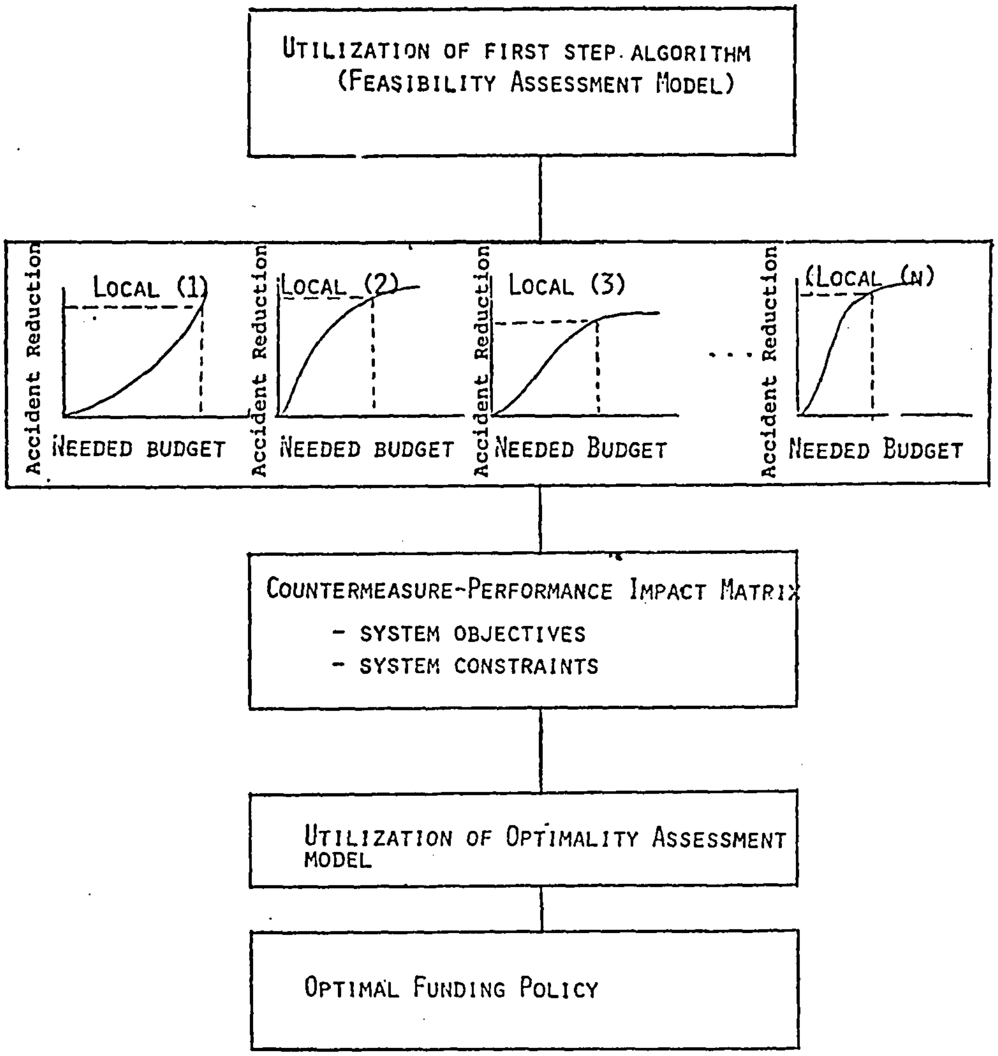
Feasibility Assessment Technique is developed in this dissertation to investigate the best possible (near optimal) solution for selecting the safety projects. This algorithm has been calibrated with the data received from the Alabama Department of Transportation and the results are demonstrated in Chapter Five. It is found that this procedure is powerful enough to be used in local or state level and can be comparable with the Dynamic Programming Technique. Feasibility Assessment Module (FAM) primarily has been designed as an independently operating module. Hence it can be applied whenever budget allocation is required and the necessary data are available.

Virtually all the optimization models developed for transportation problems have focused upon the optimization of a single objective criteria, namely, the minimization of total transportation costs, accident, delay, pollution, and etc. They have generally neglected or often ignored the multiple conflicting objectives involved in the problem especially in the public projects. The priority structure of these objectives, i.e., various environmental constraints, unique organizational values of the transportation agency, and bureaucratic decision structures have been underestimated. However, in reality these are important factors which greatly influence the decision process of transportation safety problems. In this dissertation the multi-objective goal programming approach is utilized and presented for use by different levels of decision-making (local, state, federal) to allow for the optimization of multiple conflicting goals while permitting an explicit consideration of the existing decision environment. Figure (1-1) demonstrates how these two mathematical models communicate in order to create a systematic evaluation procedure in highway safety resource allocation (bottom-up planning concept).

## (1-8) PRIORITIES AND DECISION MAKING PROCESS

Because all safety program and safety countermeasures are not equally important, highway safety development, particularly as it is influenced by fund distribution,

FIGURE (1-1) TWO-SYSTEM MODEL COMMUNICATION



depends upon choice among alternatives. These choices can involve legislators, administrators, engineers, planners, economists, and tax authorities. Generally the final decision is made by a legislative body. This is the result of negotiations used to achieve a compromise between the diverse and interrelated elements that shape highway safety program development. These negotiations are both necessary and desirable in all levels of decision-making process. But this appears to be more complex in higher levels of decision-making process less complex at the state level and more simple and less sophisticated at the local level. For this compromise to be achieved on a realistic and logical basis, the first step should be to set goals and objectives identified in all levels of decision-making (i.e., local, state, and federal), and the priorities for fund allocation usually should be assigned by the higher level decision making, i.e., states for local governments, and federal for the states government with respect to the mutually and common interests. This should be the process in which the proposed methodology can be operational.

It is noteworthy that the approach to planning and programming of each state or local government is unique. This has been given special attention in this dissertation. The main factors which contribute to this uniqueness are (1) a given set of objectives, (2) the priority structure of these objectives, (3) various environmental constraints, (4) unique organizational values of the agency, (5) bureaucratic structure in each region. The proposed methodology provides different independent modules to be used by different locals or states, when they may use partly their own approach to safety analyses and they may also use one of the independent optimization modules proposed in this thesis in their selected methodology. So, regardless of the type of selected accident or safety analysis methods, the independent modules can be easily utilized in any procedure as soon as the benefit (return) and cost of the different alternatives are available.

With regard to the above statement, the overall objectives of this dissertation are to:

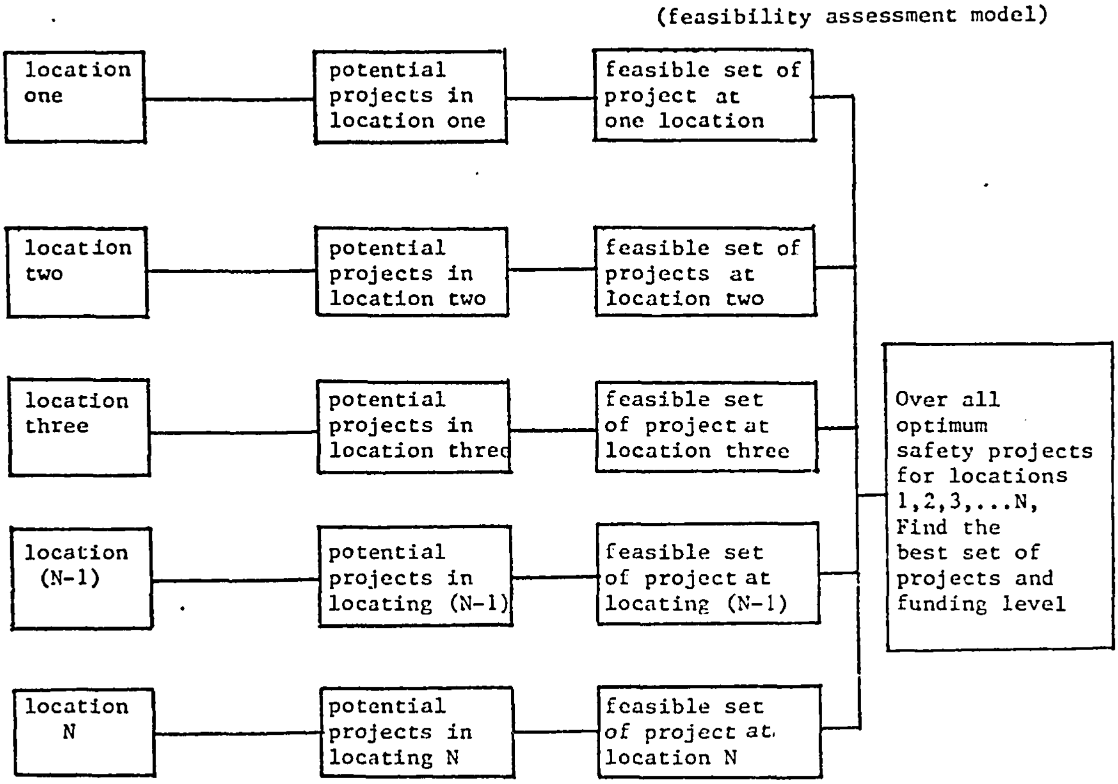
(1) Provide a framework for a systematic cost-effectiveness analysis of traffic safety projects in a local jurisdiction,

(2) Provide decision-makers (local, state, and federal) with a rational tool for allocating limited resources to traffic safety programs,

(3) Introduce the new multi-objective modeling approach in highway safety allocation assessment which can be used in all levels of government to allocate funds based on the cost-effectiveness of each safety program (countermeasure), but with more emphasis on local jurisdictions.

Figures 1-2, 1-3, and 1-4 demonstrate the types of mechanism that the procedure is demonstrating in allocating the safety resources for different levels of decision-making (local, state, and federal).

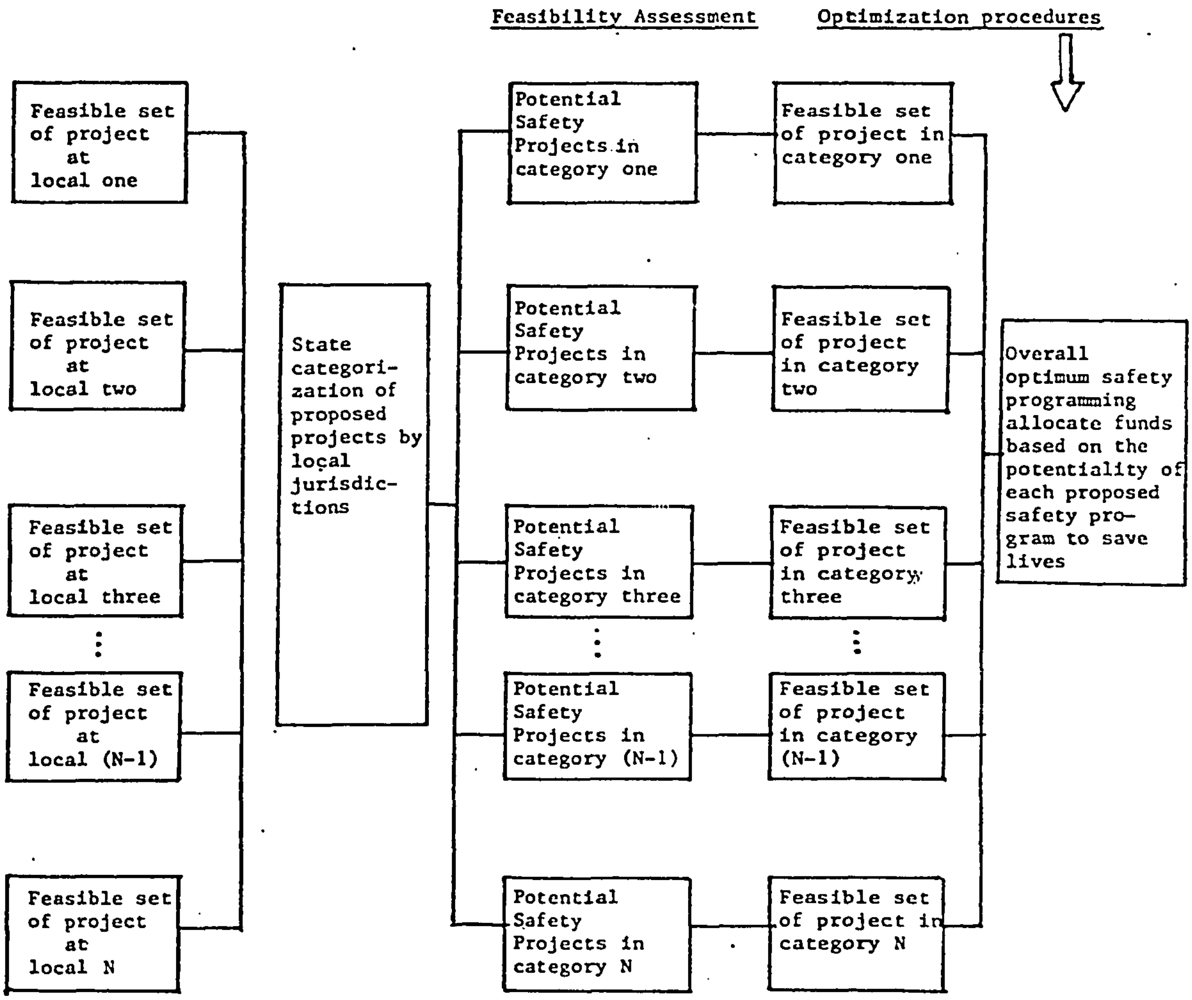
Proposed Macro Approach For
Safety Resource Allocation
(Local Level)*




* Apportionment of local government safety funds among different traffic safety projects.

FIGURE (1-2).

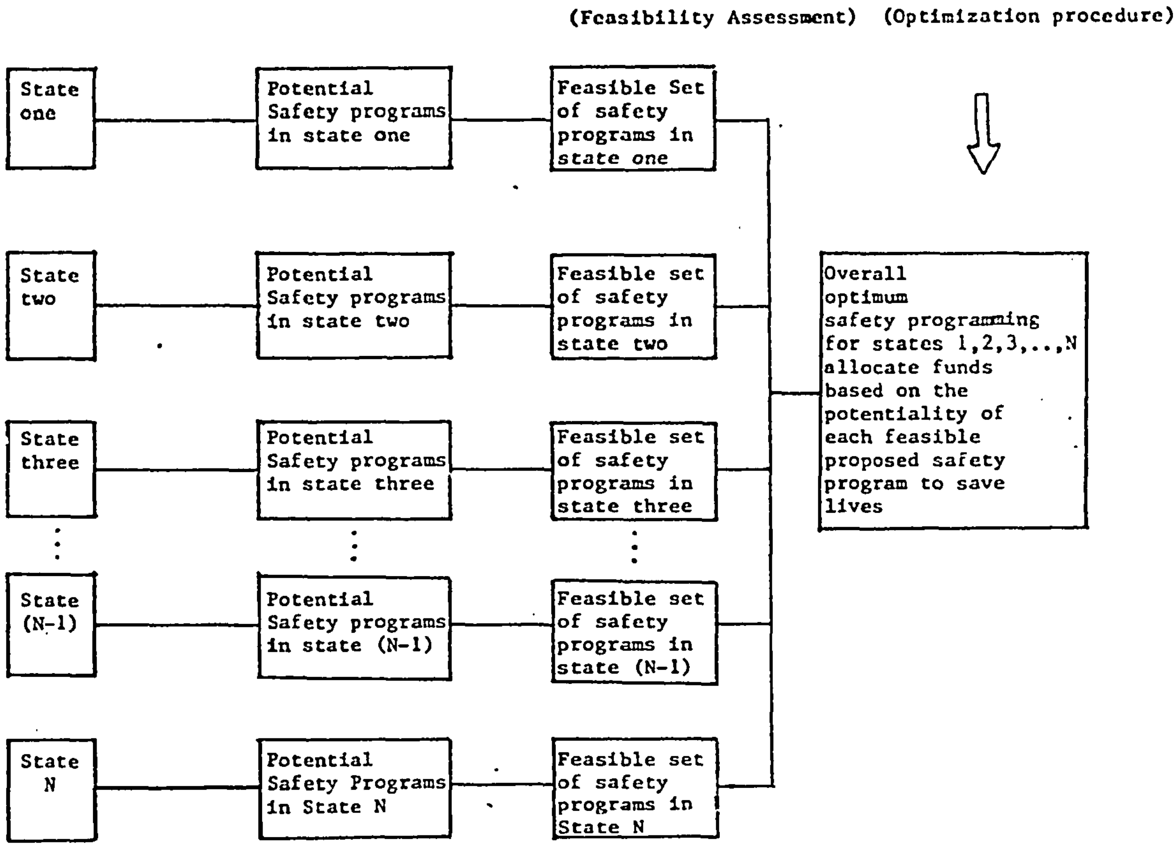
Proposed Macro Approach for
Safety Resource Allocation
(State level)*




* State apportionments to local government

FIGURE (1-3).

Proposed Macro Approach
for Safety Resource Allocation
(Federal level)*




* Apportionment of federal government safety funds among the States.

FIGURE (1-4).

## (1-9) IMPROVEMENT BY CATEGORIES:

Improvements by categories is a significant and important effort which has been made in this research study. This effort strengthens the capability of the model to respond to the different policy issues in a local jurisdiction. This enables the decision maker to allocate a percentage of the total resources on one specific category. The following example should clarify the utility of such a model capability. There is a Federal funding program established by congress with the objective of improving highway safety. As part of the requirement for this funding establishment, certain standards should be undertaken. For example, highway safety program standard 14 indicates that every state in cooperation with its political subdivision shall develop and implement a program to insure the safety of pedestrians of all ages. If the State provides the local jurisdiction with such resources, it has to fulfill such a requirement at the first stage. The proposed methodology will allow the authority to formulate the model according to the type of improvement which is required by the state or federal government in a very quantitative manner.

As mentioned, for the sake of simplicity, four basic categories have been selected. they are:

1- INTERSECTION IMPROVEMENT

2- PEDESTRIAN IMPROVEMENT

3- GEOMETRIC IMPROVEMENT

4- GENERAL IMPROVEMENT

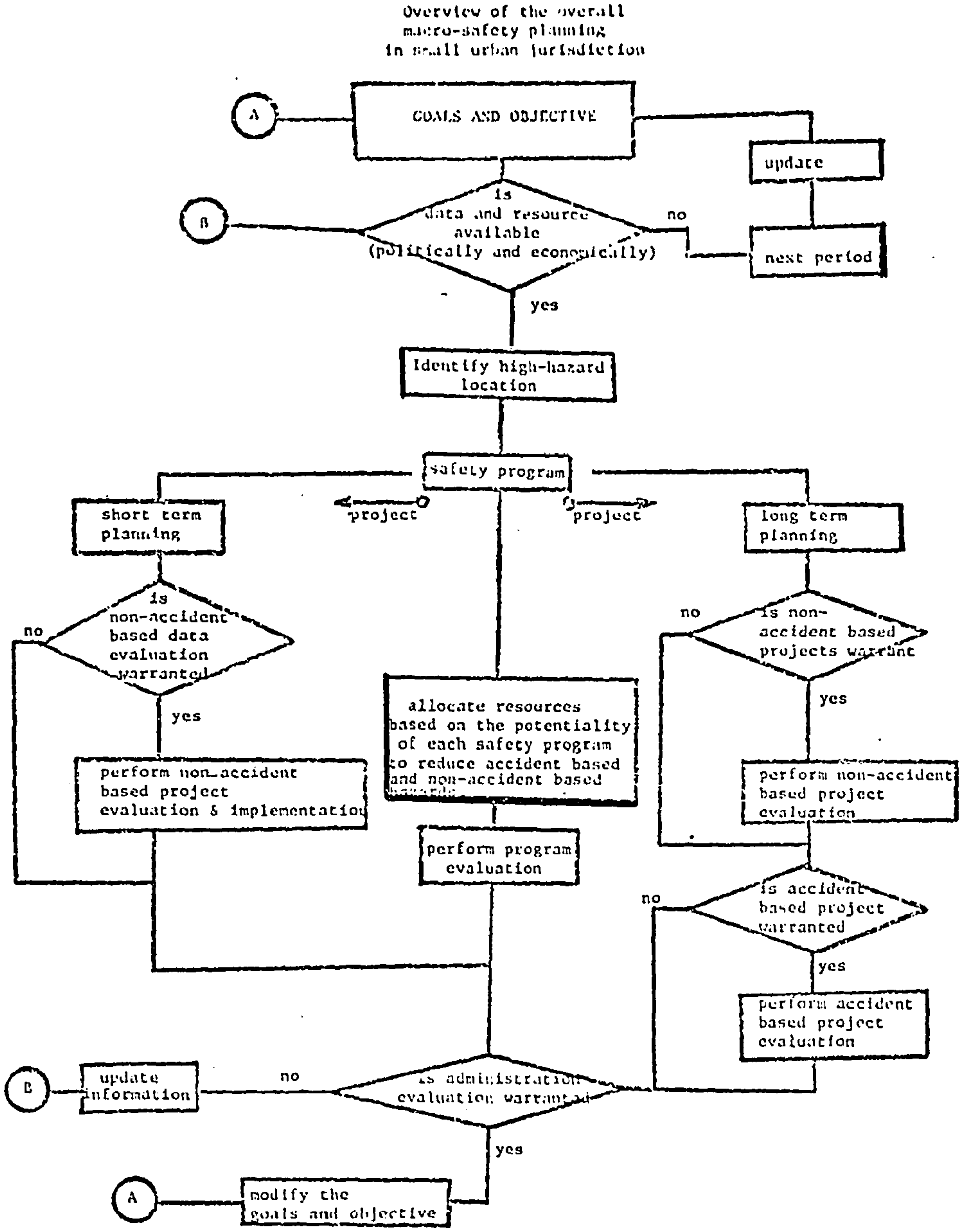
Of course the model and program can be easily converted to a general approach, having as many categories as highway standard classifications It can then be used by the higher level decision maker or state and federal government but at the expense of changing the different criteria and parameters.

## (1-10) DATA REQUIREMENTS

The urban traffic safety improvement program must be built on the precept that an accident pattern is examined to determine hazardous locations as a first step to their corrections. Confidence in these defined problems can only be gained through comprehensive and effectively operating accident, traffic and highway data systems. For fulfillment of such a requirement, it is necessary to establish a reference system to locate accidents and highway features, design elements and operating features on the roads and streets where they occur. Various techniques being used include field mile-posting, paper mile-posting, grid systems, link-node and physical features. It is important that such a system be devised and implemented which can be operated by police and urban safety officials with a degree of accuracy that allows correlation and analysis of data. Statistics show that state highway systems are completely referenced in 80 percent of the states while local highway systems are referenced in only 50 percent or less (46). Unfortunately, local agencies usually lack sufficient resources or may not perceive a real benefit in proportion to the effort.

There are several procedures or criteria for defining a hazardous location. Some of this variation can be accounted for by the differences in data systems. Traffic volume and highway inventory data are less likely to be available for the local road systems than for other roads. In chapter three of this research study, a majority of available and practical options will be discussed and the appropriate one will be selected in order to be recommended for identifying the hazardous locations in small urban jurisdictions.

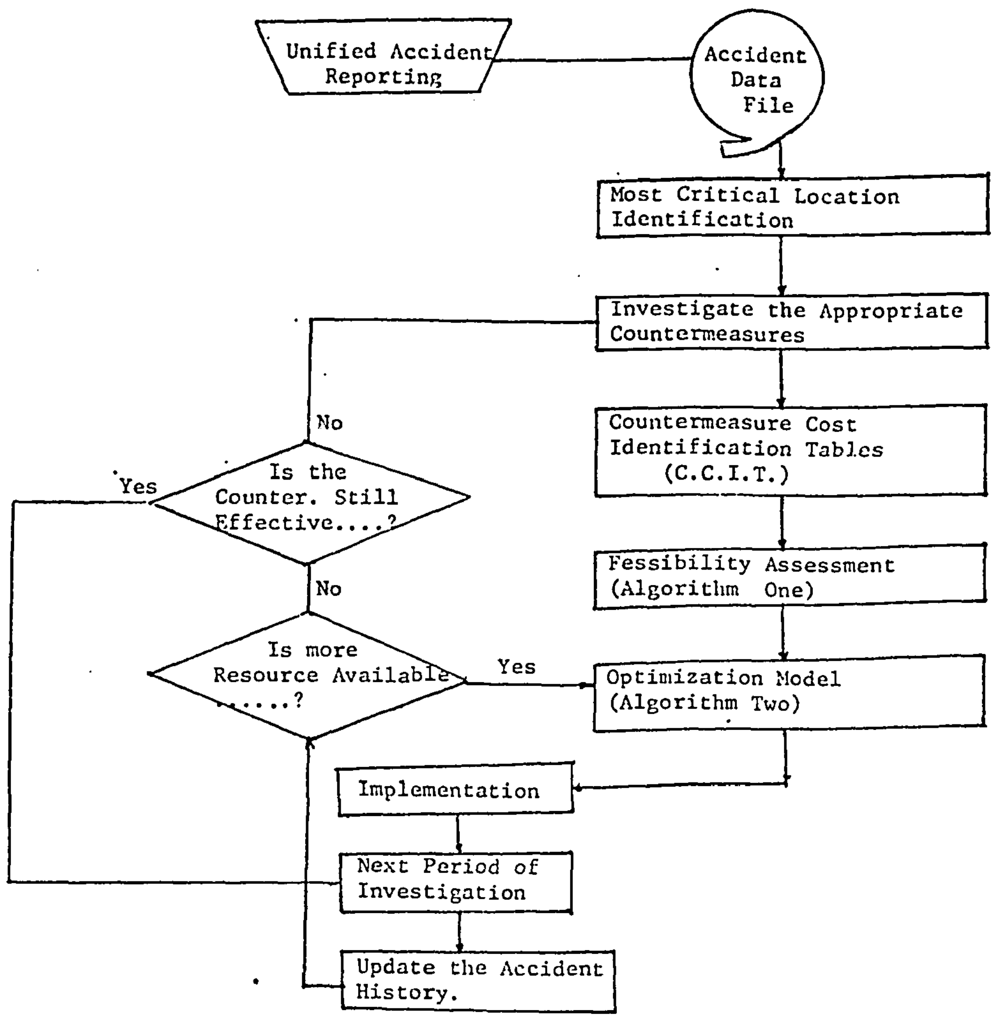
Cost-effectiveness data is the second set of the required input in this proposed methodology. A significant effort has been made to identify and quantify the needed data with the investigation of more than 120 literatures from the Department of Transportation, Federal Highway Administration, NCHRP, and many other private and federal investigators. The result of the investigation is refined



Overview of the overall
macro-safety planning
in small urban jurisdiction
A
GOALS AND OBJECTIVE
update
B
is
data and resource
available
(politically and economically)
no
next period
yes
Identify high-hazard
location
safety program
project
project
short term
planning
long term
planning
is
non-accident
based data
evaluation
warranted
no
yes
perform non-accident
based project
evaluation & implementation
allocate resources
based on the potentiality
of each safety program
to reduce accident based
and non-accident based
perform program
evaluation
is non-
accident based
projects warrant
no
yes
perform non-accident
based project
evaluation
is accident
based project
warranted
no
yes
perform accident
based project
evaluation
B
update
information
no
is administration
evaluation warranted
yes
A
modify the
goals and objective


FIGURE (1-5).

FIGURE (1-6) SYSTEM OVERVIEW UNDER MODEL UTILIZATION



and analyzed. Chapter Three of this thesis (Countermeasure Cost-Effectiveness Identification Tables) contains such brief and useful information. Again, if there is real data available, that can be easily used in the model. The flow-chart in figures (1-5) and (1-6) represent the systematic operations and planning procedures which will be the result of implementing the research methodology in a small local jurisdiction.

## (1-11) DESCRIPTION OF DISSERTATION BY CHAPTER

This dissertation consists of seven chapters. In Chapter One, the introduction, objectives, and needs for such a study are given. Chapter Two provides the necessary background for the reader to read this dissertation. The state-of-the-art and current practices are fully discussed in this chapter.

Chapter Three introduces the Countermeasure Cost Identification Tables. The most recent and updated estimated cost and countermeasure-cost-effectiveness are derived from different sources and interviews according to the suggested approach. In chapter four the different methods of identifying the high hazard location in urban areas is discussed and appropriate one is recommended.

The first-step of mathematical programming is developed in Chapter Five. In this chapter the first

FIGURE (1-7) DISSERTATION ORGANIZATION

CHAPTER 1:
INTRODUCTION AND NEED
STUDY

CHAPTER 2:
STATE-OF-THE-ART
(CURRENT PRACTICES)

CHAPTER THREE:
COUNTERMEASURE COST
IDENTIFICATION TABLES
(C.C.I.T.)

CHAPTER FOUR:
IDENTIFICATION OF HAZARDOUS
LOCATIONS: METHODS AND
CRITERIA

CHAPTER FIVE:
FEASIBILITY ASSESSMENT
MODEL; FIRST-STEP ALGORITHM

CHAPTER SIX:
OPTIMALITY ASSESSMENT
MODEL; SECOND-STEP ALGORITHM

CHAPTER SEVEN:
CONCLUSION AND
RECOMMENDATION FOR
FURTHER STUDIES

algorithm for Feasibility Assessment Model is developed and the results are compared with the powerful Dynamic Programming Algorithm.

Chapter Six introduces the second-step mathematical modeling named Optimality Assessment programming. The concept of multiple-objective optimization technique is fully developed for traffic safety resource allocation and is recommended for local and state government resource allocation procedures. Conclusion and recommendations for future studies are included in Chapter Seven. Figure (1-7) demonstrates the organization of this dissertation.

## (1-12) OVERVIEW OF THE NEXT CHAPTER

In the next chapter the state-of-the-art and the most significant methodologies for highway safety assessment are discussed. The state-of-the-art is classified into four major components for the sake of simplicity. The reader of this dissertation is expected to gain a very brief and short background of all available and sound techniques used in transportation especially, in highway safety practices. In conclusion, the most potential and more promising techniques are discussed.

# CHAPTER II

## STATE-OF-THE-ART (LITERATURE REVIEW)

### (2-1) Introduction

A comprehensive library search has been conducted to identify the current highway safety improvement evaluation practices, methodologies, and optimization techniques for budget allocation. The key words used in computer searches were safety improvement, maintenance, decision-making techniques, and high hazard location studies. Attempts also have been made to focus on the relationship between these words and small urban jurisdictions.

As a result, four different categories have been identified which are directly or indirectly related to our study. These categories are represented as follows:

(1) Transportation priority programming,

(2) Mathematical optimization concepts used in transportation studies,

(3) Cost-effectiveness methods,

(4) Traffic safety improvement programs.

To obtain the greatest benefit or return from the available resources, an effective programming or methodology needs to enable the decision maker to allocate available resources to implement the proper project or countermeasure. In this regard an effective modeling approach must provide the prioritization of projects based upon need. Before going into more detail, it is necessary to classify the numerous evaluation methodologies used by many decision makers.

## (2.1) EVALUATION METHODOLOGIES

If transportation priorities are considered as the evaluation methodology, they can be classified into five main categories:

(1) Marginal Cost Method: Can be used to compare benefits from transportation improvement vs. benefits from other types of expenditures,

(2) Benefit-Cost analysis: A significant tool in large water resource and transportation project evaluations. Criticized for the way monetary values are assigned to certain benefit,

(3) Cost-Effectiveness: Broader than B/C analysis since it takes into account nonmonetary information (e.g. number of lives saved),

(4) System Analysis: Designed to help decision makers identify a preferred course of action from among possible alternatives by specifying how men, money , and other resources should be combined to achieve a larger purpose,

(5) Planning: Provides the managers with (a) a definition of available resources, (b) an evaluation of priorities for allocation of available resources, (c) monitoring a continuous review of on-going programs, (d) proposing reform as needed.

## (2-2) PRIORITY PROGRAMMING

There are several approaches to priority programmings related to resource allocation in transportation studies. Benefit-cost, present worth, and rate of return calculations have traditionally been used as an integral part of transportation safety improvement planning programs. The essential features of the priority programming techniques involve development of sufficiency ratings. These have been derived mostly from evaluation methodologies developed in other fields of engineering such as Industrial Engineering or System Engineering which have been applied in transportation problems. Because budgets have always been an important component in any evaluation used to plan a course of action in transportation problems, priorities programming has been used by many decision makers to evaluate and implement these projects. priority methodologies can be classified in the following sections (79, p. 9):

### (2-2.1) WEIGHTING METHODS

This method is most commonly used for evaluating highway safety alternatives and is based on the following characteristics:

(1) A set of available alternatives with specific attributes and attribute values,

(2) A process comparing attributes by obtaining numerical scalings of attribute values,

(3) A well-specified objective function for aggregating the preference into a single number for each alternative,

(4) A rule for choosing the alternative on the basis of the highest weight.

MacCrimmon discusses nine weighting methods divided into three main subcategories as follows (78, P. 25)):

Inferred Preferences: In this category, "...the preferences of the decision-maker are inferred from past choices, rather than being obtained by direct query and are inputs to a general linear statistical model". McFarland indicated that use of one of these methods in safety evaluations would implicitly assume that past decisions regarding safety have been the correct ones.

Directly Assessed Preferences(Specialized Aggregation): If the decision maker explicitly states his preferences, then specific attributes can be taken to represent the whole alternative (a zero-end aggregation) such as "maximin" and "maximax". These two categories are of questionable use in highway safety analysis since they do not meet the criterion of considering all attributes of alternative(79, P. 9).

Considering the above two categories in weighting models, it is not believed that these methods are among the better available procedures, but they can be useful if they are used in combination with other methods in determining weights and other priorities approaches. For example, weights for time savings and lives saved have been developed using the "willingness-to-pay" method of analysis (31, p. 121).

Trade-off analysis and simple additive weighting methods can also be considered as "directly assessed preferences" methods which may be classified into other categories such as hierarchical additive weighting, and quasi-additive weighting(78,79,95). Trade-off analysis has been used in highway improvement projects, but it is not considered a powerful technique since it is difficult to use if there are very many alternatives. Simple-additive-weighting methods are uncomplicated and highly effective techniques. In this method weights are assigned to different, independent attributes of alternatives. McFarland has indicated two more subcategories of simple additive weighting that can be used in public decision making; those that use the monetary weights and those that use nonmonetary weights, e.g., utility(79, p. 10).

There are several methods within the monetary-weighting subcategory of simple additive methods. NCHRP Report 162 (66) indicates some of the commonly used procedures :

(1) Benefit-cost methods: Includes the benefit-cost ratio method, and the net benefit method, the incremental benefit-cost method,

(2) The total-cost method,

(3) The payback-period method,

(4) The rate-of-return method.

These four monetary approaches are important and actually have been the backbone of many sound and effective applicable procedures used in highway improvement programming; consequently, an attempt has been made to provide a brief review of these models.

## (2-2.2) COST-BENEFIT ANALYSIS

The Cost-Benefit method is used extensively in evaluating many transportation projects. In addition to the vast application in transportation related areas it also has been used in evaluating water resource projects, land usage, health, and education programs. According to Prest, Eckstein and Turvey (35,93), questions they emphasize as being important to B/C analysis are:

(1) Which costs and which benefits are to be included?

(2) How are they to be valued?

(3) At what interest rate are they to be discounted?

(4) What are the relevant constraints?

The assumption behind the B/C analysis is that the relative merit of an improvement is measured by its benefit/cost ratio. But there have been different viewpoints regarding B/C analysis. Prest and Turvey in their evaluation of effectiveness of B/C analysis indicate that "...first , judgment plays such an important role in the estimation of B/C ratios that little significance can be attached to the precise numerical results obtained...second, competition, is likely to drive the agencies (competing for limited funds) toward increasingly optimistic estimates; and far from resolving the organizational difficulties, computation of B/C ratios may in fact make them worse"(93, p.200). The above statement is of-course a pessimistic viewpoint, but in the end they conclude that:

> the case for using B/C analysis is strengthened, not weakened, if its limitations are openly recognized and indeed emphasized. It is no good expecting this technique, at any rate in its present form, to be of any use if a project is so large as to alter the whole complex of the relative prices and outputs in a country. It is no good expecting those fields in which benefits are widely diffused, and in which there are manifest divergences between accounting and economic costs or benefits, to be as cultivable as others. Nor is it realistic to expect that comparisons between projects in entirely different branches of economic activity are likely to be as meaningful or fruitful as those between projects in the same branch. The technique is more useful in the public utility area than in the social-services of government(79, p. 12, and 93, p. 203).

Considering the application of the B/C analysis in transportation related projects, the American Association of State Highway Officials has promoted the use of B/C analysis for project/design-level destination in their publication commonly known as the Red Book(1), which was originally published in 1959 and has been completely revised by the Stanford Research Institute (26). AASHTO stated that:

"....B/C analysis is not economic analysis in the

> broad sense and can not be used as such. It is an analysis of the relation of road user benefits to capital (and maintenance) costs. It cannot be used to determine the worth of a proposed investment but it can be of great assistance in comparing alternatives in location and design for a proposed investment, and, when used with other factors, can be of assistance in determining priorities of several proposed improvements."

Further discussion by McFarland indicates that the benefits considered in the Red Book are changes in road user costs, especially reductions in travel time, vehicle operating costs , accidents, and discomfort. However, a deficiency of the Red Book is in defining different approaches of B/C; no specific methods for predicting these reductions are given. The revised Red Book which will probably be widely used for at least the next decade in conducting B/C analysis of highway alternatives for various cases of safety, control, design and planning. The revised Red Book gives the decision rule for selecting the set of projects that yields the greatest net present value (NPV), as calculated using the following formula (79, p. 11):

$$NPV = \sum_{j=1} \frac{(Bj-Cj)}{(1 + i)^{j}} + \frac{R}{(1 + i)^{n}}$$

Where:

$Bj$ = the benefits in year $j$,

$Cj$ = the costs in year $j$,

$Rn$ = the residual value at the end of year $n$,

$n$ = the length of the analysis, and

i = the discount rate.

Another version of of B/C analysis similar to that of the revised Red Book is the Highway Economic Evaluation Model (HEEM), a computerized method used by California and Texas (111). The only main deviation considered in this economic procedure is the accident rate for different highway locations. The main logic of the B/C is not changed in this approach.

As research is focused mainly on safety evaluation, here an attempt is made to consider the application of these approaches in safety projects. The principal weaknesses of the B/C in both methods mentioned, i.e., revised Red Book and HEEM for comparing highway alternatives, can be classified as follows (79, p. 14)

(1) Although the formulas for B/C ratios and incremental B/C are generally correct, no algorithm is given for efficiently comparing large numbers of projects. Also, further discussion of the use of incremental benefit-cost ratios probably would be helpful.

(2) Discussion of techniques for predicting reductions in accidents is basically limited to a presentation of statewide accident rates for major design variations.

(3) Although different values are given for accident costs, there is no detailed discussion of the methods used to derive these different costs or the implicit assumptions being made when different method are used.

(4) Increase in highway accident rate and other motorist costs during the reconstruction of highways are ignored.

(5) Change in measure of effectiveness other than travel time, vehicle operating costs, and accidents need to be considered in more detail--especially changes in comfort and pollution levels.

As mentioned, NCHRP Report 162 recommended the use of the B/C ratio method for evaluating independent alternatives in what is called "AASHTO benefit-cost ratio convention". This B/C ratio is similar to that in the revised Red Book, and the annual maintenance and operating costs are added into the denominator instead of being subtracted from the numerator(66, pp. 41-42). The various aspects of this convention are discussed by Winfrey (126, pp. 148-150) and Fleisher (41).

In the 1978 Transportation Research Board presentation, Fleischer provided an illuminating critique of NCHRP Report 162, where he partially corrects some of the errors mentioned previously. However, his discussion is still lacking in several respects (79, p. 15):

(a) He indicates that the B/C ratio "...is not a measure of economic efficiency and should not be used to rank alternatives. The significance of an alternatives ratio lies in its relationship to unit"(40, p. 10).

(b) He indicates that certain costs, namely recurring annual costs, may be included in either the numerator or the denominator, apparently at the whim of the decision-maker(40, pp. 10-11). Whether this cost is included in the numerator or denominator depends upon whether only initial costs are the relevant constraint, in which case recurring costs are included in the numerator, or

> whether present value of all highway costs appear in the denominator. Only if funds are unconstrained his conclusion correct that"...the position of an economic consequence in either numerator or denominator is irrelevant..." (40, p. 11).

It is worth noting that Fleischer's conclusions are correct given the assumption of unlimited resources, which in reality is not likely to occur. He further describes another deficiency of NCHRP Report 162 when B/C method is used to optimize the return. He indicated that "...one can not determine the global optimum simply by combining local optimum solutions. That is, one cannot maximize the net benefits on an entire investment program, with budget constraints, merely by aggregating design alternatives that appear optimal with respect to their mutually exclusive alternatives". It is apparent that in operation research techniques it is not always possible to obtain the global optimum simply by combining locally optimum solutions. However the degree of accuracy in using such a procedure depends entirely on the type of problem and the condition which the decision maker deals with. Fleischer further maintains that (40, p. 16), "...all combinations of programs, or 'budget packages', must be identified and optimal programs selected from this set. The number of such programs can be very large. Fortunately, however, certain efficient algorithms can be developed through dynamic programming or linear programming ." As was also mentioned by Fleischer, the two areas of dynamic and linear programming are of special concern to be used in combination with the B/C method. One approach of this thesis is to demonstrate the capability of linear goal programming to optimize the program while the B/C method is considered as a local optimizer.

The revised Red Book further recommends the following formula for calculating B/C ratios (1, p. C-7):

$$B/C = \frac{PV(\Delta U)}{PV(\Delta I) + PV(\Delta M) - PV(\Delta R)}$$

Where :

PV = present value of the indicated amount,
$\Delta U$ = reduction in highway or transit user costs due to the investment,
$\Delta M$ = change in annual maintenance, operations, and administration due to investment,
$\Delta R$ = change in residual value, and
$\Delta I$ = change in investment cost.

The above formula is recommended whenever there is a budget constraint. Care also should be taken when there are independent projects, so that choosing one project does not preclude the selection of another project. In this case arranging the projects in declining order of B/C ratio will maximize the net present value of benefits for the available resources. There is another recommendation for application of the above another formula if projects are nonindependent, then the formula may be used to select projects if (1, p. C-5) :

Each increment of expenditure is compared with additional benefit associated with that cost increment, starting with the lowest-cost alternative at each location, and

At each location, a lower-cost alternative is displaced from the accepted list whenever a higher-cost alternative at that location is accepted.

## (2-2.3) RATE-OF-RETURN

Hirschleifer proposes another method for calculating the optimal project while the rate-of-return on the initial capital investment is considered (24,112). Using this method, it should be presumed that there is an initial capital investment and there are future costs and benefits for each project. He indicates that "... the rate of return is that rate which equates the initial capital cost with the present worth of all future benefits less all future costs plus the present worth of the salvage value."

## (2-3) NON-MONETARY WEIGHTING METHODS

These methods are conceptually similar to those with monetary weights, the original differences being that the non-monetary weights are assigned to various attributes of alternatives by the decision maker, instead of being calculated from revealed preferences of consumers (79, pp. 18-19). NCHRP Report 162 (66, p. 43) defines one version of such an analysis as "Cost-Effectiveness Analysis", which is called simple additive weighting. NCHRP Report 162 has used such a concept in assigning different weights to the different attributes such as accident types. For example he considered three types of attributes as fatal, injury, and property damage accidents and then assigned weight as 20, 9, and 1 respectively. Of course such a procedure can not be called "cost-effectiveness analysis" since a weight has been assigned to the attributes. This analysis was also criticized by Fleischer (40, p. 16). Such a technique has been used by many decision makers . A recent example is the use of the severity index in roadside clearance program by Weaver (124), and other reports such as Vesper (119), DeNeufville (31) Carter, and Burke et.al, are among the significant studies that have been done with the help of above procedure.

As it was mentioned by the McFarland et.al, study, the non-monetary simple-additive-methods can be used to compare mutually and non-mutually exclusive alternatives if it is assumed that the different magnitudes of weighted values are a clear indication of the worth of the project.

## (2-4) HIERARCHICAL ADDITIVE WEIGHTING PROCEDURES

This is a more sophisticated weighting method that ~~is widely used by many State agencies.~~ ~~A recent study by~~ Solomon, Starr, and Weingarten is a significant effort in applying this method to the safety projects(103 ). Another significant application of this method is in Highway Sufficiency Rating. These rating are an index for different roadway conditions, usually consisting of three categories as structural, functional, and safety. These categories are assigned weights, typically summing to 100 points. The majority of states either now use a sufficiency rating or have used them at some time in the past to rate roadway. Of course the weighting of categories, and subunits within categories, differs from state to state, but the same three categories are used in almost all states (79, pp. 21-32). The Traffic Control Handbook also represents an application of this method under the name of "cost utility approach" which indicates the capability of the procedure in an area other than safety (92, pp. 474-486). Walton applied such a method in various warranting procedures, and many states use it with an acceptable level of accuracy (122 ).

In conclusion, it was found that regardless of many good characteristics and the capability of the hierarchical additive methods, it also has several weaknesses, indicated by McFarland et al.(79, pp. 25-27):

> (a) There often is no logical, consistent method of determining inter- and intera-attribute weights, and there always exists the problem of determining which weight to use.
>
> (b) The hierarchical structures sometimes include as final goals elements that are intermediate goals.
>
> (c) Elements that measure reliability of effectiveness are added to those that measure degree of effectiveness.
>
> (d) Incremental effectiveness of alternatives is

sometimes not considered.

The other important type of weighting method is a quasi-additive weighting method developed and applied in many research studies by Vesper et. al.,(119), DeNeufville and Kenny (31) and DeNeufville(33). it should be assumed that the utility of multiple attributes is equal to the sum of the utilities of each of the individual attributes, otherwise as the MacCrimmon study (78) suggests "...by obtaining conditional utility functions on the attributes [ where] some of the attributes are utility independent of the others, an overall preference assessment can be made in a quasi-additive form."

## (2-5) SEQUENTIAL ELIMINATION METHOD

This method has been widely used in most highway agencies. It is actually a type of cost-effectiveness procedure but without weighting the attributes. McFarland et. al in their recent study characterizes this procedure as (79, pp. 32-34):

(1) A set of available alternatives with specified attributes and attribute values,

(2) Scalings, perhaps only ordinal, or attribute values (interattribute preferences) and in some case an ordering across attribute,

(3) A set of constraints (but in some cases empty) across attributes, and

(4) A process for sequentially comparing alternatives on the basis of attribute values so that

alternatives can be either eliminated or retained.

In using either of the above mentioned methods, care should be made to define properly the problem and consider the limitation of each methodology. Of course, neither of the above procedures will result in an optimal answer without the decision maker's judgement and the help of an expert. Only then should a positive result be expected.

## MATHEMATICAL OPTIMIZATION CONCEPT USED IN TRANSPORTATION SAFETY STUDIES (AN OVERVIEW)

(2-6) Introduction:

The last several years have seen new techniques added to transportation programming. Consequently, without substantial changes in the methodologies, neither sufficiency ratings, economic analyses, nor any non-technical methods, by themselves, are an adequate tool for priority setting. Application of operation research techniques has given a new dimension to the transportation safety analysis. With the help of this technique, various approaches of safety modeling can be solved.

An attempt has been made in this section to review the most significant mathematical models that have been used or have a potential to be applied in the safety related study. Mathematical programming methods should have the following characteristics:

(1) An objective function,

(2) An algorithm to generate more preferred points in order to converge to an optimum,

(3) An infinite, or very large, set of alternatives from a set description (i.e., constraints specified on the attribute values),

(4) A set of technological (or sometimes preference) constraints(...).

Here, mathematical programming commonly used in traffic safety programs is classified as follows:

(a) Linear Programming

(b) Non-linear Programming

(c) Integer Programming

(d) Dynamic Programming

(e) Goal Programming

(f) Network Analysis Techniques

All the above mathematical programming will be discussed in this section and their characteristics will be compared.

## (2-6.1) LINEAR PROGRAMMING

Linear programming deals with the problem of allocating the limited resources among competing activities in an optimal manner. This problem of allocation arises whenever one must select the level of certain activities which must compete for certain scarce resources necessary to perform those activities. The great variety of situations to which linear programming can be applied is indeed remarkable. It ranges from the allocation of production facilities to products to the allocation of airplane fuel to bomber runs, from portfolio selection to the distribution of federal money allocation and so on almost a infinitum. However, the one common ingredient in each of these situations is the necessity for allocating resources to activities.

There have been many proposed procedures to solve ~~linear programming~~. ~~The most common method for solving~~ linear programming is "simplex algorithm" suggested by Dantzig (30). The other version of the linear programming is called "dual simplex method", proposed by Wagner (120). However, the simplex method is found to be more simple than the others.

The linear programming problems or the problems which are nominated to be solved by a linear programming method should have the following conditions (108, p. 28):

> (1) Non-negativity condition for all the decision variables,
>
> (2) The criterion for selecting the "best" values of the decision variables should be described by a linear function of these variables, i.e., a mathematical function involving only the first powers of the variables, with no cross products. The criterion function is referred to as the "objective function."
>
> (3) The operating rules governing the process (e.g., scarcity of resources) can be expressed as a set of linear equations or linear inequalities.

This set is referred to as the " constraint set."

The mathematical statement of a general form of the linear programming problem is as follows: Find $x1, x2, \ldots, xn$ which maximizes the linear function,

$$Z = C1\ X1 + C2\ X2 + \ldots + Cn\ Xn$$ subject to the restrictions,

$$A11\ X1 + A12\ X2 + \ldots + A1n\ Xn < B1$$

$$A21\ X1 + A22\ X2 + \ldots + A1n\ Xn < B2$$

$$\cdot$$

$$\cdot$$

$$Am1\ X1 + Am2\ X2 + \ldots + Amn\ Xn < Bm$$

$$X1 > 0,\ X2 > 0, \ldots,\ Xn > 0$$

where the Aij, Bi, and Ci are given constants. The function being maximized is called the objective function. The restrictions are also referred to as constraints or restraints. The variables being solved for are called decision variables (101, pp. 26-66).

In the area of traffic safety, the linear programming is not widely used. A significant study has been made by Operation Research, Inc., related to the safety allocation resources. The linear programming approach was used to allocate Federal expenditures among different safety standards (89). But linear programming has been widely used in other areas of transportation, such as traffic control, design, traffic flow theory, etc. There are several report studies in safety areas in which the concept of linear programming has been used such as Estimating Long Range Highway Improvement and Cost by Covil(25), and Highway Investment Analysis Package(6) and other federally funded programs which will be discussed in the next section of the state-of-the-art of this paper.

(2-6.2) NON-LINEAR PROGRAMMING

Non-linear programming deals with the problem of optimizing an objective function in the presence of equality and inequality constraints. If all the functions are linear, it obviously is a linear program. The development of the simplex method for linear programming and the advent of high-speed computers have made linear programming an important tool for solving problems in divers fields. However, many realistic problems cannot be adequately represented as a linear program owing to the nonlinearity of the objective function and/or the nonlinearity of the constraints. Efforts to solve nonlinear problems efficiently have made rapid progress during the past decades (7).

Non-linearity poses a great problem in proposed traffic safety programming. It is very difficult to find the exact nonlinear function and then try to optimize such a function; however, if such a difficulties can not be avoided, the analysts would use the Lagrangian optimization which is a very powerful analytic tool to handle the non-linear functions. However, difficulties will arise in using this technique when the problem is large (large scaled problem). As will be discussed in more detail in chapter six, the non-linearity in this proposed programming will be treated with the method of "piecewise linear approximation" of non-linear relationship with a good degree of accuracy.

(2-2.3) INTEGER PROGRAMMING

Programming problems exist in which some or all the variables are restricted to integer values. These are commonly referred to as mixed or pure integer programs. Integer programming (IP), is a valuable operation research tool having tremendous potential in the design and analysis of safety program systems. Recently, this powerful optimization methodology has been widely used in transportation analysis. For example, researchers at Texas A&M University have applied a specialized zero-one IP code to a resource allocation problem involving 2700 constraints and 6000 decision variables to solve an integer program(108). Recently, Sinha et. al., (101, 1981), applied integer programming to solve the allocation problem. They still ignored the fact that safety problems are not a single objective having specific constraints. However, they considered IP in combination with a stochastic formulation which increased the accuracy of the problem but has limited the applicability of the model in real world problems.

There are several algorithms proposed to solve the IP problem. Gomory developed a very efficient algorithm named "cutting plane" in which new linear constraints are generated so as to obtain a derived problem whose optimum extreme point is an integer (108). Young (128), Glover (53), Land(73), Balas (3), Cook (22), Balinski (4) , Hillier (58), and Geoffrion (52), have developed different algorithms for solving the IP in which the more efficient and commonly used is Balas's algorithms. The general linear programming problem can be described as follows:

$$B = \sum_{j=1}^{n} Cj\ Xj$$

Subject to

$$\sum_{j=1}^{n} Aij\ Xj \leqslant Bi \qquad i=1,2,..,m$$

$$\text{integer } Xj \geqslant 0. \qquad j=1,2,...,n$$

As mentioned one version of the IP is called zero-one algorithm in which any general IP can be converted to such a procedure if it is necessary. The following transformation is needed for each solution variables.

$$Xj = \sum^{k} 2y_\ell^\ell = Yo + 2Y + 4Y + \ldots + 2^K Y_K$$

where: k=smallest integer such that $2^K \geq U + 1$

U= smallest upper bound on Xj

The above transformation can simplify the procedure for which available solution techniques are more efficient.

## (2-6.4) DYNAMIC PROGRAMMING

Dynamic programming is a mathematical technique designed primarily to improve the computational efficiency of certain optimization problems. The basic idea of the technique is to decompose the problem into (smaller) sub-problems which are computationally more manageable (taha). Pigman et al. defined such a technique as a type of optimization which transforms a multistage decision problem into a series of one-stage decision problems. According to this definition, the decision at each stage depends on the input to that stage, the feasible set of decisions at that stage, and the conditional set of decision from preceding stages(109).

Dynamic programming has been widely used in transportation planning. As described by Pigman, Agent, Mayes, and Zegeer, the following justification should be the answer for the above statement (91):

> There are three main reasons why dynamic programming is needed for transportation planning analysis. First, dynamic programming is designed to provide the best plan over a period of time inasmuch as the scheduling of a project is a critical variable. Second, dynamic programming makes it possible to obtain the best combination of projects where some approaches are inaccurate and trial-error methods can become an impossible task. Third, dynamic programming can determine the optimal investment plan where the usual B/C, present worth, or maximum rate of return approaches are not practical. When the amount of money required for a single project is a large portion of the budget, the best set of projects does not necessarily consist of those which would be chosen by conventional means of priority selection. B/C and rate of return methods may not provide the best overall use of resources because an efficient implementation of results may not be possible. In addition, the B/C method of selecting optimal alternatives does not always produce the best results because it focuses narrowly on immediate benefits and often precludes some future combinations of alternatives which are more desirable.

Considering the above justification, dynamic programming is possibly the most comprehensive and accurate method of cost allocation for a constraint budget, but it also has several shortcomings which will be discussed. Bellman (8) summarized dynamic programming applicability into three types of projects as follows:

(1) Single-Stage Dynamic Programming

(2) Multistage Dynamic Programming

(3) Multistage Incorporating a time factor

Funk and Tillman (50) used the systems approach to emphasize that the the costs and benefits occurring to all parts of the system must be evaluated to establish the effect upon a specific route. Johnson, Dare, and Skinner( 63 ) presented dynamic programming as a means of selecting highway improvement projects to eliminate hazardous locations and therefore maximize the annual cost reduction benefit. They suggest that an optimal solution is assured when several projects are being considered and construction funds are limited. De Neufville and Mori (32) developed a procedure with the help of dynamic programming for optimal construction schedule for additions over time to highways or similar transportation networks.

Brown and Carlson (10) have developed extensive work in developing the methods for selecting improvements from among various projects. B/C, present worth, or rate of return calculations were recommended by both for determining which project yields the maximum differences between the annual investment cost and the annual expected safety benefit. Lorie and Savage (77) have shown that, under a constrained budget, the selection of a large initial cost project with a high ratio of present worth to cost may preclude the selection of several smaller projects.

The Kentucky Highway Department has experienced several procedures for its safety improvement with the help of dynamic programming (10,11,71). Pigman et. al. (91) evaluated the high-accident location spot improvement program in Kentucky and it was determined that the small investment in the program had returned significant dividends. Zegeer (130) recently completed an investigation of the various methods for selecting high-accident locations. Favorable results from the studies by Agent and Zegeer, combined with the expansion of the spot-improvement program (as a result of appropriations through the Federal-Aid Highway Act of 1973) have stimulated the development of an optimal method for allocating funds within the safety improvement program, and dynamic programming has been used in most cases.

The Alabama Highway Department has also done considerable work in the application of dynamic programming to the optimization of budget allocation for the spot safety improvement program. It is found that the study by Pigman et. al., is superior to Brown's study since they used the present worth factor procedure to compute the future value of the alternatives.

## (2-6.5) ADVANTAGES AND SHORT-COMINGS OF DYNAMIC PROGRAMMING

There is no doubt that dynamic programming has been a good and reliable method in assessing highway safety improvement, but it also has a severe shortcoming which makes application of such a procedure very difficult. As mentioned, currently two states, Kentucky and Alabama, have developed and implemented highway safety spot improvement programs that involve DP in project selection under budget constraints, but many recent study evaluations show that " ...dynamic programming will not yield feasible results in its present form (Alabama/Kentucky) unless budget coefficients (alternative costs) are in units of the budget increments. Further, the current procedure will only yield optimal solutions if individual budget expenditures and the budget increments are both in the same basic units..." (79, p. 308). Dynamic programming is also a weak procedure if it is applied to problems with many constraints. Sometimes it is not possible to use this technique efficiently when the budget is not divisible by the increment which should be established at the beginning of the solution process.

On the other hand, the use of dynamic programming is relatively simple. Costs and benefits are considered as the ~~input for this technique; however, the accuracy~~ of ~~the~~ model is totally related to the input data. A prerequisite in the use of dynamic programming for the safety improvement program is an efficient method of systematically identifying locations based on accident data. In-depth field investigations are also needed so that only necessary improvements are recommended as input for the dynamic programming model.

## (2.6.6) GOAL PROGRAMMING

The concept of goal programming (GP) was first suggested by Charnes and Cooper (17). The details of the technique were further studied by Ijiri (61) and Lee (75). Goal programming is a powerful tool of decision-making analysis which it draws upon the well-developed and tested linear programming technique. Goal Programming (GP) provides a simultaneous solution to a complex system of objectives. It can handle decision problems involving multiple goals and subgoals.

The basic concept of GP involves incorporating all managerial goals into the model. In GP, instead of trying to maximize or minimize the objective criterion directly, the deviations between goals and what can be achieved within the given set of system constraints are to be minimized. The GP model is useful for three types of analysis (17, 60, 61, 74, 79):

(1) To determine the input (resource) requirements to achieve a set of goals,
(2) To determine the degree of attainment of defined goals with the given resources,
(3) To provide the optimum solution under the varying inputs and priority structures of goals.

The general GP model can be mathematically expressed as (60,75):

$$\text{MINIMIZE } Z = \sum^{m} (\overset{+}{d}i + \overset{-}{d}i)$$

$$\text{SUBJECT TO } \sum_{i=1} Ax - I\overset{+}{d} + I\overset{-}{d} = b$$
$$x, \overset{+}{d}, \overset{-}{d} > 0$$

Where m goals are expressed by an m component column vector b(b1,b2,...,bm), A is an m . n matrix which expresses the relationship between goals and subgoals, x represents variables involved in the subgoals (x1,x2,...,xn) $\overset{+}{d}_i$ and $\overset{-}{d}_i$ are m-component vectors for the variable representing deviations from goals, and I is an identity matrix in m dimensions.

As the GP is selected to solve the optimization procedure in this paper, a detailed development of the model will be given in Chapter Six.

## (2-6.7) NETWORK ANALYSIS TECHNIQUES IN TRANSPORTATION

~~Network Analysis (NA) has received considerable~~ attention in recent years. McFarland mentioned two good reasons for using network analysis rather than other techniques.

> (1) Many real-world problems can be depicted as network representations, and such representations are readily acceptable by management and can be interpreted visually.
>
> (2) Network analysis algorithms use streamlined and/or special-purpose basis-changing rules which avoid normal simplex operations. Very efficient NA algorithms exist for solving large scale problems; for example, trans-shipment problems with over 10,000 nodes and 50,000 arcs have been solved using network analysis.

One important application of NA in transportation is traffic control. A traffic network analysis approach named NETSIM represents a significant effort in using such a technique in traffic analysis. The NETSIM network simulation model, formerly called UTCS-1, performs a microscopic simulation of urban traffic flow on an urban street network. It is designed to be applied by a traffic engineer and researchers as an operational tool for the purpose of evaluating alternative network control and traffic management strategies (113). Other than the above examples, there are numerous applications and theoretical research about the network analysis in transportation areas. Good bibliographies and summaries of the state of the art can be found in Ruiter (97), and Florian (43). Daganzo and Sheffi (27), present an alternative formulation of stochastic disaggregate path-choice models based on the network formulation. Chan (16), Talvitie and Hasan (110), and Watanatada and Ben-Akiva (123) are also have done significant researches in application concepts of the network analysis in transportation studies. There are no known applications in the current literature to highway safety and accident reductions.

## (2-7) COST-EFFECTIVENESS STUDIES

Cost effectiveness is a comparison of cost to achievement of a given unit of effect. The NCHRP report 162(66) justified the application of such a technique as :

> Comparison of costs and benefits require the analyst to assign a dollar value to human life and injury. Although this practice makes cost-benefit comparison apparently more sound or explainable in terms of economic theory, the fact remains that some analyst may not wish to presume to assign monetary value to human life. In this case, the analyst may select the cost-effectiveness approach which answers the question , "How much does it cost to save one life, or prevent one injury accident, or prevent one accident?" without having to assign dollar value to them.

So, the main objective of cost-effectiveness especially in this report is applied as an alternative to the B/C technique to determine the cost to the agency of preventing a single accident and then deciding whether the project cost was justified. During the past decade cost-effectiveness techniques have been used by most transportation agencies since the Highway Safety Act of 1966 amended Title 23 of the United States Code to contain a new chapter entitled " Highway Safety"(79). In response to a request from the Highway Administration (FHWA), a special task force was established in 1969 to study the safety efforts of priorities of these efforts (107, p. 23). Since that time several highway safety programs have been implemented to determine the benefit and cost of the different projects. The cost-effectiveness approach has been known to be an effective technique which is accepted by many transportation agencies.

The important component of this method is "the measure of effectiveness" which differs from one method to the other. Solomon, et. al., (103) used six different measures of effectiveness in a weighted form. Dale (59,60)indicated five different measures of effectiveness. National Highway Safety Needs Reports (117, 125) reported five multiple measures of effectiveness. There is a common concept considered by most of the studies in selecting the measures of effectiveness. They mostly emphasized human life saved, injury and property damage per dollar of expenditure. Table (2-1) gives the measures of effectiveness considered by the respective author and agencies.

| M.O.E. | Soloman(103) | Dale(28,29) | NCHRP(66,93) |
|---|---|---|---|
| Rate Of Return | * | | |
| Lives saved/$ | * | | |
| Injuries saved/$ | * | | |
| Lives saved/year | * | | |
| Injury saved/year | * | | |
| Cost/Accident forestalled | | * | * |
| Cost/injury forestalled | | * | * |
| Cost/fatality Forestalled | | * | * |

Table (2-1) Summary Of Measures Of Effectiveness
[compiled from reference(79, p. 56)]

In the 1981 study by Fleischer (41,1981), he criticized such a procedure as having two problems:

> One arises from the fact that a unique C/E value can only be derived when there is a unique measure of effectiveness (MOF) for the project. The second problem--perhaps more important than the first--is that C/E values are useful in selecting from among alternatives in only three very special situations: dominance in both costs and

effectiveness, or projects that have equal cost. otherwise, given two or more projects with unequal costs and effectiveness, the relative attractiveness of these alternatives is not reflected by their respective ratios.

## (2.8) REVIEW OF CURRENT STATE AND LOCAL PRACTICES IN TRAFFIC SAFETY PROGRAMS

All of the techniques and procedures discussed in the previous sections are primarily directed toward safety programs of state and local governments, especially those jurisdictions that have sufficient resources to consider a large number of safety alternatives. McFarland (79, pp. 58-60) summerizes six steps for a state or local government that wants to implement any safety programs. The types of the cost-effectiveness techniques and other mathematical procedures which are currently used by the state and local agencies have been documented in several surveys and research publications. Here an attempt is made to summarize the most sound and significant safety programs currently implemented by state and local agencies in the United States.

> A comprehensive survey of state and local highway agencies has been conducted to determine the types of economic analysis used in 1962, 1966, and 1974. These surveys were directed toward identifying the methods used to compare alternative highway locations, highway designs, interchange designs, pavement designs, etc. ; the 1974 survey covered safety improvements as well (55, 79, p. 59). Another survey conducted in 1973, encompassed both state and local highway agencies specifically to determine the techniques used to compare highway safety alternatives (8). Other studies have reviewed reports of states' comparisons of highway

alternatives to determine the techniques used [55, 79, 116, 118].

In the 1974 survey, thirty-nine states replied to the questionnaires. Twenty-seven conducted limited studies [79, p.21]. From the survey results, it was estimated that from fifty to seventy percent of the states performed economic analyses on a more or less regular basis ; it was further estimated that this was a ten to twenty percent increase over the proportion performing such analyses on a regular basis in 1962 [79, p.21]. The survey indicated that the Red Book still was the primary reference source used for conducting economic analyses. Thirteen states used the original 1959 unit prices that were given in the 1960 Red Book, and another twelve states used the 1960 Red Book format but used updated cost values. In addition, five states used the NCHRP Report 111 [127], seven used the NCHRP Report 133 [26], fourteen used Winfrey's textbook [127], and seven other states used other references [79, p. 24]. It goes without saying that California was developing a computerized B/C procedure and Oregon had a highway investment rate of return program. An additional three states reported using computers in their analyses.

The same survey was conducted in 1973 and reported in NCHRP Report 162 [66]. This differed slightly from the others since the objective was to determine the specific types of analyses used for safety improvement projects rather than for general types of highway improvement projects. The results have been summerized as follows:

| METHODS | NUMBER OF AGENCIES USED | NUMBER OF AGENCIES NOT USED |
|---|---|---|
| Benefit-Cost Ratio | 32 | 9 |
| Total Benefit | 10 | 31 |
| Rate Of Return | 7 | 34 |
| Present Worth | 4 | 37 |
| Incremental Benefit | 1 | 40 |
| Other | - | - |

Table (2-2) Technique Used By Transportation Agencies
[ compiled from reference (79, p. 61) ]

In 1976 the U.S. Government Accounting Office (GAO) report reviewed and also attempted to determine the impact of the categorical safety funds provided by the Highway Safety Act of 1973. The GAO reviewed highway safety programs in California, Idaho, Louisiana, Maryland, Nevada, Pennsylvania, Texas, and Washington. The GAO Report found the following types of deficiencies in the states' safety programs [19, pp. ii-iii,7 ]:

(a) Some accident data were not being analyzed to determine the most hazardous locations.

(b) Safety improvement projects were not always ~~selected on the basis of cost-effectiveness.~~

(c) Inventories of cost-effective projects were not being used to determine priorities.

(d) Projects financed with federal-aid construction funds were not selected through a systematic approach.

(e) Federal-aid highways under some local jurisdictions were not considered and did not receive safety funds.

The GAO also reported that of the eight states reviewed, "...four did not use cost-effectiveness analysis and another did not consistently use its method for selecting safety improvement projects" [19, p. 9]. The following is a brief review of the examples of some significant current practices in traffic safety programs by state and local government agencies.

A comprehensive approach has been developed by the state highway agency of California for evaluating both major highway improvement and highway safety improvements. It developed a computerized B/C ratio procedure that includes consideration of travel time costs, vehicle operating costs, and accident costs. The key ingredient to California's approach was described by McFarland et. al., as follows:

(1) Statewide accident rate studies provide a base for evaluating new highway, major reconstructions, and safety projects.

(2) Accident costs are used together with project costs to calculate a "safety index", which actually is the project's benefit-cost ratio multiplied by 100. The costs used for accidents include direct costs plus some indirect costs but do not include the full societal costs.

(3) The effectiveness of accident countermeasures usually are calculated as percentage reductions in actual rates (if these are significantly different from average rates) or percentage reductions in the base rate.

The Texas department of Highways and Public Transportation applied the Highway Economic Evaluation Model to calculate B/C ratios for major construction , reconstruction projects [110] and also for safety type projects.

The Highway Economic Evaluation Model applied by the Texas Transportation Department is a computerized procedure ~~that calculates an economic ratio for improvement projects.~~ The technique of incremental B/C ratio discussed in previously was used for different alternative highway improvements. The procedure used can obtain a local optimum but again has the deficiencies discussed before.

Recently the application of dynamic programming in highway safety programs has been a very popular procedure. Kentucky and Alabama Transportation Departments have applied a very powerful technique for their highway safety programs. The Cost/Benefit Optimization for the Reduction Of Roadway Environment Caused Tragedies (CORRECT) is a computerized procedure which was originally studied by the Alabama Department of Transportation. The program was primarily used to allocate the Section 209 funds for spot improvement of high-hazard locations made available by the Federal-Aid Highway Safety Act of 1973 (5). The concept of DP is used in CORRECT to maximize the total benefits. The procedure has the shortcoming of Dynamic programming method since single objectives with very limited constraints can be used . The projects selected by DP are always subjected to review and possible revision by the decision-makers. In 1977, the Alabama Highway Department applied CORRECT in allocation of Section 203 (rail-highway crossings) funds which the results were promising [20]. The Kentucky Department of Transportation used the modified version of CORRECT for their highway safety projects. They used the present worth of the investment analysis in the B/C procedure, then applied the DP technique for optimizing the total benefits. The deficiencies of the Kentucky procedure are best described by McFarland et. al., as follows (79, p. 40):

> The Kentucky study, while including the present value of future maintenance costs in its calculation of project costs, is not clear as to the type of budget constraint it faces. The manner in which maintenance costs are included implies that the budget covers future periods as well as the current period; highway improvement budgets typically are concerned only with the allocation of funds for the present period. The Alabama study, on the other hand, deals with a typical, clearly defined budget that is concerned only with initial project costs that occur in the current period, but such a treatment of costs fails to account for future maintenance costs. Ignoring these costs in the DP analysis optimizes project selection only with respect to the initial projects costs.

In conclusion, both Alabama and Kentucky used the DP concept for optimizing the total benefit, but the Kentucky approach allows for future growth in benefits by assuming that future benefits grow at a stipulated rate per year [91,p. 48]. The Alabama procedure assumes that annual ~~benefits are constant [51, pp. 20-37]. Recently, NCHRP~~ Report 84 provides a more up-dated states practices in evaluation criteria and priority setting. This study investigates the California, Florida, Illinoise, Iowa, Minnesota, New Jersey, New York, Utah, Vermont, Washington and Wisconsin practices in which some of them were discussed fully in this section.

## (2-9) SUMMARY AND CONCLUSION FOR STATE-OF-THE-ART

Review of the different techniques and procedures, especially those that are applied in safety programming, indicates that many of the theoretical studies are non-operational, in that they require non-existent or unreliable data; some become unrealistic by using many simplifying assumptions for the sake of a neat mathematical solution. There is always a question of how comprehensively the method tried to measure a given cost or the benefits received. The answer is dependent up on the following factors:

(a) How accurate was the data?

(b) How adequate was the theory which underlay the model ?

(c) How easily could data be fitted to the model, if the model were theoretical in exposition.

These are the major conclusions on the present state of the safety programs evaluation procedures.

(1) Data deficiencies limit ability to make informed choices among different procedures,

(2) The largest conceptual difficulty is the identification and the measurement of the social benefits,

(3) Among the first and most important questions to be considered in evaluating safety programming systems is "what shall be the long-run objectives?" and, can the model respond to this issue?,

(4) Most of the current procedures for transportation safety analyses are too complicated and require a lot of expensive data, impractical for use by small jurisdictions,

(5) There seems to be no definitive, explicitly formulated set of criteria for judging capital projects for safety improvement,

(6) If only one alternative is considered at each accident location, then simple benefit-cost ratios can be used to rank alternative safety pro-~~jects,~~

(7) Only one technique was identified in this research study as being currently used to evaluate large numbers of locations having mutually exclusive safety projects. This technique was dynamic programming as used in Alabama and Kentucky, discussed in section (2-7).

(8) There was no attempt to consider the multiple objectives which actually dominate all the public projects in the current literature. The application of cost-efficient and cost-effective countermeasures often involve the rationalization and compensation of conflicting objectives or goals in safety programming. Further research in this dissertation will be cognizant of goal programming methodologies, and applications of this new and powerful technique will be considered.

(9) Benefit-Cost analysis which is the backbone of all procedures mentioned, should not be deprecated on grounds of fallibility; its purpose is to lead to more informed judgments than would otherwise be possible.

The above statements represent the overall opinion of the author about the current deficiencies in safety programming.

## (2-10) OVERVIEW OF THE NEXT CHAPTER (CHAPTER III)

The methods and procedures which have been discussed in this chapter require a basic data input which should be identified and gathered. Identification has been primarily based on actual accident experience for each location. The next chapter details such practices and proposes the appropriate process to be used in small urban jurisdictions.

# CHAPTER III

# COUNTERMEASURE COST AND EFFECTIVENESS IDENTIFICATION TABLES

## INTRODUCTION:

A major ingredient needed to define a traffic safety countermeasure is an estimate of its cost and effectiveness. Most of the models, including the proposed methodology, require these data as input at the first stage in order to be operational. For this reason, efforts have been made to conduct an identification procedure to review, refine, and collect most valuable and updated information about the cost and effectiveness of the various safety countermeasures employed around the United States and in European countries.

Among several ingredients necessary to adequately define potential traffic safety projects, the factor which is most difficult to obtain is the effectiveness of the safety countermeasures in reducing death, injuries, and property damage accidents. Frequently, effectiveness data for specific countermeasures may not be available for one specific countermeasure, while for others it is hard to find or difficult to come to a unique conclusion because the data are uncorrelated between different countries and even between two different states. Even more disturbing is the fact that when the same countermeasure is evaluated by different investigators, the resultant estimates of effectiveness may differ significantly.

Referring to the different literatures, vast differences in estimating countermeasure effectiveness are demonstrated. For example, considering the automatic protective devices at railroad grade crossing, Dale(28) indicates that employing such a countermeasure will reduce the total accidents by 28.4 percent while Roy Jorgenson(66) suggested different figures for accident reduction with the same safety deployment. In another conflicting case in the results of literature review, the California Department of Transportation(14) recommends a 30 percent reduction in the accident rate to reflectorized guide markers at horizontal curves, while Council, et. al., (24) stated differently and recommended that delineation on curves produces a 16 percent reduction in the accident rate(79).

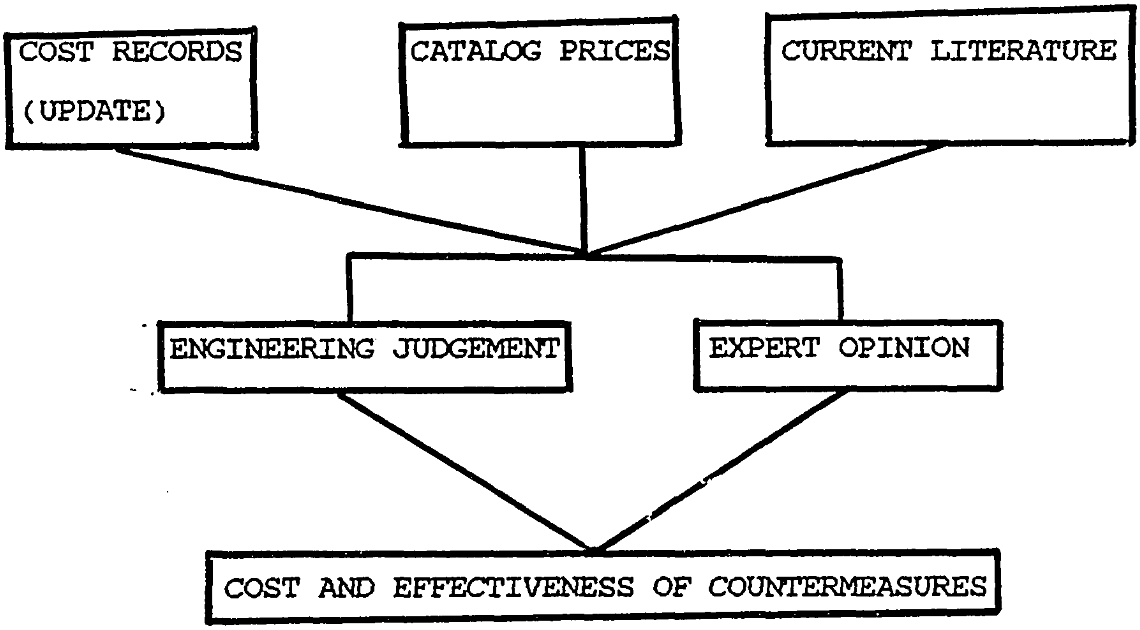
These conflicting results are mostly attributed to the lack of a systematic evaluation methodology that should be part of an on-going process where a safety countermeasure is implemented. It is a fact that many accident countermeasures have not been evaluated or have been poorly evaluated. With the lack of a safety evaluation system, the real value of many countermeasures routinely employed are unknown, and many other estimates for countermeasure effectiveness are underestimated or overestimated.

As a result of the above deficiencies, it should not be concluded that all efforts to model a cost-effectiveness study should be abandoned, but that these efforts should be increased as well as the parallel efforts to calibrate the effectiveness of data input and implement an on-going evaluation system for safety countermeasures that are already implemented.

Here an effort is made to gather the most reliable information about the cost and effectiveness of the different countermeasures that are mostly summerized in Appendix(A). Figure(3-1) demonstrates an approach that is proposed in this dissertation for updating cost and effectiveness.

FIGURE (3-1)

APPROACH TO IDENTIFY AND UPDATE THE COST AND EFFECTIVENESS OF SAFETY COUNTERMEASUES



## (3-1) COST AND EFFECTIVENESS OF SAFETY COUNTERMEASURES

This section contains the cost and effectiveness data information of the most valuable and available safety countermeasures. Appendix(A) also represents different figures related to the cost and effectiveness of safety countermeasures used by different transportation agencies around the United States. However, emphasis have been given to the Intersections, Pedestrians, and General countermeasures.

### (3-1.1) COST OF SAFETY COUNTERMEASURES FOR CONTROLLING THE INTERSECTIONS

The reliable resources for estimating the cost of intersection safety countermeasures are found to be as follow:

(1) Personal contact to city transportation officials;

(2) Reviewing the current implemented safety projects costs;

(3) Contact with the traffic device manufacturer and get an estimate.

Considering the number two option, Fleischer(20) provides the following installation and maintenance costs for five alternative means of controlling intersection traffic.

| ALTERNATIVE | INSTALLATION | MAINTENANCE ( $ per year) |
|---|---|---|
| 4-way stop | $ 187 | $ 364 |
| fixed signal | $ 6729 | $ 5465 |
| semi-act. | $ 7196 | $ 5920 |
| fully-act. | $ 7477 | $ 6148 |
| *fully-act. | $ 11682 | $ 6831 |

Table (3-1) COST OF INTERSECTION COUNTERMEASURES

Source(79, p. 62).

* Fully-actuated with left turn channelized

Dale(29) indicated an updated cost figure to Fleischer's estimate of the average cost of installing a traffic signal and it was about $ 5767. On the other hand, the State of Alabama estimates the installation cost of a traffic signal to be about $ 9000. The recent and most up-dated figure is related to the McFarland et. al., that have been used by the most States Department of Transportation as follow:

| SIGNAL TYPE | INITIAL COST (Material & Equip.) | (Labor) | TOTAL | MAIN. COST (Per Year) |
|---|---|---|---|---|
| FIXED TYPE | $ 7000 | $10-14000 | 18-21000 | 150-225 |
| FULLY ACTUATED | 10,000 | 14-1900 | 24-29000 | 300-480 |
| 5-PHASE | 16,000 | 23-31000 | 39-47000 | 300-480 |
| 6-PHASE | 17,000 | 24-32000 | 41-49000 | 300-480 |
| 8-PHASE | 18,000 | 26-35000 | 44-53000 | 300-480 |

Data have been compiled from (79, p. 63)

Table (3-2) COST OF INTERSECTION COUNTERMEASURE

## (3-1.2) ESTIMATE OF COUNTERMEASURE EFFECTIVENESS

This section provides the user with the most updated effectiveness figures for different safety countermeasures. The accident reductions that resulted from the implementation of the given countermeasure are summerized in Tables (3-3) and (3-4). The selected sources are also included for further information. These data have been compiled from DOT/FHWA/NHSTA, July 1975.

# ACCIDENT EXPERIENCE BY INTERSECTION ELEMENT

| Study Element | Average Yearly Accidents/Intersection | | | | Annual Savings in Injury Severity ($) | Statistical Confidence (%) |
|---|---|---|---|---|---|---|
| | Average Daily Traffic | Obstructed | Clear | Difference | | |
| Sight-distance visibility | ≤20 ft | | | | | |
| | <5,000 | 1.5 | 1.3 | 0.2 | 700 | 99 |
| | 5,000 to 10,000 | 2.9 | 1.9 | 1.0 | 3,700 | |
| | 10,000 to 15,000 | 4.1 | 3.2 | 0.9 | 3,300 | |
| | >15,000 | 11.4 | 6.2 | 5.3 | 19,400 | |
| | ≤50 ft | | | | | |
| | <5,000 | 1.4 | 1.38 | 0.02 | - | |
| | 5,000 to 10,000 | 2.2 | 1.9 | 0.3 | 1,100 | |
| | 10,000 to 15,000 | 4.3 | 2.9 | 1.4 | 5,100 | |
| | >15,000 | 8.2 | 6.0 | 2.2 | 8,100 | |
| | ≤100 ft | | | | | |
| | <5,000 | 1.4 | 1.3 | 0.1 | 400 | |
| | 5,000 to 10,000 | 2.1 | 1.9 | 0.2 | 700 | |
| | 10,000 to 15,000 | 4.0 | 2.8 | 1.2 | 4,400 | |
| | >15,000 | 8.7 | 4.8 | 3.9 | 14,300 | |
| | | White Lettering on Dark Background (Reflectorized) | Dark Lettering on White Background (Non-reflectorized) | | | |
| Street-sign lettering and background | <5,000 | 1.3 | 1.4 | <0.1> | - | 99 |
| | 5,000 to 10,000 | 2.3 | 1.7 | 0.6 | 2,200 | |
| | 10,000 to 20,000 | 4.0 | 3.1 | 0.9 | 3,300 | |
| | >20,000 | 10.4 | 5.3 | 5.1 | 18,700 | |
| | | With Storage Lanes | Without Storage Lanes | | | |
| Intersection geometry<br>Left-turn storage lanes (exclusive of multiphase signals) | 10,000 to 15,000 | 5.9 | 3.5 | 2.4 | 8,800 | 99 |
| | 15,000 to 20,000 | 7.8 | 5.4 | 2.4 | 8,800 | |
| | >20,000 | 16.2 | 10.1 | 6.1 | 22,400 | |
| | | With | Without | | | |
| Ceramic markers and retroreflectors | 5,000 to 10,000 | 2.1 | 2.3 | 0.2 | 700 | 95 |
| | 10,000 to 20,000 | 3.6 | 5.7 | 2.1 | 7,800 | |
| | | With | Without | | | |
| Bus stops and routes<br>Loading zones (stops) | <5,000 | 1.4 | 1.4 | 0 | - | 95 |
| | 5,000 to 10,000 | 2.4 | 2.0 | 0.4 | 1,500 | |
| | 10,000 to 15,000 | 4.4 | 3.5 | 0.9 | 3,300 | |
| | 15,000 to 25,000 | 8.3 | 4.3 | 4.0 | 19,700 | |
| | | Along Bus Routes | No Bus Route | | | |
| Routes | <5,000 | 1.4 | 1.3 | 0.1 | 400 | 95 |
| | 5,000 to 10,000 | 2.4 | 1.9 | 0.5 | 1,800 | |
| | 10,000 to 15,000 | 4.3 | 2.7 | 1.6 | 5,900 | |
| | 15,000 to 25,000 | 7.0 | 3.8 | 3.2 | 11,700 | |
| | | With | Without | | | |
| Signalization*<br>Left-turn-only signal phase | <15,000 | 0.3 | 1.1 | 0.8 | 12,600 | 90 |
| | >15,000 | 1.8 | 3.0 | 1.2 | 18,900 | |

*Figures relate to fatal injury accidents only.

Source: "Motor Vehicle Accidents in Relation to Geometric and Traffic Features" DOT/FHWA/NHTSA, July 1975

Table (3-4) Estimates of Countermeasure Effectiveness

| COUNTERMEASURE | PERCENT ACCIDENT REDUCTION Fatal | Inj | PDO | Total | SOURCE |
|---|---|---|---|---|---|
| Utility poles and trees: | | | | | |
| a. Make utility poles breakaway | 30.0 | -1.0 | 0 | | [48] Frye |
| b. Relocate utility poles 30 ft from edge of pavement. | 32.0 | -1.7 | 0 | | [48] Frye |
| c. Remove utility poles. | 38.0 | -1.5 | 0 | | [126, 127] Winfrey |
| d. Remove trees. | 50.0 | 25.0 | -20.0 | | [48] Frye |
| Automatic protective devices at railroad grade crossings. | No Change | -16.3 | | 28.4 | [110] Texas's DOT |
| Railroad highway grade crossings upgraded from passive to active status: | | | | | |
| a. Urban | | | | 12.0 | [126] Winfrey |
| b. Rural | | | | 20.0 | |
| Pavement anti-skid treatment | -8.0 | 15.7 | | 20.6 | [110] Texas's DOT |
| Resurfacing sections of highway: | | | | | |
| a. Urban, more than 2 lanes | (46) | | | 42.0 | [42] Fleischer |
| b. Rural, 2 lanes | (21) | | | 12.0 | [42] Fleischer |
| c. Rural, more than 2 lanes | (59) | | | 44.0 | [42] Fleischer |
| Pavement widening (with or without added lanes) without new median, and shoulder widening or improvement. | -13.3 | 3.18 | 1 | 28.0 | [110] Texas DOT |
| Widen the travel way (no dimensions) on rural 2 lane sections of highway. | (30) | | | 38.0 | [42] Fleisher |

ORIGINAL SOURCES.(79, 110,126, 127)

Estimated of Countermeasure Effectiveness (continued)

| COUNTERMEASURE | PERCENT ACCIDENT REDUCTION Fatal | Inj | PDO | Total | SOURCE |
|---|---|---|---|---|---|
| Installing or upgrading of traffic signs. | -15.4 | 29.2 | | 4.8 | [110] Texas's DOT |
| Install/improve warning signs along section of highway: | | | | | |
| a. Urban, 2 lane roads | (]4) | | | 14.0 | Fleischer |
| b. Urban, more than 2 lane roads | (26) | | | 20.0 | [42] |
| c. Rural, 2 lane roads | (32) | | | 36.0 | [42] |
| d. Rural, more than 2 lane roads | ( 3) | | | 18.0 | [42] |
| Install/improve warning signs on rural curves: | | | | | |
| a. 2 lane | (71) | | 23.0 | 57.0 | [42] |
| b. more than 2 lanes | (40) | | | 52.0 | [42] |
| Signing: curve warning arrows. | | | | 20.0 | [42] |
| Installation of stripping and/or delineators | 100.0 | 39.2 | | 18.9 | [110] Texas' DOT |
| Install/improve edge marking on 2 lane sections of rural highway. | (17) | | | 14.0 | [42] Fleischer |
| Right edge lines | | | | 2.0 | [42] Fleischer |
| Install delineators on rural curves: | | | | | |
| a. 2 lanes | (16) | | | 2.0 | [42] Fleischer |
| b. more than 2 lanes | (-10) | | 61.0 | 46.0 | [42] Fleischer |
| Reflectorized guide markers at horizontal curves | | | | 30.0 | [42] Fleischer |
| Delineation on curves | 16.0 | 16.0 | 16.0 | 16.0 | [127] Winfrey |

Estimates of Countermeasure Effectiveness (continued)

| COUNTERMEASURE | PERCENT ACCIDENT REDUCTION Fatal | Inj | PDO | Total | SOURCE |
|---|---|---|---|---|---|
| Concrete median barrier: | | | | | |
| a. median width 1-12 feet | 90.0 | 10.0 | -10.0 | | [48] Frye |
| b. median width 13-30 feet | 85.0 | 5.0 | -25.0 | | [48] |
| Installation or improvement of median barrier. | 17.5 | -8.5 | | -35.6 | [40] Texas' DOT |
| Install median barriers on highways with more than 2 lanes: | | | | | |
| a. Cable type | (4) | | | -33.9 | [42] Fleischer |
| b. Beam type | (-22) | | | -20.0 | [42] |
| Channelization including left turn bays | 42.3 | 51.5 | | 32.4 | [110] Texas' DOT |
| Add left turn lane without signal: | | | | | |
| a. Urban, 2 lane roads | (80) | | | 19.0 | Fleischer |
| b. Urban, more than 2 lane roads | (54) | | 18.0 | 6.0 | [42] Fleischer |
| c. Rural, more than 2 lane roads | (-1) | | | 6.0 | [42] Fleischer |
| Add left turn lane and signal: | | | | | |
| a. Urban, more than 2 lane roads | | | | | |
| b. Rural, more than 2 lane roads | (1) | | 7.0 | 27.0 | [42] Fleischer |
| Add left turn channelization at non-signalized intersections: | | | | | |
| a. Curbs and/or raised bars, urban area. | | | | 70.0 | [42] |
| b. Curbs and/or raised bars, suburban area | | | | 65.0 | [42] Fleischer |
| c. Curbs and/or raised bars, rural area | | | | 60.0 | [42] Fleischer |
| d. Painted channelization, urban area | | | | 15.0 | [42] Fleischer |

Estimates of Countermeasure Effectiveness (continued)

| COUNTERMEASURE | Fatal | Inj | PDO | Total | SOURCE |
|---|---|---|---|---|---|
| New safety lightning: | | | | | |
| a. at intersections | | | | 75.0 | [42] Fleischer |
| b. railroad crossing | *Percent of Night Accidents | | | 60.0 | [42] Fleischer |
| c. bridge approach | | | | 50.0 | [42] Fleischer |
| d. underpass | | | | 10.0 | [42] Fleischer |
| Lighting: | | | | | |
| a. Urban freeways | 50.0 | 20.0 | 14.0 | | [127] Winfrey |
| b. Urban interstate interchanges and rural primary intersections | 50.0 | 50.0 | 50.0 | | [127] Winfrey |

## (3-2) PEDESTRIAN SAFETY IMPROVEMENT PROJECTS COST & EFFECTIVENESS

This section provides brief information on the cost and effectiveness of various types of pedestrian safety facilities. This information should not be intended to substitute for the detailed analysis of costs , but rather to provide a basis for comparison between alternative safety facilities with the aid of the current literature. It goes without saying that the information presented in this section should be periodically updated.

There are many pedestrian safety facilities which have played a significant role in reducing accidents in urban areas. Here, an attempt is made to present some of the important safety facilities which may be considered by the traffic engineer manager as practical and effective safety projects. It is beyond the scope of this dissertation to discuss the structural and design elements of the pedestrian safety facilities, but the presented materials would help the decision maker to estimate and quantify the safety needs of his/her community in order to operate the feasibility and optimality models proposed in this dissertation. Appropriate references have been provided should the user need detailed information about the specific safety countermeasures.

(3-2.1) PEDESTRIAN ACCIDENT PATTERNS

Using the recent 1979 nationwide statistics, the following figures can be found (116):

(1) 20 percent of all urban motor vehicle accidents involved pedestrians;

(2) 30 percent of all urban fatal accidents involved pedestrians;

(3) 25 percent of all fatal pedestrian accidents involved children;

(4) 25 percent of all fatal pedestrian accidents involved people 65 years of age or over;

(5) 70 percent of all pedestrian accidents occurred while pedestrians were crossing the street;

(6) 40 percent of all pedestrian accidents occurred while pedestrians were crossing at an intersection.

Considering the above statistical facts, crossing the street and crossing intersections have the highest probability of accident occurrence in urban areas. For this reason four major generic pedestrian safety facilities are considered here as follows:

- highway overpasses (pedestrian bridge)
- street and highway under-passes (pedestrian

tunnels),

- elevated skyways,
- full and partial at-grade malls.

In addition to the costs of construction, there are several other type of costs that should be considered by the decision maker. These costs include delay costs due to the construction, land, excess cost of vehicle operation due to speed reduction, and social and environmental costs. References (38,88,95,100) are found to be useful if a user requires more detail informations.

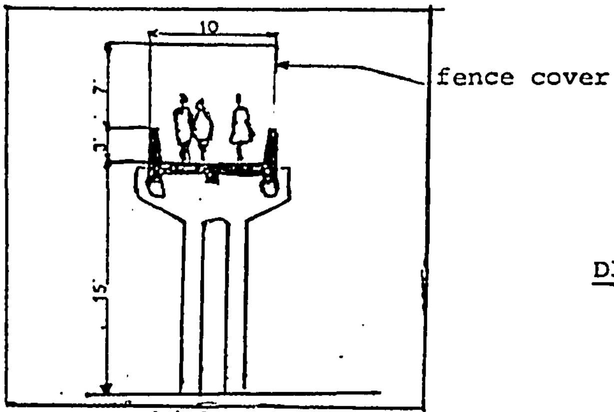
## (3-2.2) HIGHWAY OVERPASSES

In estimating the cost of a highway overpass, it is very difficult to come up with a unique number because of the differences in location, design elements, etc. However the elemental cost information necessary to estimate the base cost of constructing a highway overpass is shown under the given assumption and are shown in Table (3-5) and Figure (3-2).

| (1) UNIT COST OF AERIAL STRUCTURE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Material/ Construction | Conventional Steelwork (cased) | | | Conventional Concrete/Cast in Place | | | Concrete/Precast | | |
| Length of Clear Span (feet) | 40 | 80 | 120 | 40 | 80 | 120 | 40 | 80 | 120 |
| Cost per Lineal Foot ($) | 345 | 380 | 400 | 215 | 245 | 270 | 225 | 260 | 230 |

| (2) OTHER COSTS | |
|---|---|
| Drainage | Add $16 per lineal foot |
| Lighting | Add $28 per lineal foot |
| Pier | Add $2,420 for each pier |
| Median Strip (30' x 8') | Add $1,200 for each median |

TABLE (3-5) ELEMENTAL, CONSTRUCTION COSTS FOR HIGHWAY OVERPASSES




highway • overpass crossing

SECTION

DIMENSIONAL PROPERTIES

ASSUMPTIONS:

(1) AERIAL STRUCTURE

- 12-15 foot width overall
- Varying depth edge beams/side walls depending on span
- Protective screening (fencing cover) provided to serve as safety covering
- Lighting and drainage are costed separately
- Cost varies with finishing materials, construction and span

(2) PIERS

- 15 foot high cast-in-place concrete
- 2 foot wide at terminal of overpass
- Median strip, if required, costed separately

(3) MEDIAN STRIP

- 30 x 8 foot median
- Concrete with curbing and guard rails

FIGURE (3-2)

ASSUMPTIONS REGARDING COSTS OF HIGHWAY OVERPASSES

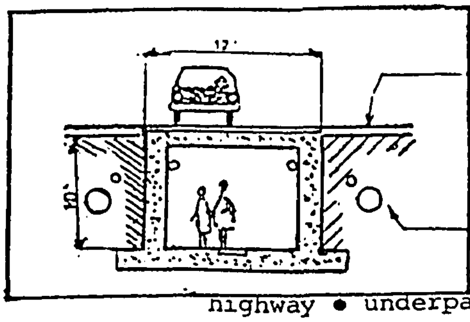
Source(100).

(3-2.3) STREET AND HIGHWAY UNDERPASSES

Table(3-6) represents the unit construction costs for a pedestrian tunnel (highway underpasses). However, any estimate for costs should always be made regarding the necessary assumptions and these assumptions are demonstrated in Figure (3-3).

| | CONDITION | PER LINEAR FOOT |
|---|---|---|
| (1) | Cut and Cover Construction No Restriction | $ 780 |
| (2) | Cut and Cover Construction With Street decking to Maintain Traffic Flow | 1170 |
| (3) | Tunneled Underpass, Cast-In-Place Concrete | 2040 |

Table (3-6) Unit Construction Costs For Highway Underpasses
All figures are in 1974 dollars.
Source(100, p. 55)




SECTION

DIMENSIONAL PROPERTIES

ASSUMPTIONS:

(1) CONDITION 1 - BUILT IN CONJUNCTION WITH NEW ROADWAY CONSTRUCTION

- Concrete, continuously supported
- 12-15 feet wide by 10 feet high, minimum
- Natural ventilation (for lengths < 200 feet)
- Lighting and drainage cost included
- Normal cut and fill excavation (rock and other foundation problems will incur extra cost

(2) CONDITION 2 - BUILT UNDER EXISTING ROADWAY

- Same as condition 1 except that added costs are incurred to remove road (street) surface and provide decking to maintain traffic flow

(3) CONDITION 3 - TUNNEL UNDER EXISTING ROADWAY

- Same as condition 1, except costs reflect tunnel excavation including normal shoring and cast-in-place concrete
- Traffic flow is unimpeded

FIGURE (3-3)

ASSUMPTIONS REGARDING COSTS OF STREET AND HIGHWAY UNDERPASSES

Source(100).

## (3-2.4) ELEVATED SKYWAYS

Elevated skyways are similar to highway overpasses in terms of their methods of cost estimation(100,105). The unit cost is dependent on material, construction and span. Table (3-7) and Figure (3-4) demonstrate the elemental construction cost and unit costs for steel trussed construction skyways respectively.

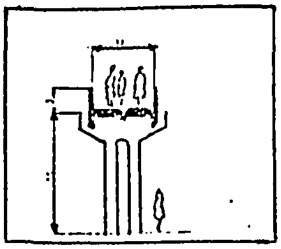
| (1) SKYWAY ONLY | | | | |
|---|---|---|---|---|
| Material/ Construction | Conventional Steel (cased) | | Conventional Concrete/Cast-in-Place | |
| Length of Clear Span (feet) | 40 | 80 | 40 | 80 |
| Cost per Lineal Foot ($) | 320 | 356 | 190 | 215 |
| (2) ENCLOSURE SYSTEM | | | | |
| (a) Covered, not enclosed | Add $60 per lineal foot to (1) | | | |
| (b) Enclosed, heated only | Add 620 per lineal foot to (1) | | | |
| (c) Enclosed, heated and air conditioned | Add 735 per lineal foot to (1) | | | |
| (3) PIER | Add $3,950 for each pier | | | |

TABLE (3-7) ELWMWNTAL, CONSTRUCTION COST FOR ELEVATED SKYWAY SYSTEMS

| CONDITION | $ PER SQUARE FOOT |
|---|---|
| (1) Structure only including decking | 98 |
| (2) Totally enclosed and air conditioned | 170 |

TABLE (3-7a) UNIT COSTS FOR STEEL, TRUSSED CONSTRUCTED SKYWAYS

SOURCE(COMPILED FROM 100).



elevated • open
walkway

SECTION

DIMENSIONAL PROPERTIES
FOR OPEN SKYWAYS

ASSUMPTIONS:

(1) AERIAL STRUCTURE

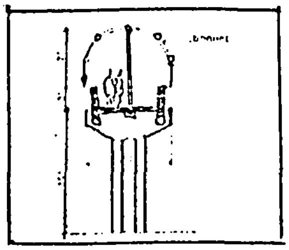
- Cost varies by materials/construction and span
- Includes costs of lighting, drainage and handrails
- Spans are 0'-40' and 40'-80'

(2) SUPERSTRUCTURE (PIER)

- Concrete, cast-in-place, includes footing
- 15 feet high, with 2-foot wide section
- Applies to all enclosure types

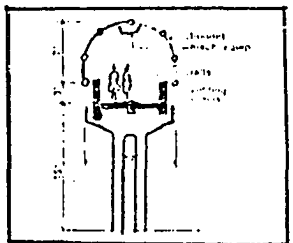
(3) ENCLOSURES

- Sectional dimensional properties



elevated o covered
walkway

covered
o Bonnet is aluminum tubing frame with ¼" tinted plexiglass



elevated o enclosed
walkway

enclosed
o heated only
o heated and air conditioned

FIGURE (3-4)
ASSUMPTIONS REGARDING ELEVATED SKYWAY SYSTEMS
(CONVENTIONAL STEEL AND CONCRETE STRUCTURES ONLY)

Source(100).

(3-2.5) STREET CROSSING

As mentioned before, about 70 percent of all pedestrians involved in accidents occurred while they were crossing the street. For this reason it is necessary and important to design a cost-effective countermeasure to reduce these pedestrian accidents. The grade-separated facilities commonly used in urban areas are considered to be an effective and comparatively low cost alternative. One 12 feet wide, enclosed, with an eighty-foot span is considered as an example, and the cost figures are estimated. Table(3-8) indicates that the elevated walkway system built using conventional construction methods appears to be the most economic solution.

| OPTION NUMBER | FACILITY TYPE | MATERIAL AND CONSTRUCTION METHODS | NUMBER OF | | | TERMINAL CONNECTORS | UNADJUSTED CONSTRUCTION COST |
|---|---|---|---|---|---|---|---|
| | | | SPANS | PIERS | MEDIANS | | |
| 1 | Overpass | Conventional Steelwork | 1-80' | 2 | 0 | Stairs | $ 57,994 |
| 2 | " | " | " | 2 | 0 | Ramps | 65,094 |
| 3 | " | " | 2-40' | 4 | 1 | Stairs | 61,410 |
| 4 | " | " | " | 4 | 1 | Ramps | 68,410 |
| 5 | Overpass | Conventional Cast-In-Place Concrete | 1-80' | 2 | 0 | Stairs | 47,194 |
| 6 | " | " | " | 2 | 0 | Ramps | 54,294 |
| 7 | " | " | 2-40' | 4 | 1 | Stairs | 50,830 |
| 8 | " | " | " | 4 | 1 | Ramps | 57,930 |
| 9 | Overpass | Precast Concrete | 1-80' | 2 | 0 | Stairs | 48,554 |
| 10 | " | " | " | 2 | 0 | Ramps | 55,654 |
| 11 | " | " | 2-40' | 4 | 1 | Stairs | 53,310 |
| 12 | " | " | " | 4 | 1 | Ramps | 60,410 |
| 13 | Underpass | Cut and Fill; New Road | | | | | 62,240 |
| 14 | " | Cut and Fill; Existing Road | | | | | 93,200 |
| 15 | " | Tunnelling; Existing Road | | | | | 163,200 |

TABLE (3-8) HIGHWAY CROSSING COST COMPARISON
SOURCE: COMPILED FROM REFERENCE 100.

## (3-2.6) PEDESTRIAN BICYCLE FACILITY COST ESTIMATION

Considering a bicycle facility as a safety countermeasure, the following criteria should be considered(69,116):

(a) The safety of the bicyclist, pedestrians or vehicular traffic must not be impaired;

(b) The proposed facility must be a part of and connect to elements of existing or planned systems;

(c) The facility must be under the jurisdiction of a public agency; and

(d) There must be sufficient existing or projected demand to render the proposed facility cost-effective.

Table(3-19) demonstrates an approximate cost-estimate for various type of bicycle safety facilities.

TABLE(3-19) BICYCLE SAFETY FACILITY COST PER MILE

| TYPE OF FACILITY | INITIAL COST | ANNUAL MAINT. COST |
|---|---|---|
| BIKEWAY | $ 30,000 | $ 1500 (ASPHALT)<br>950 (CONCRETE) |
| PROTECTED BICYCLE LANE ON STREET | 6,000 | 600 |
| UNPROTECTED BICYCLE LANE ON STREET | 3,000 | 300 |
| BIKE ROUTE | 700 | 100 |

Costs are in 1974 dollars.
Source (110)

## (3-3) SUMMARY

Attributing precise accident or fatality reduction to a particular safety improvement countermeasure is difficult and sometimes impossible. Careful research and evaluation techniques can greatly reduce the margin of error, but variations in the environment of roads and conditions from state to state compound the problems of predicting safety improvement effectiveness. All the information indicated in this chapter must be periodically updated according to the proposed procedure mentioned in section one.

## (3-4) OVERVIEW OF THE NEXT CHAPTER

Next Chapter provides guidelines for a local decision maker(s) to establish a systematic program for identifying high-hazard locations. Several procedures and techniques are discussed and an appropriate and more effective one is recommended.

## CHAPTER IV

## PROCEDURES TO IDENTIFY THE HIGH-HAZARD LOCATIONS

The objective of this chapter is to provide guidelines for a local decision maker to establish a systematic program for identifying high-hazard locations. Several procedures and techniques will be discussed, and the appropriate one will be suggested for use by the local transportation agency. Attempts also are made to define different criteria for selecting high-hazard locations.

### (4-1) MOTIVATION:

Highway Safety Program Standard No. 9 specifies that(116):

> (a) There shall be a procedure for accurate identification of accident locations on all streets and highways to produce an inventory of high-accident location and locations where accidents are increasing sharply.
>
> (b) There be a systematically organized program to maintain continuing surveillance of the road network for potentially high accident locations.
>
> ~~(c) The process shall also "include procedures for~~ identifying the high-hazard locations and to take appropriate measures for reducing accidents".

As stated above, a systematic method of identifying problem location is most important. At this point the total program is either enhanced or limited, based on the objective of the local safety program. A rather broad objective can be achieved by setting up a broadly-based identification procedure. However, the extent of the identification procedure is usually limited in small urban jurisdictions, due to a lack of resources.

Two types of procedures are recommended for identifying the high-hazard locations:

(1) Non Accident Based Evaluation Criteria,

(2) Accident Based Evaluation Criteria.

These two categories can also be extended to subcategories which can be identified as elements of the hazard-identification criteria. These elements are as follows:

(a) Traffic Measure;

(b) Field Observations;

(c) Diagnostic Team Study;

(d) Citizen Input;

(e) Enforcement Input;

(f) Use of Accident Data.

In using any of the above procedures, the local transportation agency should clearly indicate and state its evaluation objective. The evaluation objectives should usually be stated in terms of the expected effects of the projects on an accident characteristic. In chapter seven the proposed goal programming model can handle the multiple objectives as well as the local goals, but in this stage of safety programming the evaluation objectives are limited to the four fundamental objectives:

(1) Total Accident Reduction;

(2) Fatal Accident Reduction;

(3) Personal Injury Reduction

(4) Property Damage Accident Reduction.

It is also possible to construct the local safety objective based on the several purposes. But only those purposes of critical interest should be translated into the evaluation objectives.

After identifying the high-hazard locations which are subjected to statistically significant reductions in at least one location, the economic evaluation should be performed. This is the subject of the chapter five of this dissertation that represents different computer programs for economic evaluation of safety projects under a limited budget and can be used easily by the local decision maker.

As mentioned previously, current federal policy requires that identification of hazardous locations be based on analysis of accident experience (106). In applying such a federal requirement, it is necessary to establish "evaluators" which can be used directly for identifying the hazardous locations. Four different analysis techniques can be use to establish the safety evaluators as follows:

(1) Number Of Accidents Method,

(2) Rate of Accidents Method,

(3) Number Rate Method.

(4) Rate-Quality Control Method.

Usually, when the project site is located in an area where no appreciable increase or decrease in traffic volume has occurred or is expected, it is appropriate to select frequency method as an accident evaluator. When traffic volumes are expected to vary, a rate related evaluator is recommended. In this case, the frequency value is a function of traffic exposure at the project site. Exposure units are usually expressed as either the number of vehicles or the number of vehicle-miles of travel depending on the type of project site location. For example, for intersection or spot improvements, numbers of vehicles should be used as the exposure unit. On the other hand, vehicle-miles of travel is recommended to be used for extended roadway sections. Table (4-1) shows the highway safety project codes used by the Federal Highway Administration with corresponding exposure units.

TABLE(4-1) RECOMMENDED EXPOSURE FACTORS BY FHWA

| PROJECT TYPE | RECOMMENDED EXPOSURE FACTOR |
|---|---|
| **1. INTERSECTION PROJECTS** | |
| (a) Channelization | V |
| (b) Traffic Signals, installed or improved | V |
| (c) Combination of a and b | V |
| (d) Sight Distance improved | V |
| **2. CROSS SECTION PROJECTS** | |
| (a) Pavement widening, no lanes added | VM |
| (b) Lanes added, without new median | V or VM |
| (c) Highway divide, new lane | V or VM |
| (d) Shoulder widening | VM |
| (e) Skid Treatment/Grooving | VM |
| (f) Skid Treatment/Overlay | VM |
| (g) Flattening and/or clearing of side slope | V or VM |
| **3. STRUCTURES** | |
| (a) Widening existing bridge | V |
| (b) Replacing of bridge | V |
| (c) Construction of new bridge | V |
| (d) Minor construction | V |
| (e) Construction of pedestrian over crossing | V |
| **4. ALIGNMENT PROJECTS** | |
| (a) Horizontal alignment change | V or VM |
| (b) Vertical alignment change | V or VM |
| (c) Combination of a and b | V or VM |
| **5. RAILROAD GRADE CROSSING PROJECTS** | |
| (a) Flashing lights replacing signs only | V |
| (b) Elimination by relocation of highway | V |
| (c) Automatic gates replacing active device | V |
| (d) Signing and/or marking | V |
| (e) Crossing surface improvement | V |
| **6. ROADSIDE APPURTENANCES** | |

| | |
|---|---|
| (a) Installation or upgrading traffic sign | V or VM |
| (b) Breakaway sign or lighting supports | V or VM |
| (c) Installation of median barrier | V or VM |
| (d) Roadway lighting installation | V or VM |
| (e) Impact attenuators | V or VM |

** V: VOLUME

*** VM: VEHICLE-MILES

Source (54,118).

## (4-2) METHODS DESCRIPTIONS

Here an attempt is made to identify the appropriate methods which can be used by a small urban jurisdiction. Two methods are found to be appropriate for the small transportation systems (1) Number of Accident method and (2) the Frequency Related Method.

Number of Accident Method can be used effectively for small town street systems, local street systems in larger cities and low volume county roads. This is the simplest and most direct approach. All accidents are recorded by location and by the time period during which they occurred. As the number of traffre is not significant, there will not be many accidents, and few clusters of accidents will be found. Where clusters do appear, there will be an objective basis for investigation to determine if some element of roadway facility may be contributing to the accidents. In using this method, it is recommended that an accident spot map be used to facilitate the process.

The frequency evaluator method is also very simple to identify high accident location. Locations which have a large number of accidents would be studied. The shortcoming of this method is that exposure or the number of vehicles using the facility is not considered in determining the priority of the study locations, but still is recommended for small urban jurisdiction because the exposure factor most of the time is not significant nor available.

Traffic volume has a great influence on accident frequency, so it should be considered as a measure of exposure to hazard of an improper highway features; it could be expected that safety improvement payoff woul directly related to the traffic volumes. By stratifying the highway improvement by traffic volume classification, a measure of this influence may be seen. So, in this case when the exposure factor is considered the complexity of identification procedure is added. Having the exposure factor, the question of accident risk can be easily answered, i.e.,a road location may have numerous accidents because it is heavily traveled rather than because it is especially hazardous. So, risk or hazard can be expressed as an accident rate as follow:

$$\text{RATE} = \frac{\text{THE NUMBER OF ACCIDENTS AT A LOCATION}}{\text{THE NUMBER OF CARS USING THE LOCATION}}$$

This concept can be further extended for two type of locations such as intersection and roadway. The intersection rate is the number of involvements per million of users as follow:

$$\text{RATE(INTER.)} = \frac{2 * \text{ACC} * 10{*}{*}6}{T * (V1 + V2 + \ldots + Vn)}$$

where;

RATE(INTER.) is the junction involvement or accident per million vehicle entering,

ACC is the number of accidents recorded in T days,

T is the period for which accidents are counted,

V1,...Vn is average annual daily traffic on one junction leg or approach(n is the number of approach).

The same formula can be modified and is used for the roadway as the roadway sections vary in length and, therefore, give different exposure to accidents, so, rates for road sections must be in terms of accidents per million vehicle miles or 100 million vehicle miles of travel.

$$\text{RATE(ROADWAY)} = \frac{\text{ACC} * 10 ** 6}{T * V * L} \quad \text{or} \quad \frac{\text{ACC} * 10 ** 8}{T * V * L}$$

where;

RATE(ROADWAY) is the section rate in accident per million vehicle miles,

V is average annual daily traffic on a section,

T is the period for which accidents are counted,

L is the length of the section in miles.

A location with relatively high numbers of accidents per mile may appear to be quite hazardous. But if the traffic exposure is significant in the location site, the accident rate may not be abnormal and the situation may not be as bad as it seems to be.

For identifying the hazardous locations, if both the number of accidents and accident rate significantly exceed the average, there would be a strong indication that the site is hazardous.

## (4-3) RATE QUALITY CONTROL METHOD

This method is applicable to systems of all sizes and ranges of traffic volumes. It assures control of the quality of the analyses by applying a statistical test to determine whether a particular accident rate is unusual, as related to the predetermined average accident rate for locations having similar characteristics (66). Care should be made to consider that the assumption of accidents fits the Poisson distribution when such a method is applied.

## (4-4) CRITERIA FOR IDENTIFYING THE HIGH HAZARD LOCATION

The critical accident rate can be used as an evaluator for identifying the hazardous location. Usually, the critical rate is determined statistically as a function of the systemwide average accident rate for the section or roadway within certain vehicle exposure for different locations ( urban or rural). NCHRP report 162 recommends the following formula:

$$Rc = Ra + K ( Ra/m) - (0.5/m)$$

Where:

Rc = Critical accident rate

Ra = Systemwide average accident rate by highway category ( for sections...accident per MVM) ( for intersection...accident per MV)

m = Vehicle exposure during study period (MV or MVM)

K = is a constant for different level of confidence

The values of K for various levels of confidence are shown bellow (66):

| LEVEL OF CONFIDENCE | K |
|---|---|
| 0.995 | 2.576 |
| 0.95 | 1.645 |
| 0.90 | 1.282 |

As mentioned in the NCHRP Report 162, from the practical standpoint, variations in the value of K will result in different numbers of locations which will appear on the hazardous location list. So if the lower value of k is assumed , the number of hazardous locations will be increased, but with the higher value of K those numbers will be decreased. The following procedure can be used to identify the high hazard location by the small urban jurisdiction traffic agency.

## PROCEDURE TO IDENTIFY THE HIGH-HAZARD LOCATION

compute systemwide average number of accidents

Average acc. =: (no. of accidents *10**6)/(Sec ADT*Period*length)

Identify all clusters of accidents at spots

(no. of cluster accidents)*10 **6
Average Acc.(MV)= : (no. of cluster acc.)/(ADT at cluster* period)

Determine the vehicle exposure for each location

m =:
(sec. ADT * period * length)/(10 **6)

For spots:
m =:
(ADT * period)/(10 **6) ....(MV)

Compute the Rc for each location

Compute the actual observed accident rate at each location

For section:
Accident/MVM =:
(no. of accidents)/(million of vehicles)
For spots:

$$\text{Accident/MV} = \frac{\text{no. of accidents}}{\text{million of vehicles}}$$

Compare the actual accident rate with critical rate at each location

Prepare a list of hazardous location for those locations whose rates exceed the critical values.

(4-5) SUMMARY

Once the safety problems are defined, accident patterns may be used to suggest feasible countermeasures to reduce or alleviate the defined safety problemsAs mentioned, the need for accurate identification of accident patterns has been very critical to the overall safety analysis and the eventual project selection. Frequency Related Evaluator and Rate of Accident Method are quite simple and readily adaptable to the smaller highway and street systems especially in small urban jurisdiction. The Number Rate Method and Rate Quality evaluators are recommended for larger systems with higher traffic volumes. Identifying the high hazard location and the procedures used are important because the accuracy of the results of investigation is vital to the local interest in reducing the accidents. Before a local transportation's safety dollars can be spent with the realistic hope of producing a maximum return on investment, it is essential that a local be able to locate its high hazard locations and specify the reasons why those locations are hazardous. Until this step is taken, further steps will not be fruitful.

It is hoped that in the near future potential accident locations will have to be identified by means other than accident records. Now, however, the accident records ~~provide the~~ best means for identifying potentially hazardous locations.

## (4-6) OVERVIEW OF THE NEXT CHAPTER

The need for ensuring that federal and local capital funds are used effectively is becoming increasingly apparent. In this era of constraints on and close scrutiny of public expenditures, transportation safety alternatives must be carefully assessed according to the way they satisfy a locality's safety transportation needs. An important objective of the safety project selection in a local urban jurisdiction is to obtain a complete picture of how well the completed or planned projects are operating from the safety standpoint. In the next chapter the economic analysis provides an additional perspective of the effectiveness. Different techniques are discussed under budget constraints, and interactively programmed to help the local decision maker in making an accurate decision for implementing the proposed projects. A new improved algorithm is recommended and utilized to analyze up to 60 locations, each having several candidate alternatives.

# CHAPTER V

## FEASIBILITY ASSESSMENTS (SAFETY PROJECTS SELECTION)

The objective of this chapter is to introduce different macro techniques for selecting the traffic safety projects. These procedures can be easily used by any local transportation agency. Also, in this chapter a new improved algorithm is presented for incremental benefit-cost analysis. All the proposed techniques are programmed interactively and have been documented in Appendices (B) and (C).

Implementation of any local highway projects should be an on-going process which requires careful planning. To facilitate future planning and implementation decision, evaluation should be performed for those types of projects which have the highest probability of being implemented in the future. Evaluation results may be used to justify increase or reduction in expenditures for specific projects. In all the cases the cost-effectiveness criteria is used for selecting the appropriate traffic safety projects.

Two different algorithms are developed and programmed for selecting the safety projects (or programs) and resource allocation are (1) Feasibility Assessement Model (FA Assessment Model (OAM).

Feasibility Assessment Model is developed in this Chapter and is recommended to be used in local urban traffic agencies. Optimality Assessment Model will be developed in Chapter Six, and is recommended to be used by either local or state governments. Figure (5-1) demonstrates the two-step modeling approaches along with their objectives, functions and capabilities.

The Feasibility Assessment Models presented in this chapter are mathematically sound and they present an ideal level of sophistication. It is expected that the safety system engineer be capable of applying them with a high degree of accuracy. However, the interactive computer programs that are developed reduce the level of sophistication significantly and make it possible for the non-transportation engineer people to apply them with the help of available documents presented in appendices.

It is noteworthy that before any attempt is made to apply the proposed procedures, the local transportation professional should establish systematic identification procedures for high-hazard locations based on the recommended guidelines in chapter four to construct a list of "potential" areas of accident reduction. Of course, the procedure for constructing such a list might range in sophistication from pure management judgement to computerized sorting of

FIGURE (5-1) OVERALL MODELING APPROACH

MODELING APPROACH

A. - FEASIBILITY ASSESSMENT MODEL: (FAM)

1. COST-EFFECTIVENESS SUB-MODEL
2. FEASIBILITY ASSESSMENT MODULE
3. OPTIMAL-LEVEL-OF FUND ALLOCATION SUB-MODEL

- DESIGNED TO BE USED BY LOCAL TRAFFIC AGENCIES
- ALLOCATE THE LIMITED SAFETY FUNDS
- IT IS EASY TO BE UTILIZED AND NOT SO SOPHISTICATED
- CAN BE USED BY LOCAL JURISDICTION TO QUANTIFY HIS SAFETY NEEDS
- IT IS COMPARABLE WITH DYNAMIC PROGRAMMING MODEL
- OPTIMIZE A SINGLE OBJECTIVE SAFETY SYSTEM
- CAN BE OPERATIONAL BY NON-TECHNICAL PERSON

B. - OPTIMALITY ASSESSMENT MODEL

- IT IS MORE SOPHISTICATED THAN FAM
- IT IS VERY FLEXIBLE TO PERMIT A VARIETY OF GOALS
- IT PERMITS TO ACCEPT A WIDE VARIETY OF CONSTRAINTS
- IT IS CAPABLE OF SATISFYING THE GOALS TO THE EXTENT POSSIBLE BASED ON THE <u>PRIORITIES</u> ASSIGNED THEM

accident records. Most of the available sound techniques that can be used by a local transportation agency are documented in Chapter Four if the pure mangement judgment is not adequate for identifying the high-hazard locations. Therefore the first step in using the proposed macro techniques, identifies the high-hazard locations and their related countermeasures. At this level, the proposed techniques provide a definite policy. Equipped with this policy, the local transportation decision maker will be guided to the particular alternative to implement at each critical area.

## (5-1) NEGATIVE UTILITY VALUE FOR HUMAN LIFE LOSS (ACCIDENT COSTS)

In order for analyses of traffic safety improvement projects to be carried out, it is necessary that not only project costs but benefits as well be used so the question of "human-life value" will come to light.

The literature has identified four different methods for calculating the accident costs as follows:

(1) Accident costs includes only those costs directly associated with an accident - property damage, medical expenses, lost work-time from injuries, legal costs, damage awards, and loss of vehicle use.

(2) Accident costs include both direct accident costs and present value of future net production lost to society as the result of an accident.

(3) Accident costs include the gross or total future production, not net future production, of the accident victim.

~~(4)~~ Accident-costs based on the willingness to avoid a fatal accident.

As the result of using different criteria for calculating the accident severity costs, various figures are used by different transportation agencies, but recent surveys indicate that NSC accident cost values, which are the second type of accident cost described above, are the most frequently used (12,14,102,114). Table (5-1) demonstrates the summary of various accident severity costs by different transportation agencies.

SUMMARY OF ESTIMATED SEVERITY COSTS BY DIFFERENT TRANSPORTATION AGENCIES IN THE UNITED STATES

| | FATAL | INJURY | PDO |
|---|---|---|---|
| (1) NATIONAL SAFETY COUNCIL | $ 113500 | $ 6200 | $ 570 |
| (2) NATIONAL HIGH. TRAN. SAFETY | 287175 | 3185 | 520 |
| (3) NORTH CAROLINA DIVISION | 102350 | - | 585 |
| (4) ALABAMA DEPARTMENT OF TRAN. | 37000 | 2200 | 360 |
| (5) CALIFORNIA DEPARTMENT OF TRANS. | 95000 | 3000 | 900 |
| (6)TEXAS DEPARTMENT OF TRANS. | 110,000 | 3500 | 1000 |
| (7) KENTUCKY DEPARTMENT OF TRANS. | 45,000 | 2700 | 400 |
| (8) US. DEPARTMENT OF TRANSPORTATION | 307,210 | 14600 | 650 |

TABLE (5-1).
Data are compiled from (14, 79, 91, 111, 118).

## (5-2) COMPUTERIZED APPROACH FOR SELECTING THE TRANSPORTATION SAFETY PROJECTS (MACRO-APPROACH)

The Feasibility Assessment Model developed in this chapter incompasses three independent sub-models:

(1) COST-EFFECTIVENESS SUB-MODEL,

(2) FEASIBILITY ASSESSMENT MODULE,

(3) OPTIMAL-LEVEL-OF-FUNDING SUB-MODEL.

Figure (5-2) demonstrates the components of the Feasibility Assessment Model along with their objectives and functions. It is assumed that there are multiple locations and multiple alternatives, however an efficient computer program is developed for when there is a single location and multiple alternatives. This will save a tremendous amount of computer time (CPU) when a decision maker deals with this situation. Appendix (B) contains several computer programs for single location, multiple alternatives as well as multiple locations and multiple alternative safety countermeasures. If only one alternative is considered at each location, then simple benefit-cost ratios are recommended to be used to rank alternatives and no other methods can be considered cheaper and easier than the B/C analysis. So it is recommended for use by the local transportation agency to evaluate the different safety project at a location.

## (5-2.1) FEASIBILITY ASSESSMENT MODEL FOR MULTI-LOCATION SAFETY PROJECTS ANALYSIS

The cost-effective algorithm is developed in this section to find the optimal solution (best solution) for selecting the safety projects. In this regard, The problem of optimum utilization of improvement fund is divided into three distinct steps:

(1) COST-EFFECTIVENESS SUB-MODEL:

(a) Determining the benefit associated with each proposed improvement,

(b) Determine all feasible alternatives,

(2) FEASIBILITY ASSESSMENT MODULE:

(a) Array all feasible alternatives in an order such that no preferable ordering of projects can be obtained for the same level of funding,

(b) List the optimum set of projects for each level of funding,

(3) OPTIMAL-LEVEL-OF-FUNDING SUB-MODEL:

(a) Recommend the optimal funding level,

(b) Allocate the optimal fund to the selected safety program.

Figure (5-2) summerizes the components of the model along with their limitations.

The computer programs documented in Appendix(B) were developed to calculate the various steps, the cost and benefit associated with a set of proposed projects and utilization of the improved algorithm for incremental cost-benefit

FIGURE (5-2) COMPONENTS OF THE FEASIBILITY ASSESSMENT MODEL

FEASIBILITY ASSESSMENT MODEL

(1) COST-EFFECTIVENESS SUB-MODEL

(I) USES THE COST-EFFECTIVENESS MEASURES TO ASSIST IN ESTABLISHING PROJECT PRIORITIES

(II) IT IS PRIMARILY DESIGNED TO BE AN INPUT MODEL

(2) FEASIBILITY ASSESSMENT MODULE

(I) PRIMARILY HAS BEEN DESIGNED AS AN INDEPENDENTLY OPERATING MODULE

(II) IT PROVIDES MAXIMUM SYSTEM WIDE ACCIDENTS REDUCTION FOR THE DOLLAR SPENT WHILE STAYING WITHIN OVERALL FUNDING CONSTRAINTS.

(III) IT CAN BE APPLIED WHENEVER BUDGET ALLOCATION IS REQUIRED AND THE COAST AND BENEFIT INFORMATIONS ARE AVAILABLE.

(IV) THE ALGORITHM ALLOWS THE SIMULTANEOUS DETERMINATION OF PREFERRED LOCATIONS AND PREFERRED EXPENDITURES.

(V) TO DETERMINE THE COMBINATION OF SAFETY PROJECTS THAT IS MOST COST-EFFECTIVE AS AN INTERRELATED SYSTEM

(VI) USES IMPROVED VERSION OF MARGINAL ANALYSIS APPROACH TO DETERMINE WHAT IS THEORETICALLY THE BEST MIX OF PROJECTS TO BE INCLUDED IN THE PROGRAM

(VII) OUTPUT

(A) LISTS ALL THE PROPOSED PROJECTS WITH THEIR COST, BENEFIT AND COST-EFFECTIVENESS

(B) LISTS ALL FEASIBLE AND INFEASIBLE ALTERNATIVES SEPARATELY

(C) LISTS ALL OPTIMAL SET OF PROJECTS UNDER UNLIMITED CONSTRAINTS

(D) PRINT ALL OPTIMAL SET OF PROJECTS UNDER LIMITED FUNDS

(E) PRINT LEFT-OVER VALVE THAT MAY BE AVAILABLE NEXT PERIOD.

(3) OPTIMAL-LEVEL-OF-FUND SUBMODEL

- IT CAN BE USED BY ANY NON TECHNICAL PERSON TO PROCEED THIS PROCEDURE IN ORDER TO OBTAIN THE FINAL OPTIMAL BUDGET LEVEL.
- IT MAY BE USED BY HIGHER LEVEL TRANSPORTATION AUTHORITIES TO ESTIMATE THE OPTIMAL SAFETY NEEDS OF A COMMUNITY

for calculating the optimal set of projects under various funding levels.

The annual equivalent technique is used for calculating the annual cost of each alternative. The minimum ~~attractive rate of return can be input by the decision~~ maker(s). This method is preferred to the present equivalent technique since each project may have different economic lives which make it difficult to compute the actual total present value. The following exact technique is used to determine the annual equivalent of first costs and maintenance for each related alternative at each location.

$$AEC(k,j) = C(k,j) * CRF + MAIN(k,j)$$

Where:

AEC(k,j) is the annual equivalent cost of project j at location k,

C(k,j) is the capital cost of project j at location k,

MAIN(k,j) is the annual maintenance cost of project j at location k,

CRF is the capital recovery factor,
CRF=[i*(1+i)**LIFE(k,j)]/[(1+i)**LIFE(k,j) -1]

i is the minimum attractive rate of return

LIFE(k,j) is the economic life of the project j,

k is the location index, k=1,...,N

j is the alternative index, j=1,...,M

The High-Accident Location Form provided in Figure(5-2) can simplify the burden of the data input process;

## HIGH ACCIDENT LOCATION FORM (HALF)

(1) Location description________________________________________

________________________________________

________________________________________

(2) Time period of accident history:________________Year______date____________

(3) Location Accident Cause
(CAUSE OF ACCIDENT)

________________

________________

________________

| TOTAL | FATAL | INJURY | PDO |
|---|---|---|---|
| | | | |

(4) Proposed Alternatives:

(5) Number of Alternatives____________________

| PROJECT CODE | COST | MAINT. | LIFE | EFFECT ON CAUSE % REDUCTION TOT | FAT | INJ | PDO |
|---|---|---|---|---|---|---|---|
| (a)________________ | | | | | | | |
| (b)________________ | | | | | | | |
| (c)________________ | | | | | | | |
| (d)________________ | | | | | | | |
| (e)________________ | | | | | | | |
| (f)________________ | | | | | | | |
| (g)________________ | | | | | | | |
| (h)________________ | | | | | | | |

(6) Investigator:________________________________________

(7) Comment:________________________________________

FIGURE (5-3) HIGH-ACCIDENT LOCATION FORM it also represents what type of data is required for the computer input. For economic computation of each project return value, the following variables should be defined and provided to be input to the computer program:

TOT(i) = FAT(i) + INJ(i) + PDO(i)

TOT(i) is the total number of accidents for each location,

FAT(i) is the number of fatality at each location,

INJ(i) is the number of injury accidents at each location,

PDO(i) is the number of property accidents at each location,

RFAT(i,j) is the fatality reduction factor if safety project j is implemented at location i,

RINJ(i,j) is the injury reduction factor if safety project j is implemented at location i,

RPDO(i,j) is the property accident reduction factor if the alternative j is implemented at location i,

LIFE(i,j) is the economic life of safety project j if it is implemented at site i,

CFAT is the negative utility value for fatal accident,

CINJ is the negative utility value for injury accident,

CPDO is the negative utility value for property accident.

CFAT, CINJ, and CPDO parameters can be input based on the recommendation of the previous section, or according to the local decision desire, however, in case of lack of the available data, the program will assign the default value to each unknown parameters.

The following calculations are made to convert the magnitude to the relative value if any feasible alternative j is implemented at location i:

For each location, compute;

SRFAT = FAT(i) * RFAT(i,j)

SRINJ(i,j) = INJ(i) * RINJ(i,j)

SRPDO(i,j) = PDO(i) * RPDO(i,j)

Where; SRFAT(i,j), SRINJ(i,j), and SRPDO(i,j) are the saved fatality, injury and property damage accidents respectively for each location if project safety j is implemented. The following transformations are necessary in order to convert the reduction magnitude to the relative values:

$$CSRFAT(i,j) = SRFAT(i,j) * CFAT$$

$$CSRINJ(i,j) = SRINJ(i,j) * CINJ$$

$$\cancel{CSRPDO(i,j) = SRPDO(i,j) * CPDO}$$

where;

CSRFAT(i,j), CSRINJ(i,j), and CSRPDO(i,j) are the relative values of saved fatality, injury, and property accidents respectively. The annual amount of saving for each alternative j if it is implemented at location i can be estimated as follows:

$$B(i,j) = \{CSRFAT(i,j)+CSRINJ(i,j)+CSRPDO(i,j)\}/YR(i)$$

where, the B(i,j) is the annual saving which could result from implementing the safety project j at location i, and YR(i) is the accident history at each location under study and is summerized in HALF data form. Up to this stage, the first ordering of the projects at each location can be done based on the benefit-cost ratios as follow:

$$[B/C](i,j)=\{(CSRFAT(i,j)+CSRINJ(i,j)+CSRPDO(i,j))/(C(i,j)*CRF$$
$$+MAIN(i,j))\}$$

Simplifying the above equation;

$$[B/C](i,j) = B(i,j)/AEC(i,j)$$

The next step of the programming calculation is ordering the projects in a way that no preferable ordering can be obtained. The improved incremental benefit-cost technique is developed at this stage. The technique can array all the projects in an order of importance such that no preferable ordering of safety projects can be obtained for the same level of funding. In this regard, tremendous computer time is saved when this technique is compared with other optimization techniques such as Dynamic programming and linear programming regardless of the projects scale and other limitations which will be discussed. The flow chart represented in Figure (5-8) demonstrates the technique's mechanism step by step.

The computer program, called the Feasibility Assessment Module (FAM), is developed to produce the required cost benefit information. As mentioned the new improved incremental benefit-cost technique is used to evaluate not only the cost and benefit of each project, but represents the list of all unfeasible alternatives which may be considered in the near future feasible as the result of new technology, more accurate information, and other parameters that may change many current established criteria.

In Chapter Six of this dissertation, a more sophisticated model is developed which will account other parameters into the model. For the Feasibility Assessment Technique developed in this chapter, the data related to the seventeen high-accident locations in Alabama are used for model calibration. The HALF data form for each location has been filled and different safety projects which were selected by authorities as the alternatives countermeasures were considered. The program recommends a set of unfeasible, feasible, and optimal projects for each selected level of funding. The entire program documentation, coding, and the sample results are included in Appendix (B). Figures (5-4), and (5-5) demonstrate the final optimal policies for each budget level along with the expected return and saved accidents. Sample computer out put is presented in Figure (5-6) and optimal set of projects for various funding level is shown in Table (5-2).

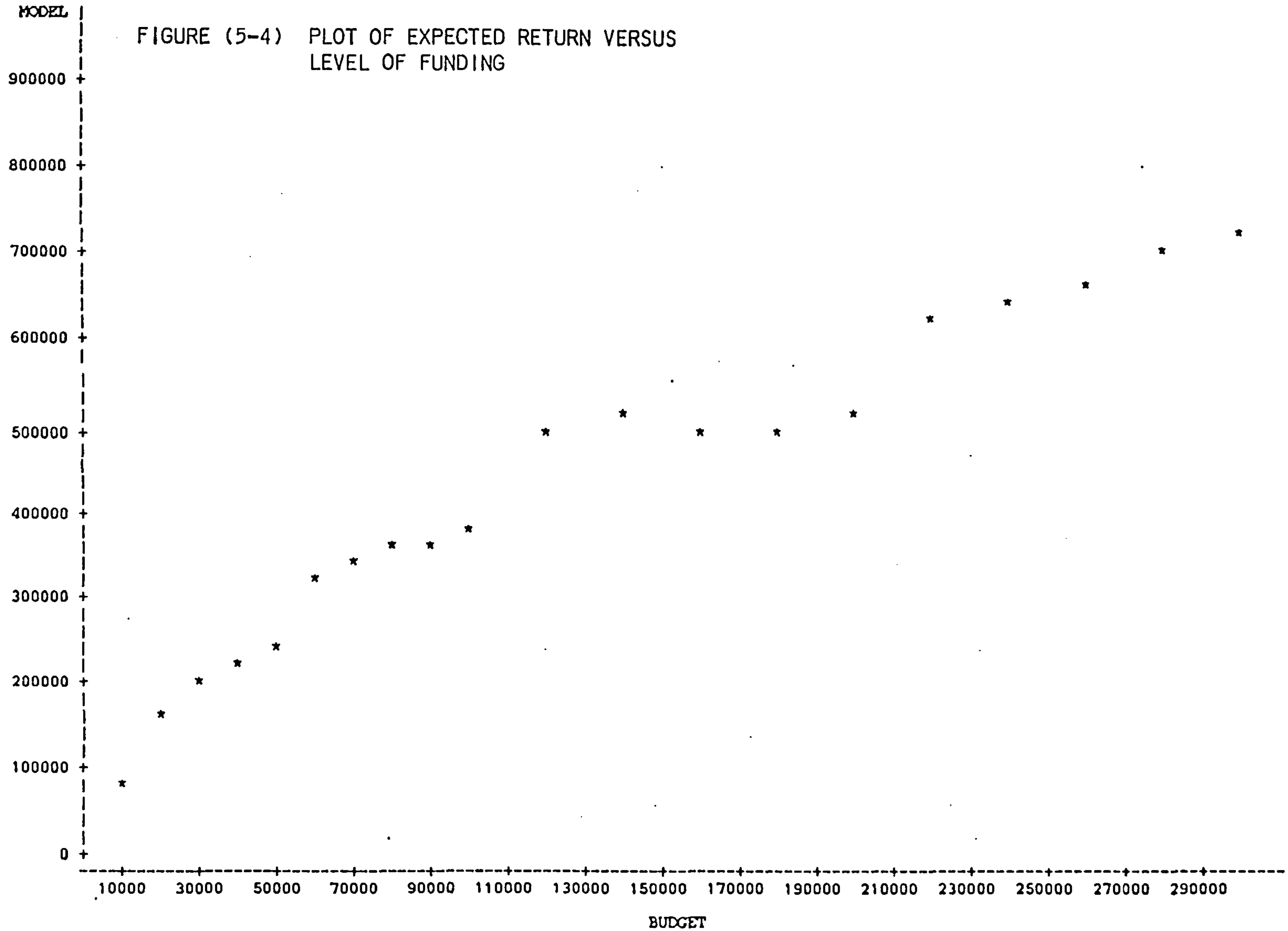
## (5-3) REQUIRED ASSUMPTIONS CONCERNING THE APPLICATION OF THE COST-EFFECTIVENESS ALGORITHM

In order to apply the recommended procedure very effectively, certain assumptions should be made. These assumptions are vital when the data inputs are collected. The following assumptions should be made if the model is utilized.

(1) All the safety projects considered in this model should be mutually exclusive and non-independent within the location but independent between the locations.

(2) It is assumed that on a given day a pool of potential project(s) is available to local or state authority for submission to a

FIGURE (5-4) PLOT OF EXPECTED RETURN VERSUS LEVEL OF FUNDING



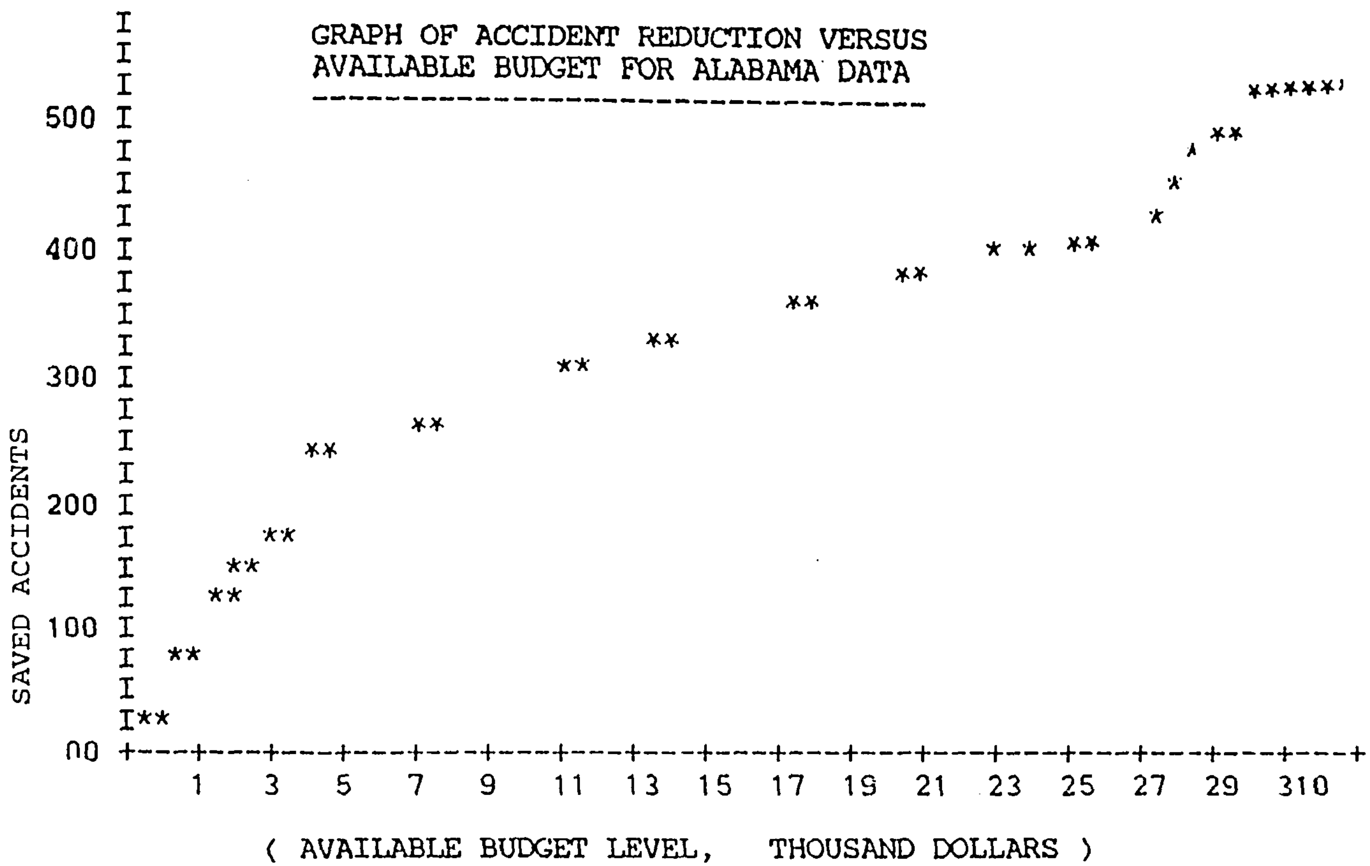



FIGURE (5-5) PLOT OF EXPECTED REDUCTION IN ACCIDENTS VERSUS AVAILABLE BUDGET LEVEL

THE PROGRAM RECOMMEND THE FOLLOWING PROJECTS AS THE OPTIMAL SELECTION UNDER UNLIMITED FUNDS

| INDEX NO. | PROJ. CODE | COST | BENEFIT | CUMULAT.COST | CUMULAT. BENEF. | MAR. B/C |
|---|---|---|---|---|---|---|
| 1 | 4-1D | 750. | 14030. | 750. | 14030. | 18.71 |
| 2 | 11-1L | 1000. | 10560. | 1750. | 24590. | 10.56 |
| 3 | 1-1A | 2000. | 20802. | 3750. | 45392. | 10.40 |
| 4 | 1-2A | 7136. | 71322. | 10886. | 116714. | 9.84 |
| 5 | 10-2K | 2200. | 16830. | 13086. | 133544. | 7.65 |
| 6 | 10-1K | 800. | 4590. | 13886. | 138134. | 5.74 |
| 7 | 16-1Q | 1200. | 6790. | 15086. | 144924. | 5.66 |
| 8 | 17-1S | 1400. | 7210. | 16486. | 152134. | 5.15 |
| 9 | 5-1E | 6000. | 21853. | 22486. | 173987. | 3.64 |
| 10 | 10-3K | 3600. | 21674. | 26086. | 195661. | 3.46 |
| 11 | 1-3A | 29645. | 118870. | 55731. | 314531. | 2.11 |
| 12 | 9-1J | 6500. | 13104. | 62231. | 327635. | 2.02 |
| 13 | 2-1B | 8000. | 14157. | 70231. | 341793. | 1.77 |
| 14 | 9-2J | 8000. | 15470. | 78231. | 357263. | 1.58 |
| 15 | 8-1H | 100000. | 136009. | 178231. | 493271. | 1.36 |
| 16 | 1-4A | 36781. | 128380. | 215012. | 621652. | 1.33 |

THE PROGRAM RECOMMEND THE FOLLOWING PROJECTS WHICH ARE WITHIN THE PROPOSED BUDGET

| INDEX NO. | PROJ. CODE | COST | BENEFIT | COMULAT. COST | COMULAT. BENEF. | MAR. B/C |
|---|---|---|---|---|---|---|
| 1 | 4-1D | 750. | 14030. | 750. | 14030. | 18.71 |
| 2 | 11-1L | 1000. | 10560. | 1750. | 24590. | 10.56 |
| 3 | 1-1A | 2000. | 20802. | 3750. | 45392. | 10.40 |
| 4 | 1-2A | 7136. | 71322. | 10886. | 116714. | 9.84 |
| 5 | 10-2K | 2200. | 16830. | 13086. | 133544. | 7.65 |
| 6 | 10-1K | 800. | 4590. | 13886. | 138134. | 5.74 |
| 7 | 16-1Q | 1200. | 6790. | 15086. | 144924. | 5.66 |
| 8 | 17-1S | 1400. | 7210. | 16486. | 152134. | 5.15 |
| 9 | 5-1E | 6000. | 21853. | 22486. | 173987. | 3.64 |
| 10 | 10-3K | 3600. | 21674. | 26086. | 195661. | 3.46 |

THE PROPOSED BUDGET IS $ 30000.

UNEXPENDED BUDGET IS $ 3914.00

NEXT-YEAR VALUE OF UNEXPENDED BUDGET $ 4187.98

FIGURE (5-6) SAMPLE OF COMPUTER OUT-PUT FOR THE BUDGET LEVEL OF 30,000 DOLLARS

## TABLE (5-2)

**Optimal Policy For Selecting The Budget Level For 17 High-Accident Locations**
(budget level: thousand)

| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3,4 | 1,2,3,4 | 1,2,3,4 | 1,2,3 | 1,2,3 | 1,2,3,4 | 1,2,3,4 | 1,2,3,4 | 1,2,3,4 | 1,2,3,4 |
| 2 | - | - | - | - | - | - | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | - | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 7 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 8 | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 9 | - | - | - | - | 1,2 | - | 1 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 | 1,2 |
| 10 | 2,1 | 2,1 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 | 2,1,3 |
| 11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 13 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 16 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | - |
| 17 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| *RE | 80.8 | 152.1 | 195.7 | 208.8 | 238.4 | 314.5 | 327.6 | 357.3 | 357.3 | 357.3 | 485.0 | 485.0 | 485.0 | 493.3 | 493.3 | 621.7 | 621.7 | 621.7 | 621.7 | 621.7 |
| *A.C | 93.5 | 164.9 | 260.9 | 325.9 | 485.9 | 557.3 | 622.3 | 782.3 | 782.3 | 782.3 | 1150.0 | 1150.0 | 1150.0 | 1782.0 | 1782.0 | 2156.1 | 2156.1 | 2156.1 | 2156.1 | 2156.1 |

*RE - Return (thousand)
A.C - Actual Cost (hundred)

cost-effectiveness model.

(3) The benefits from a given increment of expenditure can not be realized unless previous increments are spent.

(4) Only informations related to the accident-based data are included in the algorithm. However, the independent FAM module enables the decision maker to include the non-accident based information into the formulation.

(5) The model gives the best possible ranking of projects with minimum cumulative cost, but not necessarily maximum benefit ( it is actually very close to maximum).

(6) Effectiveness estimated in chapter three which may be considered by the decision maker for various countermeasures embody most updated results of previous research activities (up to 1981). The user may update this informations if it is possible.

(7) The primary focus of this methodology is directed toward measuring only the traffic safety-related benefits, so, non-safety benefit impacts have been completely ignored.

The above mentioned assumption sometimes reduces the sensitivity of the model and sometimes strength bility of the procedures. However, the advantage and disadvantage of the procedure will be discussed later in this chapter.

FIGURE (5-7) SCHEMATIC OF ALLOCATION PROCEDURE

(AN OVERVIEW)

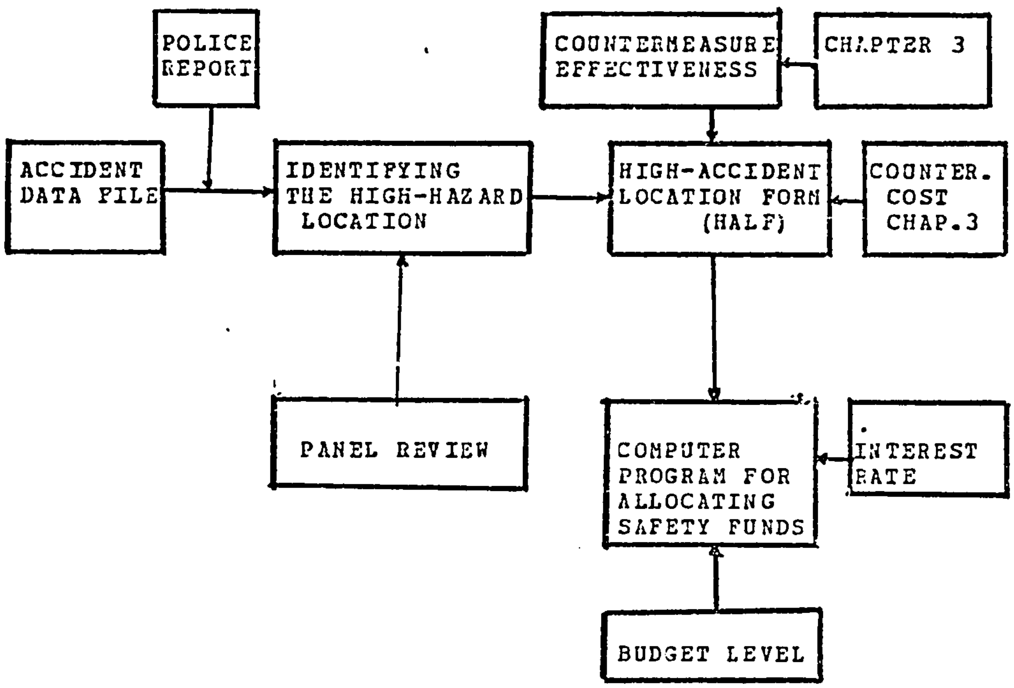
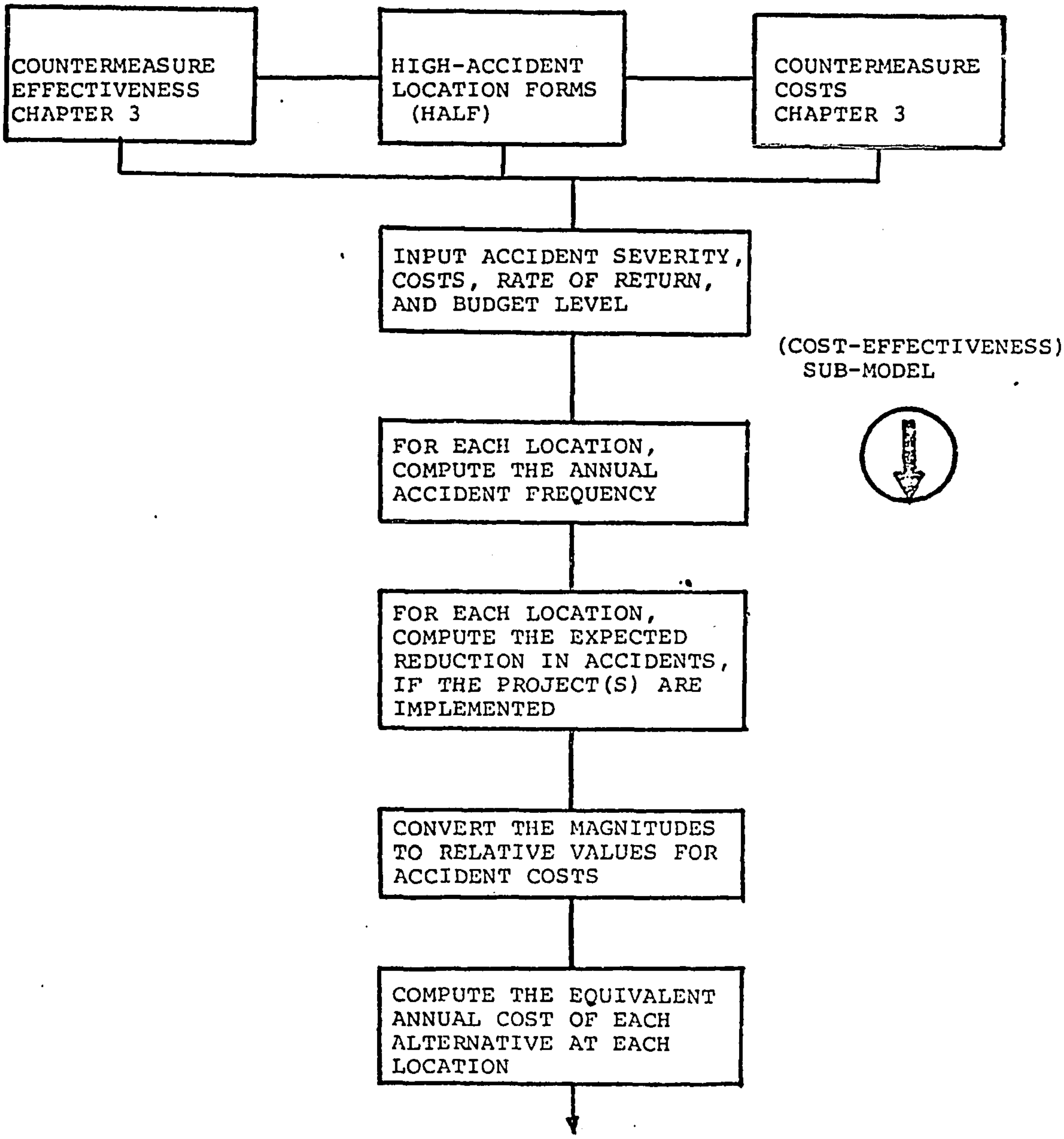


FIGURE (5-8), OVERALL FEASIBILITY ASSESSMENT PROCEDURE DEVELOPED FOR ALLOCATING THE SAFETY FUNDS IN LOCAL JURISDICTION



ESTIMATE THE ANNUAL SAVINGS IF COUNTERMEASURE (J) IS IMPLEMENTED AT LOCATION (I)

FOR EACH LOCATION (I) AND EACH ALTERNATIVE (J), ASSIGN THE ANNUAL SAVING AS A BENEFIT

FOR EACH LOCATION (I) AND ALTERNATIVE (J) COMPUTE THE B/C RATIO

FEASIBILITY ASSESSMENT SUB-MODEL (FAM)

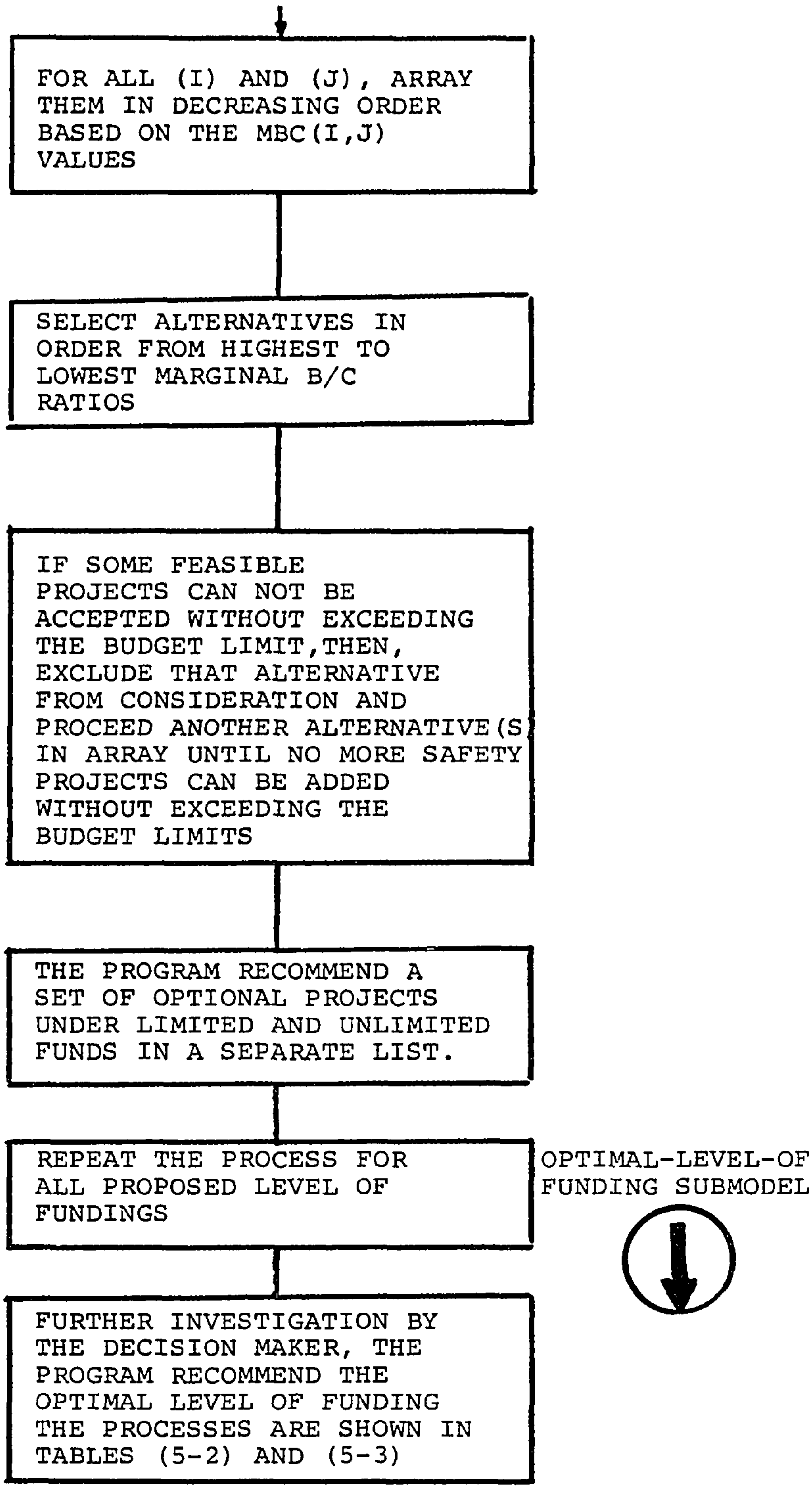
FOR EACH LOCATION, CALCULATE THE MARGINAL B/C FOR ALL PROJECTS

I=1,2...,N J=1,2...,M

FOR EACH LOCATION, DELETE ANY PROJECT HAVING MBC(I,J)<1

FOR EACH LOCATION, COMPARE MBC(I,J) WITH MBC(I,J+1), IF MBC(I,J+1) GREATER THAN MBC(I,J), RECOMPUTE THE MBC(I,J+1) =B(i,j)+B(i,j+1) DIVIDED BY C(i,j)+C(i,j+1)

REPEAT THIS PROCESS UNTIL ALL THE MBC(I,J) BE GREATER THAN THE NEXT ONE


FOR ALL (I) AND (J), ARRAY THEM IN DECREASING ORDER BASED ON THE MBC(I,J) VALUES
SELECT ALTERNATIVES IN ORDER FROM HIGHEST TO LOWEST MARGINAL B/C RATIOS
IF SOME FEASIBLE PROJECTS CAN NOT BE ACCEPTED WITHOUT EXCEEDING THE BUDGET LIMIT,THEN, EXCLUDE THAT ALTERNATIVE FROM CONSIDERATION AND PROCEED ANOTHER ALTERNATIVE(S) IN ARRAY UNTIL NO MORE SAFETY PROJECTS CAN BE ADDED WITHOUT EXCEEDING THE BUDGET LIMITS
THE PROGRAM RECOMMEND A SET OF OPTIONAL PROJECTS UNDER LIMITED AND UNLIMITED FUNDS IN A SEPARATE LIST.
REPEAT THE PROCESS FOR ALL PROPOSED LEVEL OF FUNDINGS
OPTIMAL-LEVEL-OF FUNDING SUBMODEL
FURTHER INVESTIGATION BY THE DECISION MAKER, THE PROGRAM RECOMMEND THE OPTIMAL LEVEL OF FUNDING THE PROCESSES ARE SHOWN IN TABLES (5-2) AND (5-3)

## (5-4) OPTIMAL FUNDING POLICY FOR SAFETY PROJECTS PROGRAMMING (OPTIMAL-LEVEL-OF-FUNDING SUB-MODEL)

The algorithm developed in this chapter ensures that a very close set of optimal projects will be recommended according to the given budget. However, the author hesitates to call this approach optimal since the process allows just one objective and a fixed budget. In fact, most of the time the safety budget not fixed, but sometimes the "best-possible" case may not be obtained. The algorithm allows the simultaneous determination of preferred locations and preferred expenditures the important concept on which many optimization techniques are based. The procedure represented in Table(5-3) demonstrates the final process in which the higher decision maker(s) may proceed in order to obtain the final optimal budget level. Table(5-3) demonstrates this process for the Alabama data. The marginal benefit-cost technique is proposed to be used for this step, since it is simple and easily understand by many non-technical personnel. The cost figures represented in Table (5-3), are defined as actual since the left-over determined by the program has been subtracted from the proposed budget at each funding level. The optimal budget level may be selected based on the trade off between marginal cost, marginal benefit and the marginal B/C as was shown in Table(5-3) with the different funding levels.

Procedure for Finding the Optimal Funding Level

| Budget | Actual Cost* | Return | M. Cost* | M. Return* | B/C Ratio | M. B/C* |
|---|---|---|---|---|---|---|
| 10,000 | 9350 | - | - | - | - | - |
| 20,000 | 16486 | 152134 | 7136 | 71322 | 9.22 | 9.99 |
| 30,000 | 26086 | 195661 | 960 | 43527 | 7.5 | 4.53 |
| 40,000 | 32586 | 208765 | 6500 | 13104 | 6.40 | 2.016 |
| 50,000 | 48586 | 238393 | 16000 | 29628 | 4.9 | 1.85 |
| 60,000 | 55731 | 314531 | 7145 | 76138 | 5.64 | 10.65 |
| 70,000 | 62231 | 327635 | 6500 | 9628 | 5.26 | 1.481 |
| 80,000 | 78231 | 357263 | 10000 | 29628 | 4.56 | 1.85175 |
| 90,000 | 78231 | 357263 | 0 | 0 | 4.56 | 0 |
| 100,000 | 78231 | 357263 | 0 | 0 | 4.56 | 0 |
| 120,000 | 115012 | 485643 | 36781 | 128380 | 4.22 | 3.49 |
| 140,000 | 115012 | 485643 | 0 | 0 | 4.22 | 0 |
| 160,000 | 115012 | 485643 | 0 | 0 | 4.22 | 0 |
| 180,000 | 178231 | 493271 | 63219 | 7628 | 2.76 | 0.12 |
| 200,000 | 178231 | 493271 | 0 | 0 | 2.76 | 0 |
| 220,000 | 215012 | 621652 | 36781 | 128381 | 2.89 | 3.49 |
| 240,000 | 215012 | 621652 | 0 | 0 | 2.89 | 0 |
| 260,000 | 215012 | 621652 | 0 | 0 | 2.89 | 0 |
| 280,000 | 215012 | 621652 | 0 | 0 | 2.89 | 0 |
| 300,000 | 215012 | 621652 | 0 | 0 | 2.89 | 0 |

* Actual Cost = budget - leftover

M. Cost = Marginal Cost

M. Return = Marginal Return

M. B = Marginal Benefit - Cost Ratio

TABLE (5-3) OPTIMAL FUNDING LEVEL PROCEDURE

## (5-5) PROCEDURE CALIBRATION

Dynamic programming and conventional maximum benefit-to-cost-ratio algorithms are developed in this stage to be used to compare the numerical results of the recommended procedure. This is shown in Figures (5-9) and (5-10). As mentioned, the Alabama Highway Department has experienced the application of DP to the optimization of budget allocation for the safety improvement program.

Here, an attempt is made to demonstrate the DP mechanism used in the computer program in the Appendix(B-4) by the following steps demonstrated in Section (5-6).

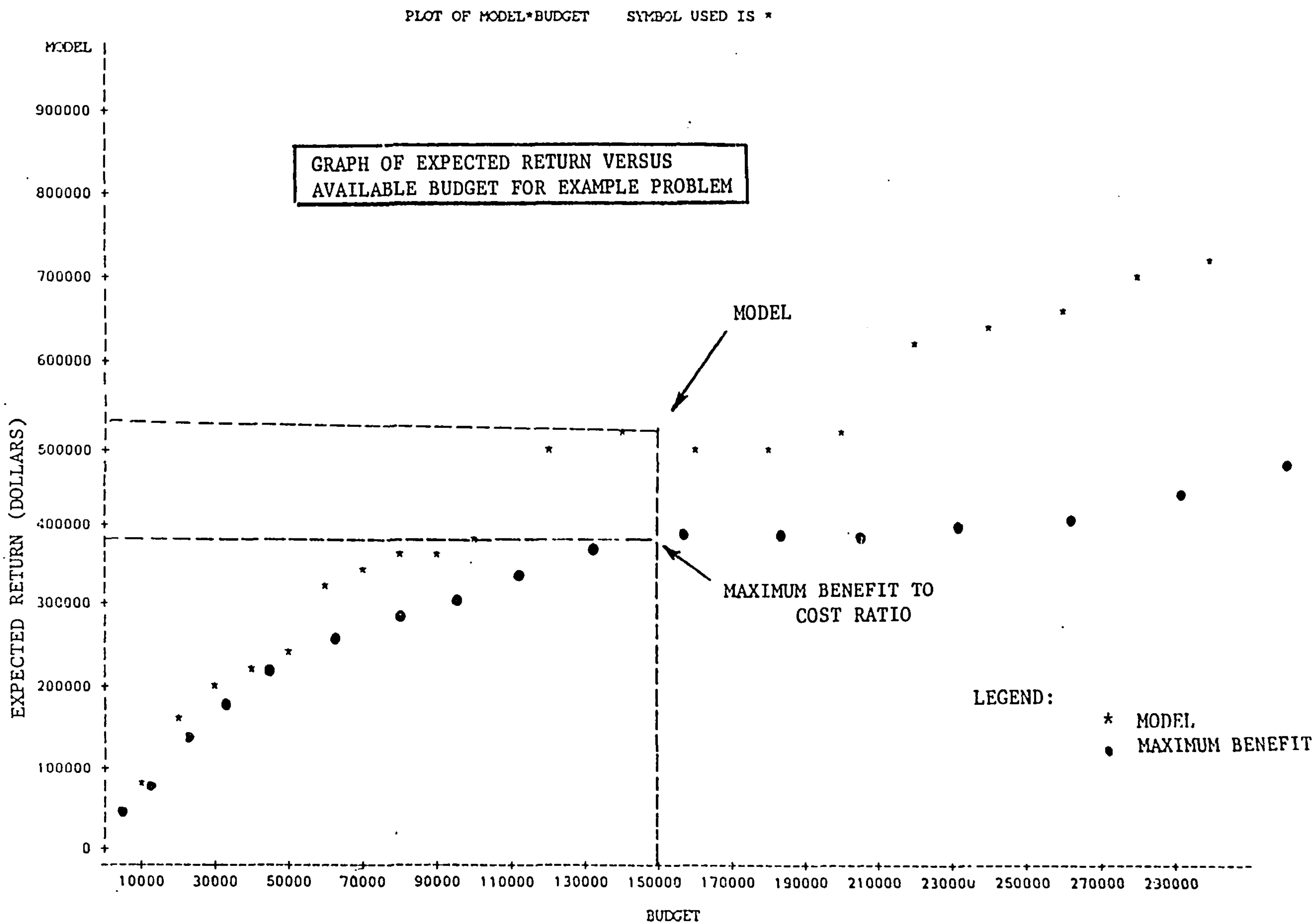
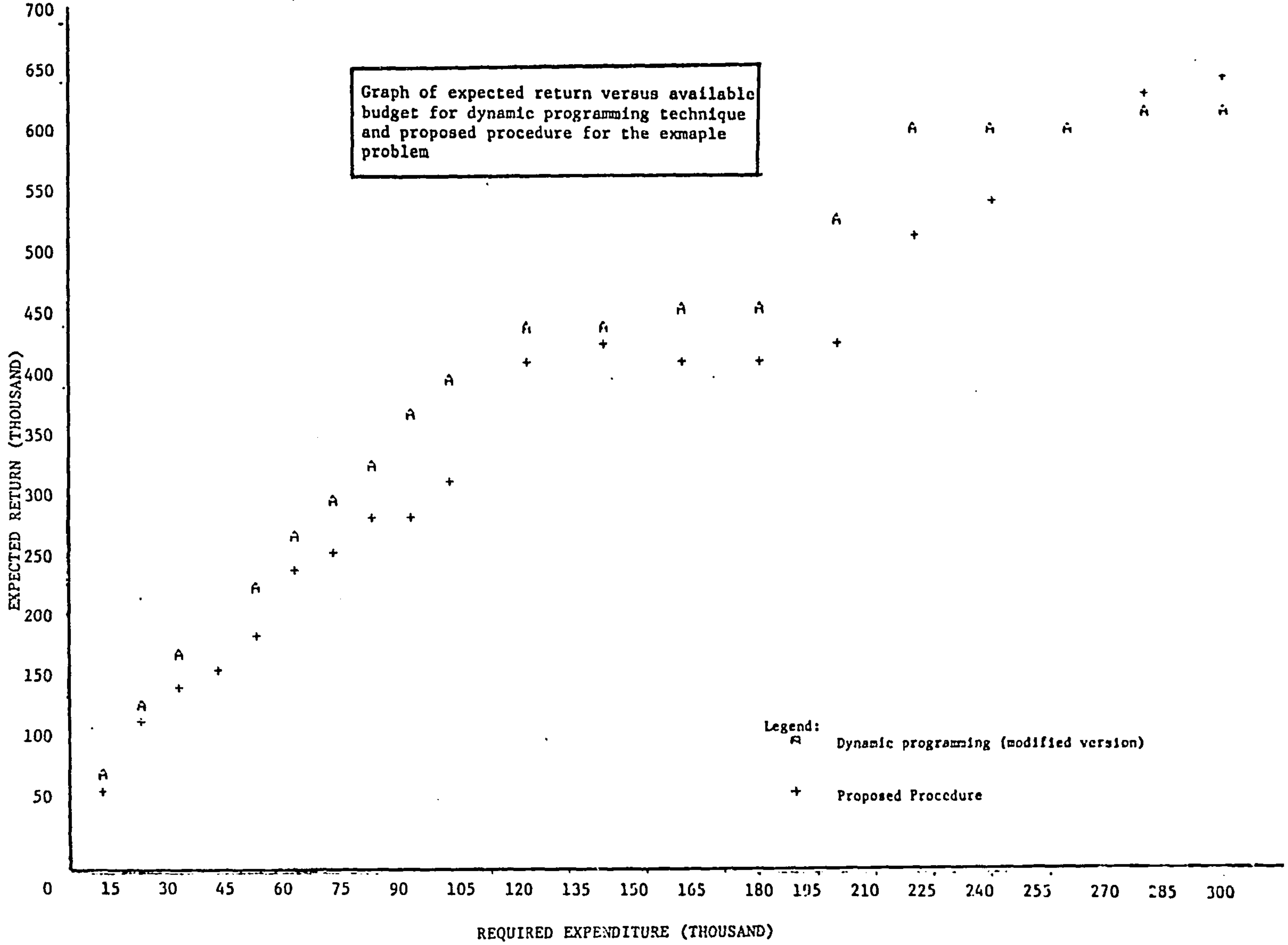



FIGURE (5-9) COMPARISON OF PROPOSED MODEL AND MAXIMUM B/C-RATIO TECHNIQUE FOR THE EXAMPLE PROBLEM

FIGURE (5-9) COMPARISON OF PROPOSED MODEL AND DYNAMIC PROGRAMMING TECHNIQUE FOR THE EXAMPLE PROBLEM



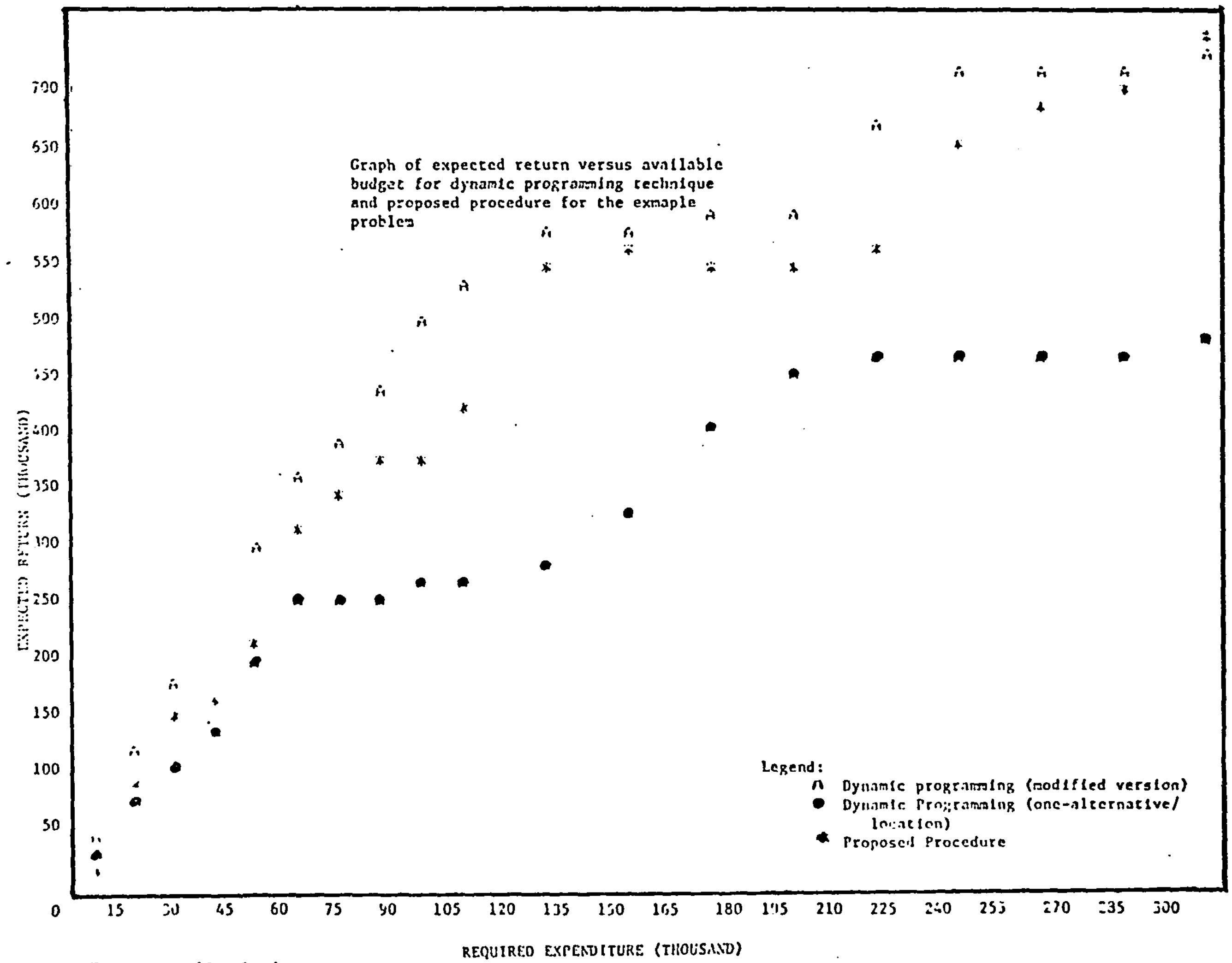



FIGURE (5-9a) EXPECTED RETURN FOR DYNAMIC PROGRAMMING AND MODEL

## (5-6) DYNAMIC PROGRAMMING ALGORITHM MECHANISM

Dynamic Programming technique is used in this dissertation for model calibration and comparison purposes. Here an attempt is made to demonstrate the model mechanism step by step. The complete computer code is provided in Appendix (B).

(step 1) DIVIDE BUDGET INTO N EQUAL INTERVALS

↓

(step 2) DETERMINE THE BEST ALTERNATIVE AT LOCATION ONE TO MAXIMIZE THE RETURN USING, J INCREMENTS I=1,2,...,N

OPT(i,j)=RET(j)
where OPT(i,j) IS TOTAL OPTIMUM RETURN AFTER STATE J FOR AN INVESTMENT OF J INCREMENTS;

RET(i,j) RETURN FROM LOCATION i FOR AN INVESTMENT OF j INCREMENTS;

SELECT(i,j) IS THE CHOSEN ALTERNATIVE AT LOCATION i FOR AN INVESTMENT OF J INCREMENTS.

↓

(step 3) REPEAT STEP 2 FOR EACH STAGE

RET(i,j)= MAX {RET(i,k) +

OPT(i-1,j-k))
i = 1,2,...,N
k = 1,2,..,j
Where N = NUMBER OF LOCATIONS

OPT(i-1,j-k) IS THE TOTAL OPTIMUM RETURN AFTER STAGE i-1 FOR AN INVESTMENT OF j-k INCREMENTS;

SELECT(i,j) REPRESENTS CHOSEN ALTERNATIVE AT LOCATION i FOR AN INVESTMENT OF j INCREMENTS.

↓

(step 4) THE OPTIMUM ALTERNATIVE AT EACH LOCATION CAN NOW BE OBTAINED BY DETERMINING THE BEST ALTERNATIVE FOR LOCATION M AT STAGE M WITH N INCREMENTS. THE REMAINING INCREMENTS CAN NOW BE USED AT STAGE (M-1), ETC.

ALTER(M)= SELECT(M,N), LEAVING N INCREMENTS AT LOCATION M;

ALTER(M-1)= SELECT(M-1,N1), LEAVING N1 INCREMENTS AT STAGE M-1;

ALTER(M-2)= SELECT(M-2,N2), LEAVING N2 INCREMENTS AT STAGE M-2

...
...
...
...

ALTER(i)= SELECT(i,Ni+1);

Where Alter(i) IS THE CHOSEN ALTERNATIVES AT i-TH LOCATION.

The above procedure has been computerized using Alabama computer coding program that is represented in Appendix (B).

## (5-7) SUMMARY

In applying the procedures mentioned in this chapter a local or in a higher level application i.e., state, would identify a large number of potential location say, 50 to 1000 locations per time period. This of course varies by the size of the local jurisdiction, and the extent of the safety program that the authority likes to investigate. However these locations would be investigated based on the procedures recommended in chapter four or other criteria. In this stage several alternatives would be identified for each location. Then based on the recommended procedure for collecting the data input, the HALF data form can be provided for each hazardous location.

Feasibility Assessment Module (FAM) and Cost-Effectiveness Algorithm Module (CEAM) are designed to determine projects which should be funded to obtain a maximum return in term of reduced accidents, injuries, and fatalities.

FAM module primarily has been designed as an independently operating module. Hence it can be applied whenever budget allocation is required and the cost and benefit informations are available. However, the CEAM module can be used in combination with FAM as a complete computer

MACRO PROCESS TO DETERMINE
THE FINAL OPTIMUN SET OF PROJECTS
AND BUDGET LEVEL

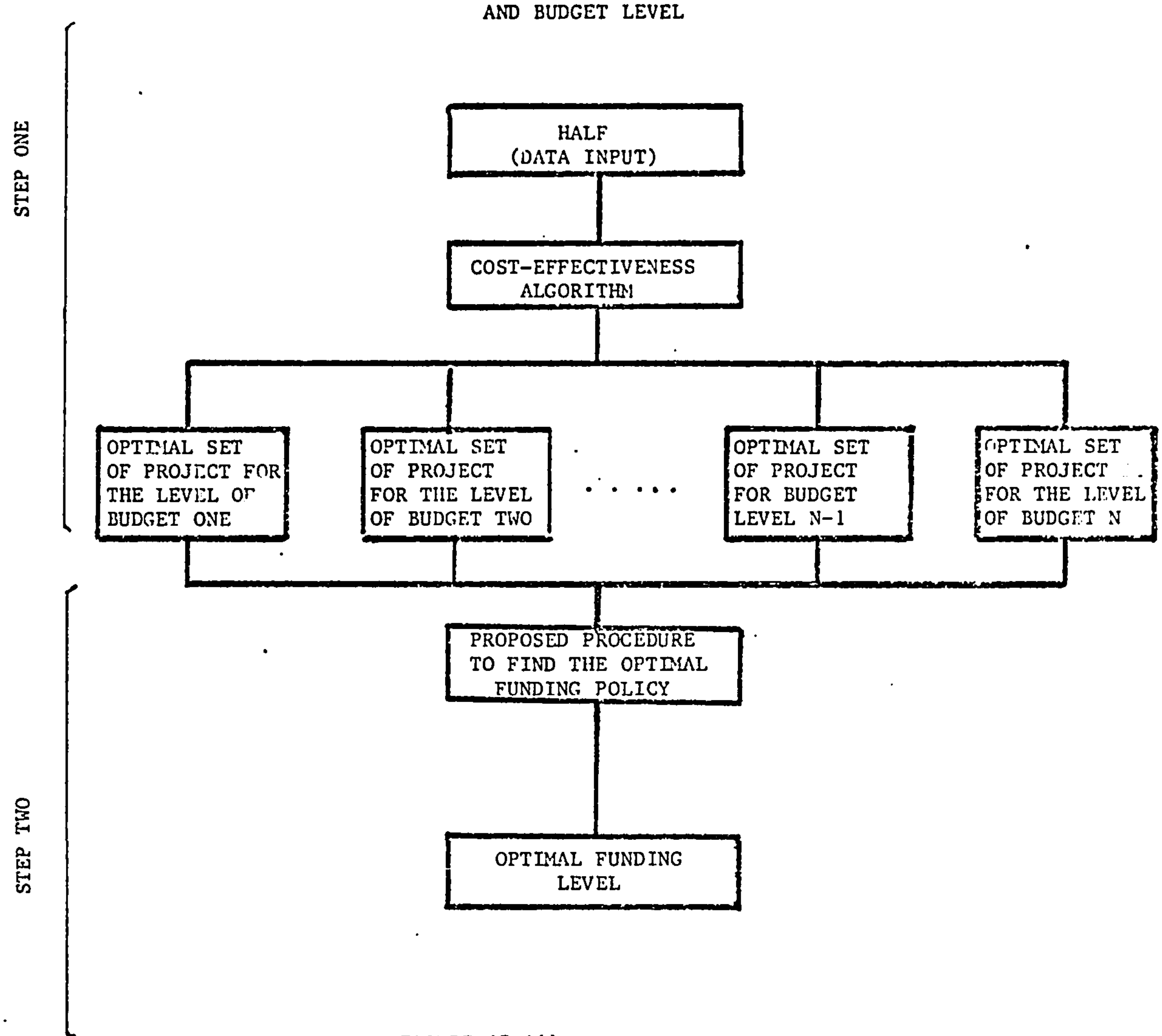



FIGURE (5-11).

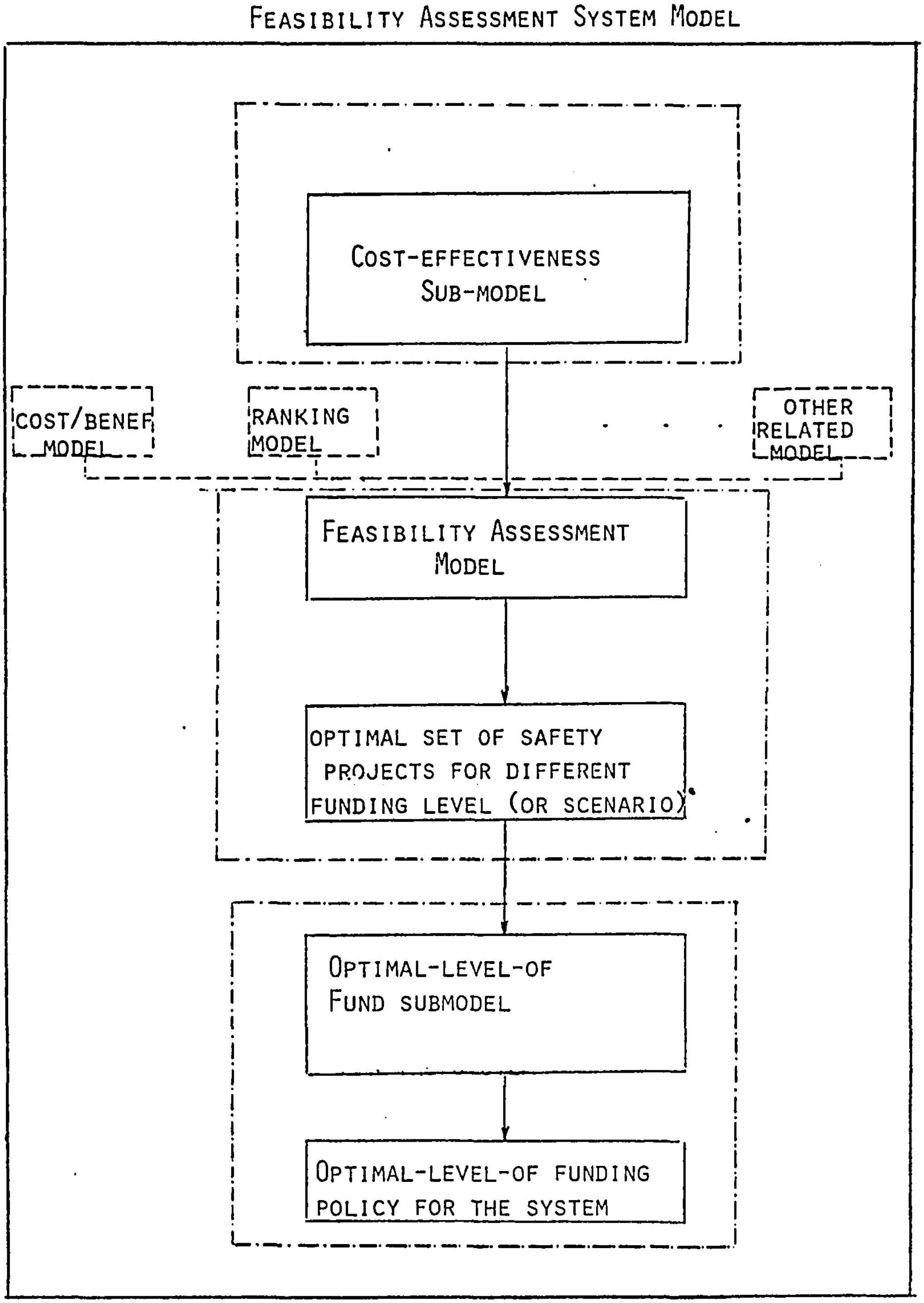



FIGURE (5-12) FEASIBILITY ASSESSMENT SYSTEM MODEL procedure for selecting the safety projects while the initial inputs are the accidents data rather than the benefit and cost components.

The final decision for implementing the optimal set of safety project and the level of funding should be made in two steps:

(1) finding the optimal set of projects;

(2) investigating the optimal level of funding.

The decision for finding the set of optimal projects is derived based on the proposed algorithm that determines which combination of the alternative will result in a highest return for various locations. The decision for finding the optimal budget level should be based on the proposed procedure indicated in the case study. This decision usually is made by higher level of decision maker, i.e., state for local jurisdiction. Figure (5-12) demonstrates the Feasibility Assessment System Models proposed in this dissertation.

## (5-8) OVERVIEW OF THE NEXT CHAPTER

The methodology described in this chapter can be used very effectively by any local jurisdiction for selecting the optimal set of safety projects. However, the final decision for implementing any specific safety program is usually made by higher level transportation officials for allocating the resources to the local jurisdiction. So, the first step is to demonstrate the state authority that a certain safety program is cost-effective and actually will fulfill the requirement of the higher level decision maker. So, the problem will no longer be a single objective problem ; it is a problem that should satisfy a multi-objective criteria with multi-goals and sub-goals. The methodology developed in the next chapter provides a very quick response to this multi-interest problem. A goal programming methodology is developed to aid the higher-level decision maker to formulate a resource allocation model that allocates the resources properly to the different local jurisdictions.

CHAPTER VI

## MACROSC OPICOPTIMIZATION PROCEDURE FOR ALLOCATING TRANSPORTATION SAFETY RESOURCES

Introduction:

This chapter develops the methodology for distributing local funds among the most potential countermeasures or safety programs that their relative importance have been recognized. The optimization procedure is designed to use the data provided by the cost-effectiveness model to determine the best mix and level of local spending on different countermeasures, subject to financial, legal and operational constraints which are based on a set of predefined local and state goals and objectives. The proposed procedure is composed of the following steps:

(1) Effectiveness Development,

(2) Countermeasure's Safety Indicator Development,

(3) Optimization Formulation,

(4) Achievement Index Development.

~~As discussed in Chapter One, allocating~~ the traffic safety resources should be based on objectives, goals and needs which satisfy both locality and state government. A useful and practical safety allocation procedure must meet certain criteria that are discussed in this dissertation. These criteria are the capability of the procedure to handle multiple objectives, to be able to respond to policy questions, and to reflect or handle state and local interests as well as the demand the least for data input. Any other model or procedure that does not meet these criteria might produce badly distorted results. The objective of this chapter is to provide the user with an efficient methodology with minimum data input, while the concept of multiple objective optimization is introduced with the help of a new and promising technique of goal programming.

## (6-1) EFFECTIVENESS DEVELOPMENT

Two measures of effectiveness have been proposed in this research study: A Benefit-Cost ratio considered in Chapter Five for Feasibility Assessment, and Cost-Effectiveness ratio for Optimality Assessment for resource allocation is considered in this chapter. However, the major question posed by the initial statement of selecting such measurements should be properly investigated. The major argument in selecting the different cost-effectiveness measures is the need for proper indicators which are compatible with the optimization technique and the reliability of the selected indicators. However, the major consideration is to find a proper "unit-of-measurement" with the highest reliability while it would be selected to be used in the optimization algorithm. When B/C ratio is considered, the "unit-of-measurement" should be commensurable, otherwise, the benefit and cost can not be computed properly. But, when the cost-effectiveness ratio is used, the transformation into a quantitative value is not essential. In using this measure, the units are generally maintained even when cancellation is permissible. So, the development of a cost-effectiveness ratio can simply be regarded as the benefit to be derived from a unit of resource expenditure, or a unit of life, injury, or property damage accident which can be saved with any level of expenditure. Use of this measure along with the mathematical procedure yields an optimum allocation expressed in physical units, since the dollar terms in the denominator of the ratio and the local expenditure cancel.

The major difficulty in using such a technique is how to find a proper cost-effectiveness ratio for each countermeasure. Such an indicator may be computed based on the national basis. This concept would help greatly in developing the technological coefficient in the proposed linear goal programming technique which will be used in the optimization procedure.

In Chapter Three, the Countermeasure Cost Identification Table would facilitates the process of computing the cost-effectiveness ratio for different countermeasures. Along with those data, the National Highway Safety Needs

Report(NHSNR) also conducted a very significant study to estimate most of the sound and proper countermeasures around the United States. In essence, the macro-allocation model could employ the information suplied in chapter four and the result of NHSNR research to compute the potentiality of each countermeasure to forestall accidents.

The effectiveness of a countermeasure depends on two factors: its own unique value as a deterrent (# of accidents or severity) and the size of the population by its deployment. The deterrent values may be estimated on the basis of survey data acquired by interviews with officials in 20 States and 593 local jurisdictions (117,125). Based on this investigation, the cost of new deployment of each countermeasure is possible. All costs were estimated in constant 1974 dollars over a 10-year period, and converted to their present value equivalent using a 10 percent discount rate. From the result of such a significant study, the 37 countermeasures selected and their cost-effectiveness ratio is computed and sorted in descending order as shown in Figure(6-1).

In summary, for the optimization allocation process, it may be assumed that the 37 selected countermeasures defined in this analysis are a collection of budgetary activities directed to the achievement of traffic accident reduction. In turn, the cost-effectiveness is directed to determining the influence of those countermeasures "the explanatory variable" on allocation process. They are assumed to be independent and mutually exclusive alternatives when they are used in the modeling procedure unless otherwise indicated.

## (6-2) COST-EFFECTIVENESS INDICATORS

Three types of indicators are developed to reflect the effectiveness of each countermeasure. These indicators posses all the characteristics necessary to accurately measure and estimate the local expenditure on safety programs. They should incorporate the physical units associated with deaths, injuries and total accidents. The bias that matters is whether all the indicators can equally describe the true effectiveness of each related countermeasure, and actually which type is more powerful in order to be recommended to the local decision maker.

A fatality related indicator should always be preferred because the public, and to a lesser extent the safety community, more closely can identify the traffic safety problem as a matter of loss of life rather than an injury-property damage issue. So, the emphasis should be given to the life saving potential of the proposed countermeasure. The significant reason is the amount and quality of fatal accident data are markedly superior to the information on a non-fatal indicator, making the estimate of a fatality indicator more reliable than the other two (117,125). Also, the tracking fatality trends on a local jurisdiction can therefore give some indication of whether the safety problem is improving or worsening, in addition, under the assumption that over a large population of accident data, there is a relatively stable relationship among the frequencies of fatalities, injuries and property damage accidents. So the fatality indicator can provide a measure of the overall magnitude of accident losses. However,e of such an indicator in judging the relative merits of individual countermeasures can be misleading if the safety concern is the totality of accident losses. It is recommended that for better and reliable computation at least two types of indicator be considered. The following computations represent three types of selected indicators:

$$\text{FIN} = \frac{\text{\# OF FATAL ACCIDENTS FORESTALLED}}{\text{PRESENT VALUE OF PUBLIC EXPENDITURES}}$$

$$\text{IIN} = \frac{\text{\# OF INJURY ACCIDENTS FORESTALLED}}{\text{PRESENT VALUE OF PUBLIC EXPENDITURES}}$$

$$\text{TIN} = \frac{\text{\# OF TOTAL (FAT.+INJ.+PDO) FORESTALLED}}{\text{PRESENT VALUE OF PUBLIC EXPENDITURES}}$$

Where: FIN, IIN, and TIN are the cost-effectiveness indicators (cost effectiveness per unit of expenditure) in terms of, respectively, fatality, injury and total accidents. Figure (6-2) represents the results of calculation for the selected countermeasures.

FIGURE(6-1)
FATALITY, INJURY AND TOTAL ACCIDENT INDICATORS FOR SELECTED COUNTERMEASURES IN THE UNITED STATES
(Practical in State and federal Levels)

| | | (FAT./$10000) | (FAT.+INJ./$10000) |
|---|---|---|---|
| 1. | MANDATORY SAFETY BELT USAGE | 19.74 | 34.01 |
| 2. | HIGHWAY CONSTRUCTION AND MAINTENANCE | .5 | .892 |
| 3. | UPGRADE BICYCLE AND PEDESTRIAN SAFETY | .49 | .892 |
| 4. | NATIONAL 55 MPH SPEED LIMIT | .47 | .6622 |
| 5. | DRIVER IMPROVEMENT SCHOOLS | .467 | .595 |
| 6. | REGULATORY AND WARNING SIGNS | .294 | .523 |
| 7. | GUARDRAIL | .2717 | .483 |
| 8. | PEDESTRIAN SAFETY INFORMATION AND EDUCATION | .238 | .3906 |
| 9. | SKID RESISTANCE | .217 | .3636 |
| 10. | BRIDE RAILS AND PARAPETS | .2024 | .3571 |
| 11. | WRONG-WAY ENTRY AVOIDANCE TECHNIQUES | .190 | .2898 |
| 12. | DRIVER IMPROVEMENT SCHOOLS FOR YOUNG | .0992 | .2197 |
| 13. | MOTORCYCLE RIDERS SAFETY HELMET | .086 | .1883 |
| 14. | MOTORCYCLE LIGHTS-ON PRACTICE | .076 | .1526 |
| 15. | IMPACT ABSORBING ROADSIDE SAFETY DEVICES | .069 | .135 |
| 16. | BREAKAWAY SIGN AND LIGHTING SUPPORTS | .047 | .07518 |
| 17. | SELECTED TRAFFIC ENFORCEMENT | .0439 | .076 |
| 18. | COMBINED ALCOHOL SAFETY ACTION COUNTERMEASUR | .0434 | .0709 |
| 19. | CITIZEN ASSISTANCE OF CRASH VICTIMS | .0398 | .0625 |
| 20. | MEDIAN BARRIERS | .0352 | .05813 |
| 21. | PEDESTRIAN AND BICYCLE VISIBILITY ENHANCEM. | .0225 | .0529 |
| 22. | TIRE AND BRAKING SYSTEM SAFETY CRITICAL | .0223 | .0483 |
| 23. | WARNING LETTERS TO PROBLEM DRIVERS | .0185 | .0483 |
| 24. | CLEAR ROADSIDE RECOVERY AREA | .016 | .0469 |
| 25. | UPGRADE EDUCATION AND TRAINING FOR BEGINNING | .0106 | .0468 |
| 26. | INTERSECTION SIGHT DISTANCE | .0059 | .0291 |
| 27. | COMBINED EMERGENCY MEDICAL COUNTERMEASURES | .0047 | .0253 |
| 28. | UPGRADE TRAFFIC SIGNALS AND SYSTEMS | .0035 | .0190 |
| 29. | ROADWAY LIGHTING | .0034 | .00179 |
| 30. | TRAFFIC CHANNELIZATION | .0028 | .0084 |
| 31. | PERIODIC MOTOR VEHICLE INSPECTION | .0028 | .0065 |
| 32. | PAVEMENT MARKINGS AND DELINEATORS | .00179 | .0060 |
| 33. | SELECTIVE ACCESS CONTROL FOR SAFETY | .00126 | .0051 |
| 34. | BRIDGE WIDENING | .00123 | .0030 |
| 35. | RAILROAD-HIGHWAY GRADE CROSSING PROTECTION | .00114 | .0029 |
| 36. | PAVED OR STABILIZED SHOULDERS | .00113 | .0023 |
| 37. | ROADWAY ALIGNMENT AND GRADIENT | .00112 | .0021 |

Data is compiled from source (117).

## (6-3) OPTIMIZATION FORMULATION

GENERAL DESCRIPTION:

A most important but difficult area in the field of management science is "management by multiple objective" where managers must make decisions involving conflicting multiple objectives. The following brief discussion will be devoted to the study of techniques which can be implemented to solve the modeling approach.

The goal programming approach which will be used in this paper is capable of handling any decision problems with a single goal with multiple subgoals as well as problems with multiple subgoals. In the conventional linear programming method, the objective function is undimensional -either to maximize benefits or to minimize the costs. The GP model handles multiple goals in multiple dimensions. Therefore, there is no dimensional limitation of the objective function.

Usually, goals set by the decision makers are achieved only at the expense of other goals. Furthermore, these goals are incommensurable. Thus, there is a need to establish a hierarchy of importance among these incompatible goals so that the low order goals are considered only after the higher order goals are satisfied or have reached the point beyond which no further improvements are desirable. If the decision maker can provide an ordinal ranking of goals in terms of their contributions or importance to the organizations, the problem can be solved by GP. In this method, instead of trying to maximize the objective criterion directly, the deviations between goals and what can be achieved within the given set of constraints are to be minimized or maximized. In the simplex algorithm of linear programming, such deviations are called "slack" variables. These deviational variables take on a new significance in GP. The deviations from each subgoal or goal, then in the objective function become the minimization of these deviations, based on the relative importance or preemptive priority weight assigned to them. The objective function, however, may also include real variables with ordinary or preemptive weights in addition to the deviational variables (17,75).

## (6-3.1) GENERAL SOLUTION FORMULATION

The primary characteristic of GP is that it allows for an ordinal solution as was mentioned. Stated differently, management may be unable to obtain information on the cost or value of a goal or a subgoal, but often upper or lower limits may be stated for each subgoal.

The general GP algorithm can be mathematically expressed as:

$$\text{MINIMIZE } Z = \sum ( \overset{+}{d}_i + \overset{-}{d}_i )$$

SUBJECT TO:

$$AX - I\overset{+}{d}_i + I\overset{-}{d} = B$$

$$X, \overset{+}{d}_i, \overset{-}{d}_i \geq 0$$

Where m goals are expressed by an m component column vector B(B1,B2,...,Bm), A is an m*n matrix which expresses the relationship between goals and subgoals, X represents variables (X1,X2,...Xn) , $\overset{+}{d}$ ,and $\overset{-}{d}$ are m-component vectors for the variable representing deviations from goals and I is an identity matrix in m dimensions.

In formulating the objective function, the following "classes" would be considered as stated by Ignizio and Lee :

(1) The desire (or aspiration) of the decision maker,

(2) Limited resources,

(3) Any other restrictions either explicitly or implicitly placed on the choice of decision variables.

Typical objectives in the first class might include the following goals or subgoals:

(i) maximize benefits,

(ii) minimize costs,

(iii) minimize overtime,

(iv) maximize the utilization of personnel or process,

(v) minimize the delay,

(vi) minimize the risk,

(vii) maximize the probability that a process remain within certain control limits,

(viii) minimize labor turnover rate.

Objectives within the second class could include the objective either not to violate, or perhaps to minimize the violation of resources restrictions such as :

1- limited manpower,

2- limited raw material,

3- limited budget,

4- limited time.

Within the third, and final class, goals would be to satisfy or attempt to satisfy various "legal" restrictions such as :

(1-a) physical requirements that specifies that variables be nonnegative,
(1-b) a contractual requirement that specifies that a variable or variables must be equal or exceed a certain minimum value.

The manager must analyze each one of m goals considered in the model in terms of whether over or under achievement is acceptable; d's can be eliminated from the objective function. For example, if under achievement is satisfactory, $\bar{d}_i$ should not be included in the objective function. If the exact achievement of the goal is desired, both $\overset{+}{d}_i$ and $\bar{d}_i$ must represent in the objective function.

The deviational variables $\overset{+}{d}_i$ and $\bar{d}_i$ must be ranked according to their preemptive priority weights, from the most important to the least important. In this way the low goals are classified as k ranks, the preemptive priority factor p(j=1,2,..,k) should be assigned to the deviational variables,d and d . The priority factors have the relationship of Pj>>>Pj-1(j=1,2,...,k), which implies that the multiplication of n, however large it may be, can not make Pj-1 greater than or equal to Pj. Of course, it is possible to refine goals even further by the means of decomposing the deviational variables. To do this, additional constraints and additional priority factors are required.

<u>(6-3.2) TECHNOLOGICAL COEFFICIENTS :</u>

The major question posed by the initial statement of the allocation models involves the proper definition and measurement of technological coefficients in the optimization approach. The cost-effectiveness ratio has been considered here as an effective technological coefficient for most of the constraints involved. Many other methods of determining the technological coefficient can also be considered such as net benefit and costs,ranking methods, or impact measure, which would be investigated to determine the best suitable indicator for the allocation process. The effectiveness coefficients will be computed for each individual candidate countermeasure with respect to the type of accidents( fatal,non-fatal,PDO,or total accident). Then such an indicator can be used in the optimization model to maximize the accident reduction for the entire system. However, the comparative discussion of marginal benefit and the cost-effectiveness ratio will be investigated as they are primarily focused on the questions of units of measure and the meaning and implication of measure. Both measures of effectiveness lend themselves to multiple objectives of the optimization model.

The major differences between net-benefit indicators and cost-effectiveness indicators is related to the definition of their "unit-measurements." This is particularly important when the units are not commensurable. In this case, net benefit ratio can not be computed. Consequently, if net benefits are to be used the physical units associated with deaths and injuries must be converted to a numeric, while the cost-effectiveness indicators do not need such a transformation. In using this measure, the units are generally maintained even when cancellation is permissible. The cost-effectiveness ratio indicates the benefit to be derived from a unit of resource expenditures. This incorporates the physical units associated with all types of accidents rather than requiring transformation into numerical values. Such ratios actually are weighted by the total countermeasure costs (cost+maintenance) to reflect the total social burden associated with any improvement categories.

## (6-3.3) OPTIMALITY ASSESSMENT MODEL COMPONENTS

The Optimality Assessment Formulation developed in this chapter is based on:

(1) SYSTEM OBJECTIVES and

(2) SYSTEM CONSTRAINTS.

(1) System Objectives: includes the improvement of traffic safety system condition, provision of reduction in death, injury, and property damage accidents. However, the extent of the impacts can be measured by the Countermeasure Effectiveness-Performance Impact Matrix. The elements of this matrix is shown as EF(i,j,k,l) where the matrix element EF(i,j,k,l) denotes the reduction in system objective l due to implementation of countermeasure j in category k at location i. Then, the total system-wide improvement objective l, considering j=1,2,3,...m safety countermeasures or safety programs, and i=1,2,3,...,n local government is then given by the following expression:

$$\sum\sum\sum EF(i,j,k,l) \geq E(l)$$

$l=1,2,3,\ldots$objectives

$E(l)$ is the target for objective l

In multiple objective optimization programming the system objectives are represented as constraints that have positive and negative deviational variables to denote over-achievement and under-achievement of the target so the system objectives can then be expressed as:

$$\sum\sum EF(i,j,k,l) * BUD(i,j) + \bar{D}(l) - \overset{+}{D}(l) = E(l)$$

The above expression indicates that system-wide improvement in objective l actually achieved may exceeds the target $E(l)$ if and only if $D(l) > 0$. or may fall short of the target if and only if $D(l) > 0$. In this regard the objective function of the goal programming optimization problem is to minimize the deviations from the goals, i.e.:

$$\text{MINIMIZE: } ZZ=\sum P(l) \; [\; \overset{+}{D}(l),\; \bar{D}(l) \;]$$

where; $P(l)$ is the preemptive priority for each objective level and can be assigned by decision maker(s).

## (6-3.4) DEVELOPMENT OF THE TECHNOLOGICAL COEFFICIENTS: COUNTERMEASURE-PERFORMANCE IMPACT MATRIX

Let us establish the following goals and objectives for a hypothetical safety program in an urban area and then start to formulate this process according to the proposed modeling approach.

- Maximize the reduction of fatal accidents,
- Maximize the reduction of injuries accidents,
- Maximize the reduction of property damage accidents,
- Maximize the reduction of total accidents,
- Minimize the total expenditure,
- At most allocate 50 percent of total resources for pedestrian safety improvement.

The following parameters should be established :

$(RACC)_{ijkl}$:

where;

$(RACC)_{ijkl}$ is expected reduction of accident by type l, in location i, due to implementing the countermeasure j, in category k.

"i" is the location index number, i=1,...n ;

j is the reference to the implemented countermeasures, j=1,..total number of alternative

k is the number of categories, considered to be:

1=INTERSECTION

2=RESIDENTIAL AREA GENERAL IMPROVEMENT

3=PEDESTRIAN IMPROVEMENT

4= GEOMETRIC IMPROVEMENT

(EF)ijkl is a countermeasure indicator(technological coefficient) related to the location i, countermeasure j, category k and type l of objectives. Then this relationship can be represented as :

$$(EF)ijkl=(RACC)ijkl/(C)ijkl$$

where (C)ijkl is the estimated cost of countermeasure j at location i,in category k which is allocated to reduce the accident type l. So, "TC" is the expected reduction of accident with a dollar expenditure. On the other hand , EF is the expected rate of accident reduction. Figure (6-2) demonstrates the Countermeasure-Performance Impact Matrix for k categories, l objectives, i locations, and j countermeasures.

(BUD)ijkl : Is the optimized level of expenditure by the local for implementing the countermeasures j at location i, for reducing(optimizing) the accident type l in the category k.

R is the total available resources

LOCATION(I)

COUNTERMEASURE (J)

$$
\begin{bmatrix}
(EF)_{1,1,K} & (EF)_{1,2,K} & (EF)_{1,3,K} & \cdots & (EF)_{1,N,K} \\
(EF)_{2,1,K} & (EF)_{2,2,K} & (EF)_{2,3,K} & \cdots & (EF)_{2,N,K} \\
(EF)_{3,1,K} & (EF)_{3,2,K} & (EF)_{3,3,K} & \cdots & (EF)_{3,N,K} \\
(EF)_{4,1,K} & (EF)_{4,2,K} & (EF)_{4,3,K} & \cdots & (EF)_{4,N,K} \\
\vdots & \vdots & \vdots & \ddots & \\
(EF)_{M-1,1,K} & (EF)_{M-1,2,K} & (EF)_{M-1,3,K} & \cdots & (EF)_{M-1,N,K} \\
(EF)_{M,1,K} & (EF)_{M,2,K} & (EF)_{M,3,K} & \cdots & (EF)_{M,N,K}
\end{bmatrix}
$$

FIGURE (6-2):
COUNTERMEASURE-PERFORMANCE IMPACT DEVELOPED FOR THE OBJECTIVE K, BASED ON COST-EFFECTIVENESS CRITERIA (SUGGESTED UNIT OF MEASUREMENT: SEVERITY PER $)

LOCAL JURISDICTION (i) ⟶

| COUNTERMEASURE (j) ↓ | 1 | 2 | 3 | 4 | | N |
|---|---|---|---|---|---|---|
| 1 | 19.74 | 19.74 | 19.74 | 19.74 | . . . . . . | 19.74 |
| 2 | 0.5 | 0.5 | 0.5 | 0.5 | . . . . . . | 0.5 |
| 3 | 0.49 | 0.49 | 0.49 | 0.49 | . . . . . . | 0.49 |
| 4 | 0.47 | 0.47 | 0.47 | 0.47 | . . . . . . | 0.47 |
| 5 | 0.467 | 0.467 | 0.467 | 0.467 | . . . . . . | 0.467 |
| 6 | 0.294 | 0.294 | 0.294 | 0.294 | . . . . . . | 0.294 |
| 7 | 0.2717 | 0.2717 | 0.2717 | 0.2717 | . . . . . . | 0.2717 |
| 8 | 0.238 | 0.238 | 0.238 | 0.238 | . . . . . . | 0.238 |
| . | . | . | . | . | . . . . . . | |
| . | . | . | . | . | . . . . . . | |
| 37 | 0.00112 | 0.0011 | 0.0011 | 0.0011 | . . . . . . | 0.0011 |

FIGURE (6-4):

NATION-WIDE COUNTERMEASURE PERFORMANCE MATRIX
DEVELOPED FOR THE OBJECTIVE OF MINIMIZING FATALITY
ACCIDENTS
(UNIT OF MEASUREMENT: FATAL PER 10,000 DOLLARS)

LOCATION ($i$) →

| COUNTERMEASURE ($j$) ↓ | 1 | 2 | 3 | 4 | | N-1 | N |
|---|---|---|---|---|---|---|---|
| 1 | 34.01 | 34.01 | 34.01 | 34.01 | . . . | 34.01 | 34.01 |
| 2 | 0.892 | 0.892 | 0.892 | 0.892 | . . . | 0.892 | 0.892 |
| 3 | 0.891 | 0.891 | 0.891 | 0.891 | . . . | 0.891 | 0.891 |
| 4 | 0.6622 | 0.6622 | 0.6622 | 0.6622 | . . . | 0.6622 | 0.6622 |
| 5 | 0.595 | 0.595 | 0.595 | 0.595 | . . . | 0.595 | 0.595 |
| 6 | 0.523 | 0.523 | 0.523 | 0.523 | . . . | 0.523 | 0.523 |
| 7 | 0.483 | 0.483 | 0.483 | 0.483 | . . . | 0.483 | 0.483 |
| 8 | 0.363 | 0.363 | 0.363 | 0.363 | . . . | 0.363 | 0.363 |
| . | . | . | . | . | . . . | . | . |
| . | . | . | . | . | . . . | . | . |
| 37 | 0.002 | 0.002 | 0.002 | 0.002 | . . . | 0.002 | 0.002 |

FIGURE (6-3):

NATION-WIDE COUNTERMEASURE-PERFORMANCE MATRIX DEVELOPED FOR THE OBJECTIVE OF MINIMIZING INJURY ACCIDENTS

(UNIT OF MEASUREMENT: INJURIES PER 10,000 DOLLARS)

(E)ijkl :

The term (E)ijkl represents the relative effectiveness of each selected goal, i.e., the maximum effectiveness levels for deaths, injuries, or property damage. where the maximum has been either preset by the decision maker(s). These can also be considered as the expected minimum critical accident( state-wide rate) for each category.

## (6-3.5) ASSINGNING OBJECTIVES TO PRIORITY LEVELS

In typical linear programming only a single objective problem can be optimized. In terms of goal programming definition, a "linear program" is simply a multiple objective decision model wherein all objectives, save one, are absolute. In the terminology of linear programming , there is a "single" objective and one or more "constraints". Thus, in this regard, if a solution violates one or more absolute objective,(i.e., constraints) it is termed "infeasible". The inflexibility of the linear programming model serves to deny the fact that some, if not all, of these "constraints" may actually not be absolutely binding. Such a difficulty can be easily circumvented by the more flexible multiple objective decision model.

When multiple objectives exist, and they often do in all the public work projects, care should be made to satisfy all of them (if at all possible). This can be accomplished by assigning the top priority P1, to these absolute objectives. So, all the absolute objectives should be given a priority level one to insure that they, at least, are completely satisfied. The remaining set of nonabsolute objectives should then be grouped according to their respective priority levels. The assignment of priorities to these objectives is normally decided by the local decision maker or the decision maker in conjunction with the analyst.

As mentioned, only commensurable objectives may be assigned to the same priority level. Objectives expressed in different measures can be assigned to the same priority level only if they can be expressed in terms of a common unit of measure.

## (6-3.6) PRIORITY SELECTION PROCEDURE

As mentioned in the previous section, the priority should be established by the decision maker for different selected countermeasures. The following procedure is recommended.

Define the goals and objectives (from State and local views), then based on that try to assign the priority to different countermeasures with regard
ng parameters;

(a) Cost-Effectiveness Ratios,
(b) Priority based on The NHSNR,
(c) Delphi Panel,
(d) Literature Search.

Figure (6-1) represents a priority which is calculated based on the NHSNR.

## (6-3.7) STEPS REQUIRED TO FORMULATE THE ALLOCATION MODEL

In optimizing the allocation of local resources for traffic safety improvement, the following steps are recommended:

(1) Aggregate the total available budget internally and externally (local and federal funds),

(2) Set up the main goals and objectives,

(3) Select the proper countermeasures (Chapters Three and Five for proper procedure and computer programs "Feasibility Assessment"),

(4) Compute the cost-effectiveness ratio for each countermeasure (Chapters Three and Five)

(5) Assign the priority to each countermeasure or safety program (Sections 6-3.5, and 6-3.6),

(6) Model the problem based on the recommendation and guideline in Sections (6-3.5, and 6-3.9),

(7) Input the data to the computer according to the instruction in Appendix(C-2),

(8) Try with different possible parameters to find out the best return under limited resources. Figure (6-5) demonstrates the required steps needed for utilizing the Optimality Assessment Model.

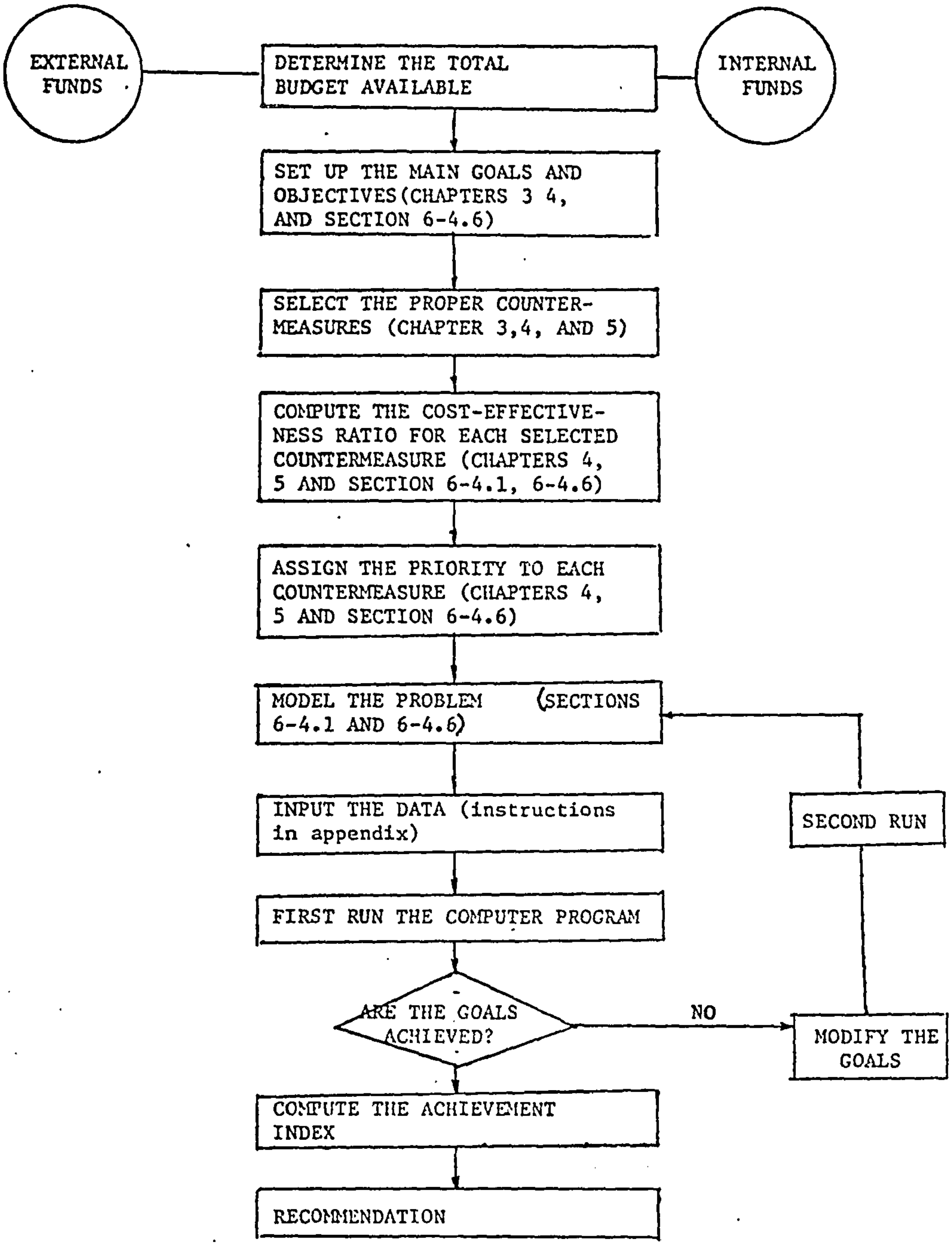
## (6-3.8) MATHEMATICAL OPTIMIZATIOM FORMULATION FOR TRAFFIC RESOURCE ALLOCATION IN A LOCAL URBAN JURISDICTION

Based on the notations described in previous section, the following formulations can be arranged:

### SYSTEM OBJECTIVES:

(a) Maximize the reduction of fatal accidents,

FIGURE (6-5)
STEPS REQUIRED TO FORMULATE THE ALLOCATION MODEL



(c) Maximize the reduction of injury accidents and

(d) Maximize the reduction of property damage accidents.

**SYSTEM CONSTRAINTS:**

(a) At most allocate 50% of total resources for the second category (pedestrian),

(b) Limited budget.

**DECISION VARIABLES:**

BUD(i,j) is the optimal fund allocated to countermeasure j at location i.

**TARGET:**

E(l) is the relative effectiveness of each selected goal and it should preset by the decision maker for each goal.

**EXPRESSION OF SYSTEM OBJECTIVES:**

$$\sum\sum\sum EF(i,j,k,1) * BUD(i,j) \geqslant E(1)$$

$$\sum\sum\sum EF(i,j,k,2) * BUD(i,j) \geqslant E(2)$$

$$\sum\sum\sum EF(i,j,k,3) * BUD(i,j) \geqslant E(3)$$

EXPRESSION OF SYSTEM CONSTRAINTS:

$$\sum\sum \text{BUD}(i,j) \leq R$$

R is total available fund (local share and state),

$$\sum\sum \text{BUD}(i,j) \leq .50 * R$$

The sum of budget allocated to the countermeasures in the second category,

$$(1-F)\sum\sum \text{BUD}(i,j) < L(s)$$

Where; L(s) is the local share, G is the set of projects or countermeasures that are federally funded, and F is the fraction of cost of safety countermeasure that is federal funding matching grant.

$$F\sum\sum \text{BUD}(i,j) < S(s)$$

Where; S(s) is the state share.

$$\text{BUD}(i,j) \geq \text{MIN.}(j)$$

Where; MIN.(j) is the minimum required fund for deploying countermeasure j.

Considering the above definitions, the overall formulation including the over and under achievement variables are as follows:

C=[P1(D1), P2(D2), P3(D3), P4(D4,D5), P5(D6), P6(D7,D8), P7(D9)]

P1, P2, P3, P4, P5, P6, and P7 are the preemptive priorities.

$$\sum\sum\sum EF(I,J,K,1) * BUD(I,J) + \bar{D}1 = E(1)$$

$$\sum\sum\sum EF(I,J,K,2) * BUD(I,J) + \bar{D}2 = E(2)$$

$$\sum\sum\sum EF(I,J,K,3) * BUD(I,J) + \bar{D}3 = E(3)$$

$$\sum\sum BUD(I,J) + \bar{D}4 - \overset{+}{D}5 = R$$

$$\sum\sum BUD(I,J) - \overset{+}{D}6 = .5 * R$$

$$(1-F)\sum\sum BUD(I,J) - \overset{+}{D}7 = L(S)$$

$$F \sum\sum BUD(I,J) - \overset{+}{D}8 = S(S)$$

$$BUD(I,J) - \overset{+}{D}9 = MIN(J)$$

$$J \in [(1,2,3,..M)]$$

where P(i,j) [i=1,...,2m,j=1,2,..,k) are preemptive priority factors which were discussed previously, with the highest preemptive factor being P1 and (i=1,2,...,2m) are real numbers and ds for weighting at the same priority level.

This was the very aggregated formulation which was briefly described. The appearance of each deviational goal variable in objective function depends on its associated priority which the decision-maker has made.

The above problem can be easily solved by the computer program indicated in Appendix (C-1). It is noteworthy that the reduction of accidents for the second category (pedestrian safety improvement) has been given a higher weight than the other three categories, also, fatality reduction is given a higher priority, but not more than resource constraints.

### (6-3.9) MULTI-OBJECTIVE DECISION MAKING FORMULATION FOR ALLOCATING THE STATE'S SAFETY RESOURCES AMONG LOCAL GOVERNMENT OR STATE HIGHWAYS

The basic objective of this proposed formulation is to develop an evaluation technique by which state government can input the values and priorities of its transportation goals into an analytical process, with the output, identify and establish an allocation policy that will satisfy these goals to a reasonable extent. It is noteworthy that, the established policy for allocating the safety resources must satisfy a variety of local or community's goals, state and federal's objectives, so the candidate budgeting policies must be assessed to decide which best fits the range of these goals.

As mentioned, highway safety funds received by the states from Federal grants or from state-levied taxes, and used for highway purposes, are either distributed to local governments or spent directly on-state-controlled highways. However, for the sake of simplicity and the macro nature of this research, there is no attempt to consider the financial structure of the safety resources within the local, state, and federal governments. It is assumed that safety resources available to the local and state government compose of two parts; federal grant-in-aid and the local or state share.

At a local level, the Feasibility Assessment Modules(FAM) developed in chapter five can be used for the allocation purposes when there are a fixed budget and a single objective. However, the FAM modules can be used as a filter to select the most feasible and cost-effective countermeasures if there are multi-objective criteria and many constraints. The output resulted from the first step programming can be used in the second steps programming i.e., Optimality Assessment modules for the final optimal results.

In this formulation, it is supposed that the goals of transportation agency at the local level is to satisfy the objectives of minimizing the fatal, injury, property damage accidents, and satisfying the State's priorization for safety programs. the optimization formula, for a "N" local regions with "M" safety programs, Three system objectives and four safety improvement categories are developed below:

<u>SYSTEM VARIABLES:</u>

N local jurisdictions,

M safety programs,

K categories,

L objectives or subgoals,

EF safety program-performance impact matrix,

BUD(I,J) decision variables,

E(L) standard(TARGET) aimed at for objective L,

$\bar{D}$(L) underachievement in objective L,

$\overset{+}{D}$(L) overachievement in objective L,

P(L) priority for objective L,

F(J,K) is the fraction of cost of safety program (countermeasure); that is federal funding matching grant in category K,

S is the budget provision from state for one year for all local jurisdictions,

S(s) is the state's share safety resources,

MIN(I,J,K) is the minimum identified resource needed for various safety program in order to be deployed and can be obtained from Chapter Three and Appendices (A-1, A-2, A-3),

Y(K) is the fraction of resources required to be allocated to safety category K.

L=1 ... MINIMIZE FATAL ACCIDENTS (FIRST PRIORITY)

L=2 ... MINIMIZE INJURY ACCIDENT (SECOND PRIORITY)

L=3 ... MINIMIZE PROPERTY ACCIDENTS (THIRD PRIORITY).

<u>SYSTEM OBJECTIVES EXPRESSED AS CONSTRAINTS:</u>

$$\sum\sum EF(I,K) * BUD(I,J,K) + \bar{D}(K,L) - \overset{+}{D}(K,L) = E(K,L)$$

Where:

EF(I,K): safety activities performance impact coefficient described as Accident/$ for local I and objective K i.e.,

EF(1,1) is the safety performance impact coefficient related to the reduction of fatal accident(K=1) in local 1,

EF(2,1) is the safety performance impact coefficient related to the reduction of injury accidents(K=1) in local 2,

EF(3,3) is the safety performance impact coefficient factor related to the reduction of property accidents objective(K=3) in local 3.

E(L,K) is the standard(target) aimed at for objective L in category K,

$\bar{D}(L,K)$ is the underachievement in objective L and category K,

$\overset{+}{D}(L,K)$ is the overachievement in objective L and category K, J=1,2,...,M (safety programs)

I=1,2,...,N (reference index for local governments)

L=1, 2, 3 (objective functions) where;
L=1....fatality , L=2....injury and L=3 for property damage related objective

K=1,2,3,4 (safety categories).

FUNDS:

Total local or state's share on eligible safety program activities should not exceed the state allocation of federal grant, so:

$$\sum\sum [F(J,K) * BUD(I,J) < S(s)$$
$$\sum\sum BUD(I,J) < S$$

Where;

F(J,K) is the fraction of cost of safety countermeasure J that is federal funding matching grant.

BUD(I,J) is the optimal allocation policy for safety countermeasure (safety program) J at local jurisdiction I aggregated for all categories.

S(s) is the budget provision from state for one year for all local jurisdictions.

MINIMUM NEEDS:

To meet a minimum of the identified resources for various safety program in order to be implemented i.e.;

$$\sum\sum BUD(I,J,K) \geq MIN(I,J,K)$$

CATEGORICAL CONSTRAINTS:

Allocate safety resources ( Y percent) to the specific safety category;

$$\sum \sum BUD(I,J) \geq Y(K) * S$$

OBJECTIVE FUNCTION:

The objective function is to minimize a weighted sum of the underachievement with respect to the preemptive priorities discussed in previous sections, i.e.;

$$\text{MINIMIZE : } ZZ = \sum\sum W(K,L) * [\overset{+}{D}(k,L),\ \overset{-}{D}(K,L)]$$

$$K=1,2,3,\ \ldots,\ \#\text{ of categories}$$

$$L=1,2,3,\ \ldots,\ \#\text{ of objectives}$$

The above formulation can be easily done by the transportation safety engineer and can be solved by the Optimality Assessment Module(OAM) documented in Appendix (C-1).

## (6-4) ACHIEVEMENT INDEX

The effectiveness of the final state allocation policy can be measured by the fact that what proportion of the local safety system's needs are met by the recommended allocation policies. This can be mathematically described by the following formula:

$$EFF(i) = X(i..) / C(i..)$$

in which EFF(i) is the proportion of needs met(funded) on local safety system i; X(i..) is the total funds allocated to local safety system i (aggregated for all categories and safety programs); and C(i..) is the needs of local safety system i. Alternatively if W(i) is represented as a proportion of needs not met, using the above equation, the measure of achievement for the proposed funding policies can be shown as:

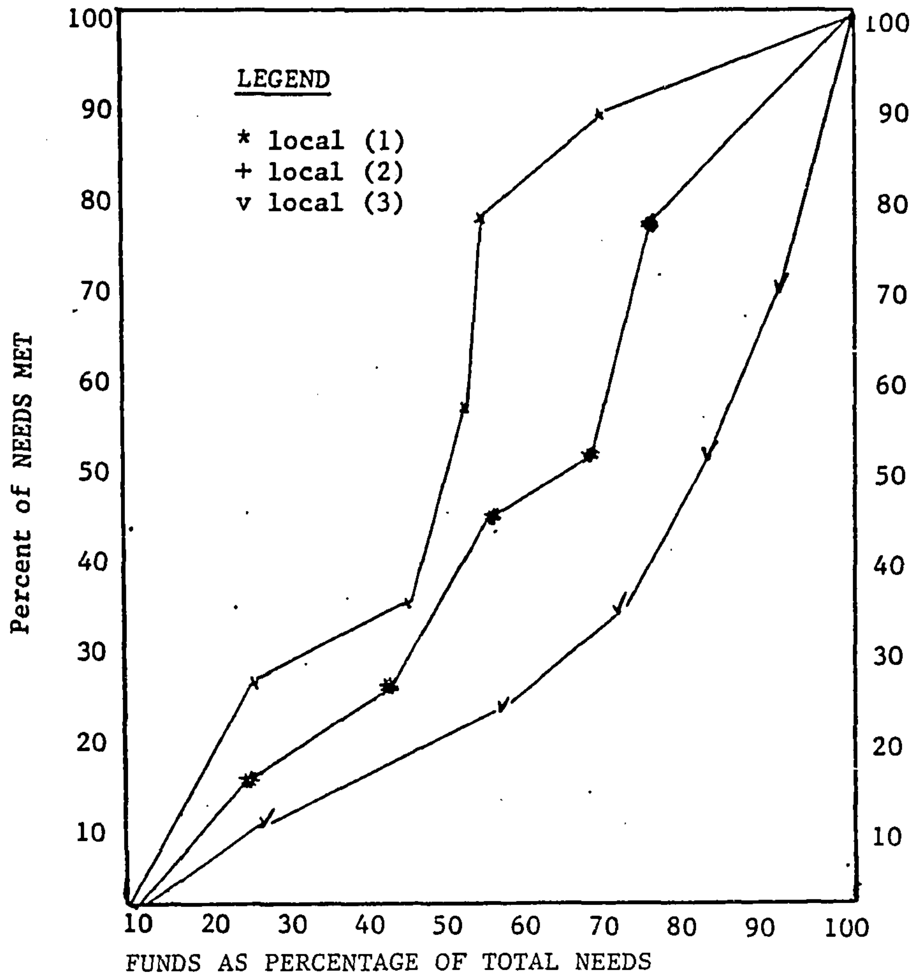
$$W(i) = 1- X(i..) \text{ or;}$$

$$W(i) =[C(i..) - (Xi..)]/ [ C(i..)] * 100$$

Where; W(i) is the relative deficit in local i.

The above simple formulation can be used to represent how effective the allocation policies can reduce or minimize the value of deficit with modifying the goals and objectives if it is possible. So, when the value for W(i) is zero, that means that all the needs are fulfilled and if the value is 50 percent, that indicates that allocation policy resulted from the implication of the model satisfies the safety needs by 50 percent. Figure(6-6) represents the percentage of needs met versus funds available for different jurisdictions in a hypothetical example.

FIGURE (6-6)
PERCENTAGE OF NEEDS MET VESUS AVAILABLE FUNDS

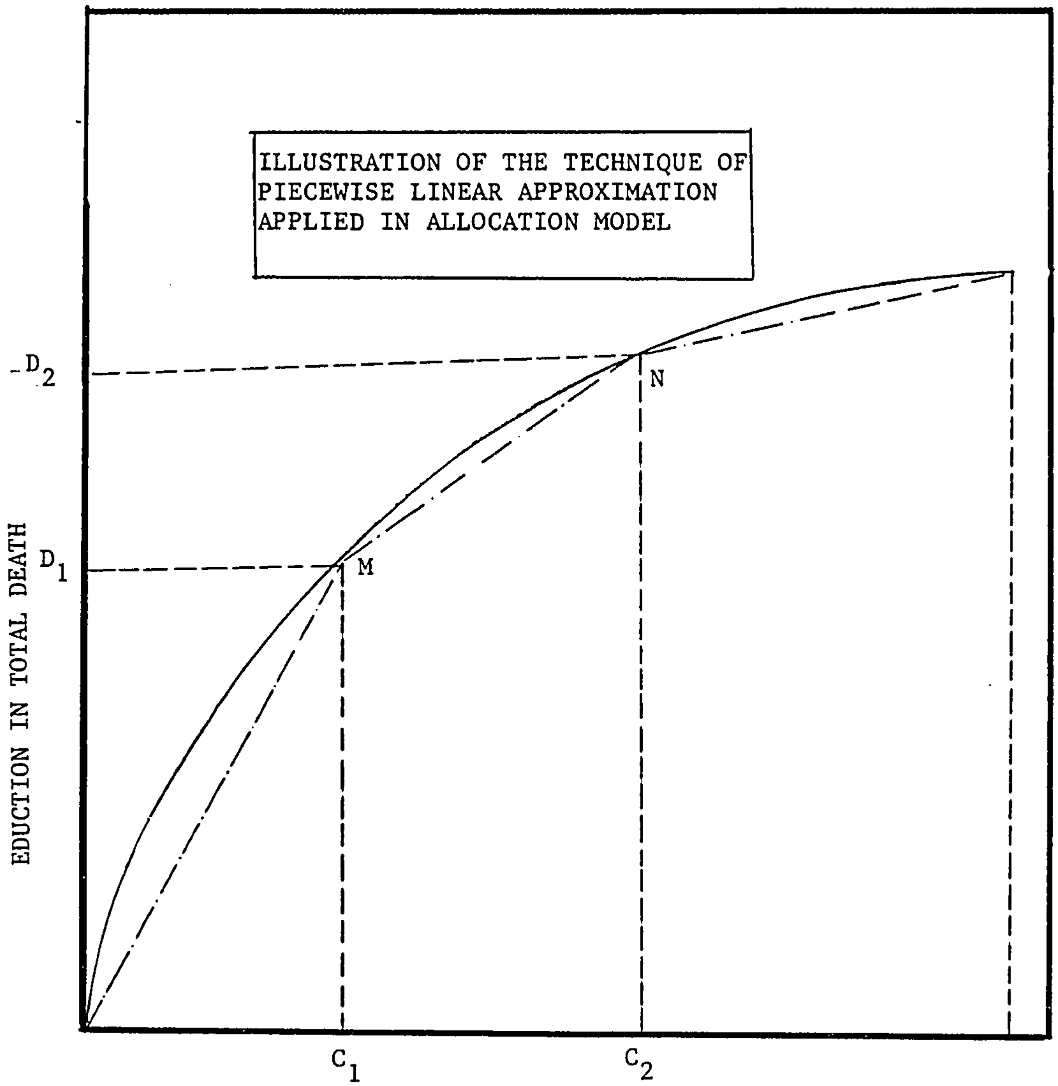


## (6-5) TREATMENT OF NON-LINEARITY

As mentioned in chapter one, the non-linearity may pose the greatest problem for the proposed allocation procedure since linear goal programming inherently assumes linearity among the constraints and objective functions. Once a measure of effectiveness has been chosen, then, the cost-effectiveness ratio for each safety category or program can be computed. Three different rates would be considered for each program, first, an average cost-effectiveness measure which can be computed by measuring the benefit increment obtaining by increasing the expenditure levels above the amounts that would have otherwise been spent and dividing this increment by the corresponding increment in local government plus private cost. Second, a marginal cost-effectiveness ratio, by dividing the marginal benefit increment by the marginal increment to the program or countermeasure costs. Third, the computed cost-effectiveness for the national level can be applied. On the theoretical grounds, the second type of cost-effectiveness ratio is more informative since the marginal cost-effectiveness ratios for all the programs or countermeasures will pinpoint the optimal direction in which expenditures should be expanded.

$$TC = [(D2-D1)/(1/C2)-(1/C1)]/(C1+C2)]$$

As illustrated in Figure (6-7), the function is approximated over each expenditure level. For each expenditure level, the marginal benefit from expenditures on each safety




LEVEL OF LOCAL SAFETY EXPENDITURE

FIGURE (6-7) PIECE-WISE LINEAR APPROXIMATION TECHNIQUE program or countermeasure is assumed to be a constant equal to the slope of the cord from M to N. If the final allocation is, in fact, made at level Cp, the marginal benefit per unit of safety program or countermeasure output will be the slope of the cord from M to N.

## (6-6) RUNNING THE ALLOCATION COMPUTER PROGRAM

The decision maker should run the allocation program at least two times as follows:

First Run:

Some of the goals may not be achieved in the first run. In this regard, the decision maker should modify some of the parameters if it is possible.

Second Run:

After reviewing the first run result, the decision maker should modify his goals to be more realistic. The result of the first run may indicate that a certain set of goals may not be achieved unless some changes are made. Therefore, the decision maker should modify the goals to some acceptable degree, then run the program for the second time. Table (6-4) demonstrates the summary of computer out-put for the hypothetical example under three different scenarios and three safety programs.

TABLE (6-4)

(SUMMARY OF COMPUTER OUT-PUT FOR OPTIMALITY ASSESSMENT)

COMPARISON OF ALTERNATIVE ALLOCATING POLICIES UNDER DIFFERENT OBJECTIVES AND PRIORITIES (SCENARIOS) (THOUSAND DOLLARS)

| SYSTEM OBJECTIVES AND PRIORITIES (SCENARIO) | LOCAL(1) | | | LOCAL(2) | | | LOCAL(3) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| SAFETY PROGRAM 1 | 35 | 36 | 20 | 35 | 36 | 36 | 18 | 15 | 36 |
| SAFETY PROGRAM 2 | 28 | 5 | 45 | 12 | 18 | 15 | 15 | 38 | 23 |
| SAFETY PROGRAM 3 | 12 | 12 | 0 | 24 | 25 | 12 | 26 | 20 | 20 |

TOTAL ALLOCATED BUDGET WAS 205,000. DOLLARS

FIGURE (6-4a)

BUDGET REQUESTED BY LOCAL(i)

| | |
|---|---|
| LOCAL(1) | $ 115,000. |
| LOCAL(2) | $ 135,000. |
| LOCAL(3) | $ 128,000. |

FIGURE (6-4b)

OVERALL ACHIEVEMENT INDEX

| | SCENARIO 1 | 2 | 3 |
|---|---|---|---|
| LOCAL(1) | .625 | .460 | .565 |
| LOCAL(2) | .488 | .585 | .466 |
| LOCAL(3) | .460 | .570 | .593 |

## (6-7) TWO-SYSTEM MODEL COMMUNICATION

In this dissertation two mathematical models were developed namely, Feasibility Assessment Model in Chapter Five and Optimality Assessment Model in this chapter. These two system models are able to communicate with each other in order to produce a powerful systematic allocation procedure to allocate local, state, or federal resources to different political jurisdictions.

The safety needs of each political jurisdiction (subdivision) can be investigated and quantified by utilizing the Feasibility Assessment Model proposed In Chapter Five. Then Optimality Assessment Procedure can be utilized by higher-level decision maker to allocate the safety resources to different political subdivision while maintaining the national and local government interests. Figure (6-8) is demonstrating how this communication is taking place between state and local jurisdictions.

## (6-8) BASIC ASSUMPTIONS CONSIDERED IN THE MODELING APPROACH

In order to demonstrate the applicability of MOBSI in the analysis of an urban safety allocation problem with multiple conflicting goals, a series of assumptions should be made as follows:

(1) The Cost-Effectiveness Ratios (CER) indicate the benefit to be derived from a unit of resource expenditures. For example, if the CER associated

## TWO-SYSTEM MODEL COMMUNICATION

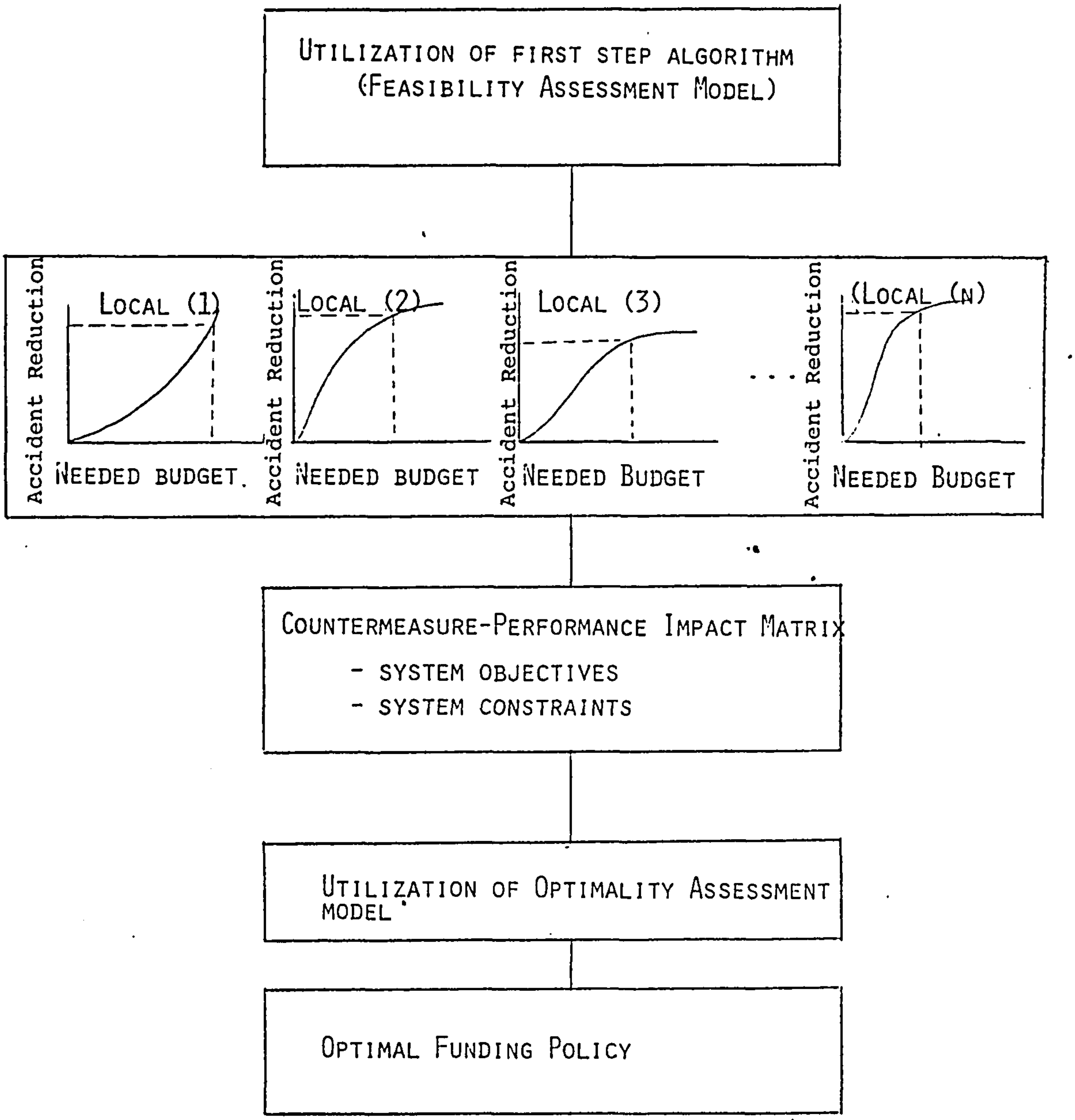



FIGURE (6-8).

ith injuries for a particular safety measure were .001, an expenditure of $ 1,000 would decrease injuries by one,

(2) Effectiveness estimates for various countermeasures embody most up-dated results of previous research activities, (3) It may be possible that, additional technological advances will occur during or after the time period for which allocations are projected, but they should be assumed having the same pattern that has prevailed over the recent past,

(4) The primary focus of this study id directed measuring only the traffic safety related benefits. So, non-safety benefits are not considered in this research study,

(5) Both costs and benefits are assumed to be linearly additive,

(6) The question of at what point should the measurement be taken because the ratio may change as the level of expenditure may change can be answered by the using the technique described in Section (6-5). This problem actually is minimized in the case of decreasing return to factor by emphasizing the piecewise approximation technique for each category.

## (6-9) IMPROVEMENT BY CATEGORIES:

Improvement by categories is a very significant and unique effort which has been made in this research study. This effort strengthens the capability of the model to respond to the different policy issues in a local jurisdiction. This enables the decision maker to allocate a percentage of the total resources on one specific category in which he has received federal aid. The following example should clarify the usefulness of such a model capability. There is a federal funding program established by congress with the objective of improving highway safety. As part of the requirement for this funding establishment, certain standards should be undertaken. For example, highway safety program standard 14 which indicates every state in cooperation with its political subdivision shall develop and implement a program to insure the safety of pedestrians of all ages. If the state provides the local with such a resources, he has to allocate as much money to fulfill such a requirement at the first step. The proposed technique will allow him to formulate the model according to the type of improvement which is required and respond to the policy issues in a very quantitative manner.

For the sake of simplicity only four categories have been selected:

1- INTERSECTION IMPROVEMENT
2- PEDESTRIAN IMPROVEMENT
3- GEOMETRIC IMPROVEMENT
4- GENERAL IMPROVEMENT

Of course the model and program can be easily converted to a general approach, having as many categories as desired. It can then be used by the higher level decision maker or state and federal government, but at the expense of changing the different criteria and parameters.

## (6-10) INTERACTION OF RECOMMENDED PROCEDURE AND THE DECISION MAKER

It is expected that the proposed technique would assist the local decision maker to allocate the available resources for traffic safety improvement and selection of the proper countermeasure for future implementation. It is hoped that the maximum reduction of accidents will be achieved with limited resources while a set of local and state objectives is satisfied. However, to achieve the best solution requires iterative interaction between the feasibility assessment model in chapter five , the allocation model in Chapter Six, analyst, and the decision maker. Stated somewhat negatively , blind reliance on the "optimal" properties of any model including the proposed methodology, in the absence of sophisticated understanding of its operating characteristics, could result in an incredibly poor result.

# CHAPTER VII

## CONCLUSION AND RECOMMENDATIONS

A major challenge to the local, state, and federal governments is allocation of safety funds in the face of competing needs for public money, increasing costs, and inflationary effects. Therefore, there is a serious need to develop a general methodology that can be used by all three levels of government to allocate limited financial resources for traffic safety improvement projects(programs) based on the potentiality and effectiveness of the safety projects(programs) to save more lives and the basic needs of a community for this safety program.

This dissertation has discussed the development of the two-step allocation models including the Feasibility Assessment and Optimality Assessment Techniques to be used by local, state, and federal decision-makers in allocating the safety resources. In addition, the thesis recommends a systematic procedure to identify, analyze, and select safety countermeasures suitable for small urban jurisdictions that want to build such a safety system for the first time. The recommended procedure enables the decision-maker(s) to select the best possible safety project(programs) alternatives under limited financial resources.

The Feasibility Assessment Technique proposed in this dissertation is simple and easy to implement in any local jurisdiction, and most of the time, the solution obtained from this algorithm is very near the optimal. The interactive computer programs developed in this dissertation enable the decision-makers in a small local jurisdiction to apply them very easily and effectively. The importance of the Feasibility Assessment Technique in local jurisdiction is to aid the decision-maker to quantify his/her community's needs for safety resources. Based on these quantitative figures received by states from their local jurisdictions, the formulation for safety resource apportionment can be made.

The Optimality Assessment Technique provided in this thesis develops a goal programming technique to the multi-objective decision problem of highway safety allocation. The multiple-objective technique has been found to be a very effective mathematical tool that can be used for highway safety allocation resources. It is noteworthy at this conclusion that each state's or local's approach to planning and programming is unique. This was considered in this dissertation when the multiple-objective optimization technique was developed. Experience indicates that in a given set of objectives for different target areas, the priority structure of these objectives, various environmental constraints, unique organizational values of the different transportation agencies, and the bureaucratic structure in each target area is different and so a powerful optimization model should be developed to handle the safety allocation process.

During the 1982 Transportation Research Board convention at Washington D.C., the author visited with many top transportation professionals and scientists who had earlier received a rough draft of this technique. From these interviews and their responses, the experience of the author in developing such a mathematical procedure for allocating the safety funds has been encouraged and confirmed at that convention. It is believed that the recommended procedure will be more effective and powerful if it is used at local and state levels. Applying such a macro-technique in a higher level of decision-making (federal) received less attention since the model requires more verification due to the complexity of the allocation process at the federal level, but, the procedure was considered as a potential mathematical methodology that may be considered by higher level decision-makers.

It is believed that the recommended procedure be used as a design allocation aid and not as a substitute for making a final decisions since the proposed technique is in macro level. This subservient role for the model was well received at the different interviews and communications with transportation agencies throughout the country. Many had feared that quantifying the priorities, unique organizational structures of different transportation agencies and possible interactions between safety countermeasures have already created uncertainties which may disrupt the optimality nature of the procedure in recommending the set of optimal policies for safety allocation. In a state level application, the need for professional judgment in preparation of data, establishing goals and objectives, and in analysis of the results has also become apparent.

Considering the application of the proposed procedure in the local level it is believed that the Feasibility Assessment Technique will be able to handle the problem of safety allocation resources for different countermeasure alternatives with a good degree of accuracy. This model was compared with the powerful DP model and the results were very close to DP but with a tremendous saved compuet time. If a local government applies this procedure, then there would be no need to apply the second algorithms if the given results were confirmed by the local decision-maker(s).

It is believed that the methodology presented in this dissertation will provide the highway-safety profession with a valuable tool that, when widely used, will significantly advance the highway-safety resource allocation process in all levels of government. For the procedure to obtain its widest use, professionals must be ecposed to and trained in its application.

Finally, it is hoped that the maximum reduction of accidents will be achieved with limited resources while a set of local and state government objectives are satisfied if the proposed methodology is considered and implemented by the decision-maker(s). However, to achieve the best solution requires iterative interaction between the Feasibility Assessment Model in Chapter Five, the Optimality Assessment and allocation model in Chapter Six, analyst, and the decision makers.

## (7-2) RECOMMENDATION FOR FUTURE STUDY

This study suggests the following areas for further study.

(1) Consideration should be given to the development of an effective procedure to identify the interactions between the grouping of safety countermeasures. Such an effort will help many mathematical models in which they require the countermeasures's effectiveness data.

(2) Development of a practical, effective and efficient evaluation system for accident countermeasure as a subsystem for small urban jurisdiction is necessary and will increase the effectiveness of any highway safety allocation models. Such a system should provide an on-going process to evaluate the existing safety countermeasures.

(3) Multi-objective goal programming technique utilized in this thesis is a very effective optimization methodology, but utilizing such a powerful technique requires a proper technological coefficient which should be compatible with the available data. Cost-effectiveness ratios developed in this dissertation was one version in which was selected among several potential alternatives. With proper definition of "unit-of-measurement" for the safety system, a more effective indicator may be developed.

(4) This dissertation develops a cost-effectiveness algorithm based on the accident-based data. However, the independent designed computer modules will enable the decision maker(s) to have a variety of options for

selecting and implementing other methodology or sub-systems. But future study may integrate the accident and non-accident based data into one computer module. In this case, the complexity and expense of data gathering will be substantially increased, but it is hoped that in the future more systematic data will be available at a lower cost. In this regard, while the enhancement of highway safety is retained as a primary criterion in the future methodological process, the following parameters would be considered:

(a) importance of projects to the overall transportation network,

(b) improvement in air quality

(c) reduction in fuel consumption,

(d) impacts on other modes

(e) improvement in maintenance and service factor,

(f) and finally, future studies would be designed and conducted with ample input from interested parties; substitute statistical analyses for value judgement and combine the best features of the incremental cost/benefit, and optimization techniques to result in the best possible output.

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APPENDIX (A-1)

## SAFETY IMPROVEMENT PROJECT CODES, DESCRIPTIONS, AND SERVICE LIVES USED

| Code | Description | Service Life (Years) |
|---|---|---|
| | Intersection Projects | |
| 10 | Channelization, left-turn bay | 10 |
| 11 | Traffic signals | 10 |
| 12 | Combination of 10 and 11 | 10 |
| 13 | Sight distance improved | 10 |
| 19 | Other intersection, except structures | 10 |
| 1A | Combination of 10 and 19 | 10 |
| 1B | Combination of 11, 13, 19, 65 | 10 |
| | Cross Section Projects | |
| 20 | Pavement widening, no lanes added | 20 |
| 21 | Lanes added without new median | 20 |
| 22 | Highway divided, new median added | 20 |
| 23 | Shoulder widening or improvement | 20 |
| 24 | Combination of 20-23 | 20 |
| 25 | Skid treatment - grooving | 10 |
| 26 | Skid treatment - overlay | 10 |
| 27 | Flattening, clearing side slopes | 20 |
| 29 | Other cross section or combinations of 20-27 | 20 |
| 2A | Combination of 20 and 26 | 15 |
| | Structures | |
| 30 | Widening bridge or major structure | 20 |
| 31 | Replace bridge or major structure | 30 |
| 32 | New bridge or major structure (except 34 and 51) | 30 |
| 33 | Minor structure | 20 |
| 34 | Pedestrian over- or under-crossing | 30 |
| 39 | Other structure | 20 |
| | Alignment Projects | |
| 40 | Horizontal alignment changes (except 52) | 20 |
| 41 | Vertical alignment changes | 20 |
| 42 | Combination of 40 and 41 | 20 |
| 49 | Other alignments | 20 |
| | Railroad Grade Crossing Projects | |
| 50 | Flashing lights replacing signs | 10 |
| 51 | Elimination by new or reconstructed grade seperation | 30 |
| 52 | Elimination by relocation of highway or railroad | 30 |
| 53 | Illumination | 10 |
| 54 | Flashing lights replacing active devices | 10 |
| 55 | Automatic gates replacing signs | 10 |
| 56 | Automatic gates replacing active devices | 10 |
| 57 | Signing, marking | 10 |
| 58 | Crossing surface improvement | 10 |
| 59 | Other RR grade crossing | 10 |
| 5A | Any combination of 50, 54, 55, 56, 57, 58 | 10 |
| | Roadside Appurtenances | |
| 60 | Traffic signs | 6 |
| 61 | Breakaway sign or luminaire supports | 10 |
| 62 | Road edge guardrail | 10 |
| 63 | Median barrier | 15 |
| 64 | Markings, delineators | 2 |
| 65 | Lighting | 15 |
| 66 | Improve drainage structures | 20 |
| 67 | Fencing | 10 |
| 68 | Impact attenuators | 10 |
| 69 | Other roadside | 10 |
| 6A | Combination of 60-64 | 10 |
| 6B | Combination of 64 and 68 | 10 |
| 6C | Combination of 60 and 62 | 8 |
| 6D | Combination of 60 and 64 | 4 |
| 6E | Combination of 62 and 69 | 10 |
| 6F | Combination of 62, 66 and 69 | 10 |
| 6G | Combination of 60 and 63 | 10 |
| | Other Safety Improvements | |
| 90 | Safety provisions for roadside features and appurtenances | 20 |
| 99 | All projects not otherwise classifiable | 20 |
| 9A | Combination of 11, 26, 69 | 10 |
| 9B | Combination of 26, and 66 | 15 |
| 9C | Combination of 27, 30, 62 and 99 | 20 |
| 9D | Combination of 11 and 60 | 8 |
| 9E | Combination of 11 and 64 | 6 |
| 9F | Combination of 23, 26, and 62 | 15 |
| 9G | Combination of 27, 61, 62, 64 | 10 |
| 9H | Combination of 22, 39, 65 | 20 |
| 9I | Combination of 23, 61, 62, 64, 65, 66 | 15 |

SOURCE (118)

APPENDIX (A-2).

## RANKING OF HIGHWAY SAFETY IMPROVEMENTS BY BENEFIT[1] TO COST RATIO

| Rank | Description (Code) | Ratio[2] | Rank | Description (Code) | Ratio[2] |
|---|---|---|---|---|---|
| 1 | Traffic Signs (60) | 9.30 | 19 | Combination Cross Section Improvements (29) | 1.26 |
| 2 | Other Roadside Impr. (69) | 5.92 | 20 | Lanes Added - No Median (21) | 1.15 |
| 3 | Minor Structural Impr. (33) | 5.71 | 21 | Railroad Automatic Gates Replacing Signs (55) | 1.15 |
| 4 | Intersection Sight Distance (13) | 5.33 | 22 | Pavement Overlay (Skid Treatment)(26) | 1.12 |
| 5 | Other Intersection Impr. (19) | 4.38 | 23 | Horizontal Alignment (40) | 1.00 |
| 6 | Road Edge Guardrail (62) | 3.80 | 24 | Other Structural Impr. (39) | 0.79 |
| 7 | Pavement Grooving (25) | 3.78 | 25 | Replace Bridge (31) | 0.27 |
| 8 | Highway Divided - New Median (22) | 3.52 | 26 | Railroad Grade Separation (51) | 0.13 |
| 9 | Safety Provisions for Roadside Feature and Appurtenance (90) | 3.21 | 27 | Shoulder, Breakaway Signs, Guardrail, Marking, Lighting, and Drainage Structure (91) | 0.08 |
| 10 | Markings and Delineators (64) | 2.90 | 28 | New Bridge (32) | INCR.[3] |
| 11 | Pavement Widening and Shoulder Improvement (24) | 2.33 | 29 | Shoulder Widening or Impr. (23) | INCR. |
| 12 | Intersection Channelization (10) | 2.31 | 30 | Vertical and Horizontal Alignment (42) | INCR. |
| 13 | Pavement Widening - No Lanes Added (20) | 2.28 | 31 | Pavement Widening and Overlay (2A) | INCR. |
| 14 | Signs and Guardrail (6C) | 2.13 | 32 | Sideslopes, Widen Bridge, Guardrail, Misc. (9C) | INCR. |
| 15 | Intersection Traffic Signals (11) | 2.12 | 33 | Lighting (65) | INCR. |
| — | All Improvements | 1.76 | 34 | Guardrail, Drainage Structures, Misc. (6F) | INCR. |
| 16 | Railroad Flashing Lights Replacing Signs | 1.74 | | | |
| 17 | Median Barrier (63) | 1.72 | | | |
| 18 | Intersection Channelization and Traffic Signals (12) | 1.66 | | | |

SOURCE (118)

[1] Benefits are reductions in accident costs using DOT "Societal Costs"

[2] Annual safety benefits to annual construction cost

[3] Incr. — Increase in accident costs

## SIGNIFICANT[1] REDUCTIONS IN FATAL AND INJURY ACCIDENTS BY SAFETY IMPROVEMENTS

| Code | Description | Annual Nos. of Fatal & Injury Acc. Reduced | Annual Cost[2] Per F&I Reduced ($1,000) |
|---|---|---|---|
| | INTERSECTION | | |
| 10 | Channelization | 85.9 | 21.9 |
| 11 | Traffic Signals | 244.2 | 9.1 |
| 12 | Channelization and Signals | 257.6 | 7.9 |
| 13 | Sight Distance Improvements | 19.1 | 6.4 |
| 14 | Other | 70.6 | 8.4 |
| | CROSS SECTION | | |
| 21 | Lanes Added - No Median | 42.7 | 32.7 |
| 26 | Pavement Overlay - Skid Treatment | 202.8 | 11.8 |
| 29 | Combination Cross Section | 136.2 | 29.7 |
| | STRUCTURES | | |
| 33 | Minor Structure | 15.4 | 6.7 |
| | RAILROAD GRADE CROSSING | | |
| 50 | Flashing Lights Replacing Signs | 24.3 | 45.7 |
| 51 | Elimination by Separation | 6.1 | 27.8 |
| 55 | Automatic Gates Replacing Signs | 25.1 | 72.4 |
| 56 | Automatic Gates Replacing Active Devices | 21.3 | 65.1 |
| | ROADSIDE APPURTENANCES | | |
| 63 | Median Barrier | 97.0 | 21.3 |
| 69 | Other Roadside Improvements | 50.8 | 21.0 |
| 6C | ...gns and Guardrail | 112.0 | 9.9 |
| | OTHER | | |
| 90 | Safety Provisions for Roadside Features and Appurtenances | 53.7 | 29.8 |
| All[3] | Safety Improvement | 1,524.1 | 28.2 |

SOURCE(117)
REPORTED

1/ Significant at .05 level with one degree of Freedom - Chi Square
2/ Annual Construction Cost
3/ Not a total includes all reported data

APPENDIX (B-1) COMPUER PROGRAM FOR SINGLE LOCATION, MULTIPLE ALTERNATIVES

```
*       MOHAMAD SEYED-HOSSEIN
*       PHD DISSERTATION DECEMBER 10, 1981
*       FEASIBILITY ASSESSEMENT MODULE
*       RECOMMENDED FOR A LOCATION WITH MULTIPLE ALTERNATIVES
*       ----------------------------------------------
*       ...DOCUMENTATION...
*       THIS PROGRAM WILL EVALUATE SEVERAL INVESTMENT
*       OPPORTUNITIES AND RANK THEM IN ORDER OF MAXIMUM RETURN.
*       THE INCREMENTAL COST/BENEFIT ALGORITHM HAS BEEN DEVELOPED
*       IN THIS PROGRAM THAT INTERACTIVELY ALLOCATE THE GIVEN
*       BUDGET TO SELECT THE BEST POSSIBLE SAFETY ALTERNATIVE.
*       -----------------------------------------------------
*       ...VARIABLE DEFINITION...
*       FORM: PRINT FORMAT
*       CHOICE: PROGRAM REPEAT VARIABLE
*       N: NUMBER OF ALTERNATIVES
*       I,J,K: LOOP INDEXES
*       O: ALTERNATIVE NUMBERING ARRAY
*       P: PRICE ARRAY
*       C: CAPITAL COST ARRAY
*       M: MAINTENANCE COST ARRAY
*       R: USER COST ARRAY
*       H: M+C
*       BC: BC RATIO ARRAY
*       DEP: DEPENDING ALTERNATIVE ARRAY
*       BCI: INCREMENTAL BC RATIO
*       BUD: BUDGET FOR PROJECTS
*       Q: NUMBER OF ALTERNATIVES DESIRED
*       MAIN: BASIC MAINTENANCE COST
*       USER: BASIC USER COST
*       ----------------------------------
*       ...VARIABLE DECLARATION...
        CHARACTER*5 CHOICE ,ALTER(1:40)
        CHARACTER*40  FORM, FORM2, FORM3
        INTEGER N, I, J, K, O(1:40) ,LIFE(1:40)
        REAL P(1:40), C(1:40), M(1:40), R(1:40), H(1:40)
        REAL BC(1:40),  BCI(1:40), BUD, CRF(1:40)
        REAL MAIN, USER, S(1:40)
        REAL APR,SUM, INT
        INTEGER Y, DEF(1:40), COST(1:40)
        PARAMETER (FORM = '(A,T10,A,T21,A,T35,A,T50,A,T65,AT75,A)')
        PARAMETER(FORM2= '(T5,A,T20,A,T40,A,T54,A)')
        PARAMETER(FORM3= '(T5,I4,T20,A,T35,F10.0,T50,F8.3)')
*       ------------------------------------------------
*       ...INPUT...
        PRINT'(T20,A)', 'PROGRAM TO CALCULATE THE BEST ALTERNATIVE'
        PRINT*,'---------------------------------------------------'
        PRINT*,'THIS PROGRAM IS DEVELOPED TO EVALUATE UP TO 40 SAFETY'
        PRINT*,'PROJECTS OR PROGRAMS AND GIVES THE OPTIMAL POLICY FOR'
        PRINT*,'IMPLEMENTING THE PROJECTS.  TWO DIFFERNT ALGORITHMS'
        PRINT*,'IS USED TO COMPUTE THE OPTIMAL ANSWER, IN THE FIRST'
        PRINT*,'STEP REGULAR B/C ANALYSIS IS USED AND IN THE SECOND'
        PRINT*,'STEPS THE INCREMENTAL B/C ANALYSIS IS APPLIED.  THE'
        PRINT*,'USER WILL BE ABLE TO CONSIDER ALL POSSIBLE ALTERNATIVES'
        PRINT*,'THAT IS RECOMMENDED BY THE PROGRAM WITH RESPECT TO HIS'
        PRINT*,'AVAILABE BUDJET.  AT THE END AFTER THE PROPOSED OPTIMAL'
        PRINT*,'PROJECTS ARE PAID, THE PROGRAM RECOMMEND HOW MUCH MONEY'
        PRINT*,'WILL BE AVAILABLE FOR THE NEXT PERIOD'
        PRINT*
        PRINT*
        PRINT*,' FIRST INPUT THE TOTAL NUMBER OF ALTERNATIVES IN FREE FORMAT'
        PRINT*
 1      READ*, N
```

```
      IF (N .GT. 40) THEN
         PRINT*,'LESS THAN 40, PLEASE'
         GOTO 1
      ENDIF
 5    PRINT*,' PLEASE ENTER THE PROJECT CODE, REQUIRED INVESTMENT'
      PRINT*,' SALVAGE, MAINTENANCE, USER COSTS AND LIFE '
*     ALTERNATIVE AS INDICATED BELOW, IN FREE FORMAT, THE PROJECT CODE
      PRINT*,' THE PROJECT CODE SHOULD BE LESS THAN 7 CHARACTERS AND'
      PRINT*,' AND BE LOCATED BETWEEN QOUTES'
      PRINT*,'=================================================='
      DO 10  I=1,N
         READ*, ALTER(I), P(I), S(I), M(I), R(I), LIFE(I)
 10   CONTINUE
      PRINT*,' NOW ENTER THE YEARLY INTEREST YOU WISH TO USE'
      READ*,APR
 30   DATA O, BC / 40*0, 40* 0.0/
      PRINT*,'NOW ENTER THE BASIC MAINTENANCE AND USER COSTS (BEFORE)'
      READ*,  MAIN, USER
      PRINT*,' NOW ENTER YOUR MAXIMUM BUDJET FOR THE PROJECTS'
      READ*, BUD
*     ------------------------------------------
*     ...CALCULATIONS AND OUTPUT...
      INT=APR/100
      DO 16 I=1,N
      CRF(I)=((INT*(1+INT)**LIFE(I))/((1+INT)**LIFE(I)-1))
 16   CONTINUE
      DO 15  I=1,N
         C(I) = P(I) * CRF(I)
15    CONTINUE
      CALL SORT (N, P, O, BC, C, M, R, S, ALTER)
      PRINT*
           PRINT*
      PRINT*,'THIS IS THE LIST OF ALL PROPOSED PROJECTS FOR IMPROVEMENT'
      PRINT*,'========================================================'
      PRINT*
      PRINT FORM,'PROJECT','PROJECT','INVESTMENT','SALVAGE','ANNUAL',
&     'MAINT','USER'
      PRINT FORM,'NUMBER','CODE','(CAPITAL)','VALUE','COST','COST','COST'
      PRINT*,'---------------------------------------------------
&     -------------------------'
      DO 20  I=1,N
         O(I)=I
         H(I)=C(I) +M(I)
         BC(I) = (USER-R(I))/(H(I)-MAIN)
      PRINT'(I3,T8,A,T20,F7.0,T35,F7.0,T50,F7.0,T62,F7.0,T74,F7.0)',
&     O(I),ALTER(I),P(I),S(I),C(I),M(I),R(I)
 20   CONTINUE
      CALL SORT (N, BC, O, P, C, M, R, S, ALTER)
      PRINT*
      PRINT*,'---------------------------------------------------
&     ----------------------------'
PRINT*
      PRINT*
      PRINT*,'THE FOLLOWING PROJECTS HAVE A B/C RATIO LESS THAN ONE'
      PRINT*,' AND ARE CONSIDERED TO BE UNSUITABLE FOR INVESTMENT'
      PRINT FORM2,'NUMBER','PROJECT CODE','INVESTMENT','B/C'
      PRINT*,'-------------------------------------------------------'
      II=0
      DO 40  I=1,N
      IF ((BC(I)) .LT. 1) THEN
      II=II+1
      PRINTFORM3, II, ALTER(I), P(I), BC(I)
      ENDIF
 40   CONTINUE
      PRINT*,'-------------------------------------------------------
      PRINT*
```

```
      PRINT*,'================================================================'
       PRINT*
      PRINT*
      PRINT*, 'AFTER THESE PROJECTS(S) ARE PAID YOU WILL HAVE A'
      PRINT*,' LEFT-OVER THAT YOU CAN USE IT NEXT YEAR AS:'
      PRINT'(A,F7.0)', 'LEFT-OVER IS $', YY
      PRINT'(A,F4.0)', 'INTEREST RATE CONSIDERED TO BE    %', APR
      PRINT*,'================================================================'
      PRINT*
      PRINT*,'IF YOU WANT TO RETURN THIS PROGRAM WITH THE'
      PRINT*,'SAME PROJECTS, JUST TYPE " REPEAT"'
      PRINT*,'IF YOU WANT TO CHANGE THE PROJECTS, JUST TYPE "CHANGE" '
      PRINT*,'IF YOU WAND TO END THE PROGRAM, JUST TYPE "STOP" '
      READ'(A)',CHOICE
              IF(CHOICE .EQ. 'REPEAT') GO TO 1
      IF(CHOICE .EQ. 'CHANGE') GO TO 5
      PRINT*,'SO LONG FOR NOW'
      STOP
      END
      SUBROUTINE SORT (N, PRIME, A, B, C, D, E, F, G)
      INTEGER N, A(1:*)
      CHARACTER*5 TEMPT8, G(1:*)
      REAL PRIME(1:*), B(1:*), C(1:*), D(1:*), E(1:*)
      INTEGER I,J, TEMP2
      REAL TEMP1,TEMP3,TEMP4, TEMP5,TEMP6
      REAL TEMP7, F(1:*)
      DO 200 I=1,N-1
         DO 250  J=1, N-I
              IF  (PRIME(J) .GT. PRIME(J+1))  THEN
              TEMP1=PRIME(J)
              PRIME(J)=PRIME(J+1)
              PRIME(J+1)=TEMP1
              TEMP2=A(J)
              A(J)=A(J+1)
              A(J+1)=TEMP2
              TEMP3=B(J)
              B(J)=B(J+1)
              B(J+1)=TEMP3
              TEMP4=C(J)
              C(J)=C(J+1)
              C(J+1)=TEMP4
              TEMP5=D(J)
              D(J)=D(J+1)
              D(J+1)=TEMP5
              TEMP6=E(J)
              E(J)=E(J+1)
              E(J+1)=TEMP6
              TEMP7=F(J)
              F(J)=F(J+1)
              F(J+1)=TEMP7
              TEMPT8=G(J)
              G(J)=G(J+1)
              G(J+1)=TEMPT8
              ENDIF
250      CONTINUE
200   CONTINUE
      END
      SUBROUTINE SORT2 (BB,CC,ALL,KL)
      REAL BB(1:*), CC(1:*)
      CHARACTER*5 ALL(1:*), TT
              DO 203 I=1,KL-1
              DO 202 J=1,KL-I
      IF(BB(J) .LT. BB(J+1)) THEN
      T1=BB(J)
      BB(J)=BB(J+1)
      BB(J+1)=T1
```

```
      CALL SORT (N,BC,O,P,C,M,R,S,ALTER)
      PRINT*,'THESE PROJECTS ARE CONSIDERED SUITABLE.'
      PRINT FORM2,'NUMBER','PROJECT CODE','INVESTMENT','B/C'
      PRINT*,'-------------------------------------------------------------
      JJ=0
        DO 60  J=1,N
          IF ((BC(J)) .GT. 1) THEN
      JJ=JJ+1
          PRINT FORM3,JJ,ALTER(J),P(J),BC(J)
           ENDIF
60    CONTINUE
      CALL SORT (N, P, O, BC, C, M, R, S, ALTER)
      DO 80  J=1,N
        DEF(J)=1
        DO 70  I=2,N
           IF (J .GT. 1) THEN
              DO 65  K=1,J-1
                 IF (I .EQ. DEF(K))GOTO 70
65    CONTINUE
           ENDIF
        Y=DEF(J)
           BCI(I)=(R(Y)-R(I))/((C(I)+M(I))-(C(Y)+M(Y)))
      IF (BCI(I) .GT. 1) THEN
              DEF(J)= I
      ENDIF
70     CONTINUE
80    CONTINUE
      PRINT*
      PRINT*,'=================================================='
      PRINT*
      PRINT*
      PRINT*
      PRINT*,'THE PROGRAM RECOMMEND THE FOLLOWING PROJECTS AFTER'
      PRINT*,'INCREMENTAL ANALYSIS ARE EXECUTED IN THIS ORDER'
      CALL SORT (N,BCI,C,O,P,M,R,S,ALTER)
      PRINT FORM2,'RANK','PROJECT CODE','INVESTMENT','B/C'
      PRINT*,'-----------------------------------------------------------'
      MM=0.
              DO 90 KK=1,N
              K=N+1-KK
              IF (BCI(K) .GT. 1) THEN
              PRINT FORM3,KK,ALTER(K),P(K),BCI(K)
              MM=MM+1
              ENDIF
90            CONTINUE
      CALL SORT2 (BCI,P,ALTER,N)
      SUM=0
      L=0
      DO 68 J=1,MM
      SUM=SUM+P(J)
      IF(BUD-SUM) 102,103,88
88    L=L+1
      IF(L .EQ. MM) GO TO 103
68    CONTINUE
102   SUM=SUM-P(J)
103   EXTRA=BUD-SUM
      YY=EXTRA*(1+INT)
      PRINT*
      PRINT*
      PRINT*
      PRINT*,'THIS COMBINATION OF PROJECTS IS WITHIN YOUR BUDJECT'
      PRINT*,'-------------------------------------------------------------'
      PRINT FORM2,'RANK','PROJECT CODE','REQ.INVEST.','B/C'
                      DO 110 KKK=1,L
              PRINT FORM3,KKK,ALTER(KKK),P(KKK),BCI(KKK)
110           CONTINUE
```

```
      T2=CC(J)
      CC(J)=CC(J+1)
      CC(J+1)=T2
      TT=ALL(J)
      ALL(J)=ALL(J+1)
      ALL(J+1)=TT
      ENDIF
202   CONTINUE
203   CONTINUE
      END
```

THE PROGRAM RECOMMEND THE FOLLOWING PROJECTS AS THE OPTIMAL SELECTION UNDER UNLIMITED FUNDS

| INDEX NO. | PROJ. CODE | COST | BENEFIT | CUMULAT.COST | CUMULAT. BENEF. | MAR. B/C |
|---|---|---|---|---|---|---|
| 1 | 4-1D | 750. | 14030. | 750. | 14030. | 18.71 |
| 2 | 11-1L | 1000. | 10560. | 1750. | 24590. | 10.56 |
| 3 | 1-1A | 2000. | 20802. | 3750. | 45392. | 10.40 |
| 4 | 1-2A | 7136. | 71322. | 10886. | 116714. | 9.84 |
| 5 | 10-2K | 2200. | 16830. | 13086. | 133544. | 7.65 |
| 6 | 10-1K | 800. | 4590. | 13886. | 138134. | 5.74 |
| 7 | 16-1Q | 1200. | 6790. | 15086. | 144924. | 5.66 |
| 8 | 17-1S | 1400. | 7210. | 16486. | 152134. | 5.15 |
| 9 | 5-1E | 6000. | 21853. | 22486. | 173987. | 3.64 |
| 10 | 10-3K | 3600. | 21674. | 26086. | 195661. | 3.46 |
| 11 | 1-3A | 29645. | 118870. | 55731. | 314531. | 2.11 |
| 12 | 9-1J | 6500. | 13104. | 62231. | 327635. | 2.02 |
| 13 | 2-1B | 8000. | 14157. | 70231. | 341793. | 1.77 |
| 14 | 9-2J | 8000. | 15470. | 78231. | 357263. | 1.58 |
| 15 | 8-1H | 100000. | 136009. | 178231. | 493271. | 1.36 |
| 16 | 1-4A | 36781. | 128380. | 215012. | 621652. | 1.33 |

THE PROGRAM RECOMMEND THE FOLLOWING PROJECTS WHICH ARE WITHIN THE PROPOSED BUDGET

| INDEX NO. | PROJ. CODE | COST | BENEFIT | CUMULAT. COST | CUMULAT. BENEF. | MAR. B/C |
|---|---|---|---|---|---|---|
| 1 | 4-1D | 750. | 14030. | 750. | 14030. | 18.71 |
| 2 | 11-1L | 1000. | 10560. | 1750. | 24590. | 10.56 |
| 3 | 1-1A | 2000. | 20802. | 3750. | 45392. | 10.40 |
| 4 | 1-2A | 7136. | 71322. | 10886. | 116714. | 9.84 |
| 5 | 10-2K | 2200. | 16830. | 13086. | 133544. | 7.65 |
| 6 | 10-1K | 800. | 4590. | 13886. | 138134. | 5.74 |
| 7 | 16-1Q | 1200. | 6790. | 15086. | 144924. | 5.66 |
| 8 | 17-1S | 1400. | 7210. | 16486. | 152134. | 5.15 |
| 9 | 5-1E | 6000. | 21853. | 22486. | 173987. | 3.64 |
| 10 | 10-3K | 3600. | 21674. | 26086. | 195661. | 3.46 |

THE PROPOSED BUDGET IS $ 30000.

UNEXPENDED BUDGET IS $ 3914.00

NEXT-YEAR VALUE OF UNEXPENDED BUDGET $ 4187.98

SAMPLE OF COMPUTER OUT-PUT FOR THE BUDGET LEVEL OF 30,000 DOLLARS

APPENDIX (B-2) COMPUTER PROGRAM FOR FEASIBILITY ASSESSMENT MODEL (COST-EFFECTIVENESS SUB-MODEL AND FEASIBILITY ASSESSMENT SUB-MODEL)

NOTE* FOR LARGE SCALE PROBLEMS, THE DIMENSIONS SHOULD BE MODIFIED.

```
*       ----------------------------------------------------------
*       S. M. SEYED-HOSSEIN, FEASIBILITY ASSESSEMENT PROGRAMMING
*       INCLUDE FEASIBILITY ASSESSEMENT AND COST-EFFECTIVENESS MODULES
*       THE UNIVERSITY OF OKLAHOMA
*       SPRING 1982
*       ----------------------------------------------------------
*       ECN, PDP 11/70 COMPUTER:  UNIX, VERSION 7: FORTRAN, F77
*       ----------------------------------------------------------
*       PROGRAM STATEMENT:
*
*               THIS PROGRAM IS A PART OF PHD DISSERTATION NAMED
*               "MACRO-OPTIMIZATION PROCEDURE FOR ALLOCATING THE
*               SAFETY RESOURCES IN LOCAL JURISDICTION" THAT IS
*               SUPERVISED BY PROFESSOR LEONARD WEST FROM CIVIL
*               ENGINEERING DEPARTMENT AT THE UNIVESITY OF OKLAHOMA
*               IN SPRING 1982.
*                    All THE DOCUMENTATIONS ARE AVAILABLE IN APPENDIXES
*               WITH SOME RECOMMENDATION FOR DATA INPUT AND OTHER POSSIBLE
*               ADVANTAGE THAT THIS COMPUTER PROGRAM OFFERS IN COMBINATION WITH
*               OTHER MODULES. THE PROGRAM CAN BE AVAILBLE TO THE PUBLIC
*               WITH A WRITTEN REQUEST TO PROFESSOR LEONARD WEST AT THE
*               UNIVERSITY OF OKLAHOMA (DEPARTMENT OF CIVIL ENGINEERING)
*       ----------------------------------------------------------
* ...   VARIABLE USED:
*               APT:            INTEREST RATE
*               AL(I    ):      # OF ALTERNATIVES AT EACH LOCATION I
*               BB(I    ):      TRANFORMATION FOR BENEFIT AT LOCATION I
*               BBC(I   ):      TRANSFORMATION FOR BENEFIT/COST
*               BC(I,J  ):      MARGINAL BENEFIT
*               C(I,J   ):      COST OF PROJECT J AT LOCATION I
*               CC(I,J  ):      TRANSFORMATION FOR COST VARIABLES
*               CLASS:          ESTIMATED ACCIDENT COST FOR EACH SEVERITY
*               COD(I   ):      TRANSFORMATION FOR PROJECT'S CODE
*               CODE(I,J):      CODE OF PROJECT J AT LOCATION I
*               C(I,J):         ESTIMATED ANNUAL COST OF ALTER. J AT LOCATION I
*               FAT(I):         FATALITY COST
*               F1              FIX FORMAT FOR OUT PUT TITLE
*               INJ(I):         INJURY COST
*               INT:            INTEREST RATE
*               LIFE(I,J):      ECONOMIC LIFE OF PROJECT J AT LOCATION I
*               MAIN(I,J):      ANNUAL MAITENANCE COST
*               MMB(I):         TRANSFER FOR MARGINAL COST
*               MMC(I):         TRANSFER FOR MARGINAL COST
*               N:              NUMBER OF ALTERNATIVES
*               NL:             NUMBER OF FEASIBLE ALTERNATIVES
```

```
*               PDO(I):         COST OF PROPERTY ACCIDENT
*               RFAT(I,J):      FATALITY REDUCTION RATE
*               RINJ(I,J):      INJURY REDUCTION RATE
*               RPDO(I,J):      PROPERTY ACCIDENT REDUCTION RATE
*               RTOT(I,J):      TOTAL ACCIDENT REDUCTION FACTOR
*               T1:             FIXED FORMAT STAEMENT FOR OUT PUT
*       ------------------------------------------------------------
        real  C(20,10), MC(20,10),B(20,10),BC(20,10), MB(20,10)
        real YR(20), TOT(20), FAT(20), INJ(20), PDO(20)
        real COST(20,10), MAIN(20,10), LIFE(20,10), RTOT(20,10)
        real RFAT(20,10), RINJ(20,10), RPDO(20,10)
        real CC(30), BB(30), MMC(30), MMB(30), BBC(30)
        real C1(20,10), BC1(20,10)
        character*50 class
        character*10 COD(30)
        character*12 CODE(20,10)
        character T1*60, F1*50
        parameter (F1='(a,t10,a,t28,a,t39,a,t48,a,t61,a,t82,a)')
        parameter (T1='(i5,t11,a,t24,f10.0,t37,f10.0,t48,f10.0,
&t62,f10.0,t76,f10.2)')
        INTEGER AL(30), r
        DATA MC,BC,MB /200*0.,200*0.,200*0./
        print*,' PLEASE INPUT THE NUMBER OF LOCATIONS'
        read*,N
        print*,'PLEASE INPUT THE NUMBER OF ALTERNATIVES FOR EACH
&LOCATION'
        read*,(AL(i), i=1,N)
        print*;'PLEASE INPUT THE INTEREST RATE'
        read*,int
        print*,'PLEASE INPUT THE ACCIDENT SEVERITY COSTS, I.E.,'
        print*,'FATALITY, INJURY, AND PROPERTY DAMAGE ACCIDENT COSTS'
        print*,'...BUT, YOU HAVE THE OPTION OF SELECTING ONE OF THE'
        print*,'FOLLOWING NATIONAL ESTIMATION CURRENTLY USED IN'
        print*,'DIFFERENT HIGHWAY SAFETY PROGRAMS'
        print*,'   RECOMMENDED AGENCY              FAT.     INJ.     PDO. '
        print*,'=============================================================='
        print*,' (1) NATIONAL SAFETY COUNCIL    113500    6200      570  '
        print*,' (2) NHTSA                      287175    3185      520  '
        print*,' (3) ALABAMA                     37000    3185      360  '
        print*,' (4) CALIFORNIA                  95000    3000      900  '
        print*,' (5) TEXAS                      110000    3500     1000  '
        print*,' (6) KENTUKY                     45000   27000      400  '
        print*,' (7) DOT                        307210   14600      650  '
        print*,' (8) NEITHER ONE '
        print*,'-----------------------------------------------------------'
```

```
print*,' IF YOU WANT TO SELECT ONE OF THE ABOVE FIGURES PLEASE'
print*,'JUST TYPE THE ASSOCIATED NUMBER FOR EACH FIGURE, FOR EXAMPLE'
print*,'IF YOU TYPE A 2, THAT MEANS THAT YOU SELECTED THE'
print*,'THE NHTSA ACCIDENT SEVERITY COSTS ESTIMATION'
read*, select
if(select .eq. 1) then
        CFAT=113500
        CINJ=6200
        CPDO=570
else if( select .eq. 2) then
        CFAT=287175
        CINJ=3185
        CPDO=520
        class='NATIONAL HIGHWAY TRANSPORTATION SAFETY AGENCY'
else if( select .eq. 3) then
        CFAT=37000
        CINJ=2200
        CPDO=360
        class='ALABAMA RECOMMENDATION'
else if (select .eq. 4) then
        CFAT=95000
        CINJ=3000
        CPDO=900
        class='CALIFORNIA RECOMMENDATION'
else if(select :eq. 5) then
        CFAT=110000
        CINJ=3500
        CPDO=1000
        class='TEXAS RECOMMENDATION'
else if ( select .eq. 6) then
        CFAT=45000
        CINJ=27000
        CPDO=400
        class='KENTUKY RECOMMENDATION'
else if (select .eq. 7) then
        CFAT=307210
        CINJ=14600
        CPDO=650
        class='DOT RECOMMENDATION'
else if (select .eq. 8) then
        print*,'OK....IN THIS CASE PLEASE INPUT YOUR DESIED'
print*,'ACCIDENT SEVERITY COSTS'
read*,CFAT, CINJ, CPDO
class='LOCAL ACCIDENT SEVERITY COSTS CONSIDERED'
Else
```

```
      print*,'*******ERROR IN SELECTING THE ACCIDENT SEVERITY COSTS'
      print*,'THE DEFULT VALUE IS COSIDERED (NSC RECOMMENDATION)...'
      print*,'PROCESS IS CONTINUING'
      CFAT=113500
      CINJ=6200
      CPDO=570
      Endif
      print*,'PLEASE INPUT TOTAL ACCIDENT, INJURY, PDO AND ACCIDENT'
      print*,'HISTORY FOR EACH LOCATION SEPARATED BY COMMA, THEN PROJECT '
      print*,'CODE AND EACH PROJECT COST, MAINTENANE, LIFE, TOTAL REDUCTION'
      print*,'FATAL REDUCTION, AND PROPERTY DAMAGE ACCIDENT REDUCTION FOR '
      print*,'EACH ALTERNATIVE ACCORDING TO THE APPEARANCE IN THE '
      print*,'RECOMMENDED FORMAT'
      do 300 i=1,N
      read*,TOT(i),FAT(i),INJ(i),PDO(i),YR(i)
      do 299 j=1,AL(i)
      read'(a)',CODE(i,j)
      read*, COST(i,j),MAIN(i,j),LIFE(i,j), RTOT(i,j),RINJ(i,j),RPDO(i,j)
 299  continue
 300  continue
*.............................................................
*...computation
      rate=real(int)/100.
      do 303 i=1,N
      do 302 j=1,AL(i)
      crf=((1+rate)**LIFE(i,j) -1)/(rate*(1+rate)**LIFE(i,j))
      C(i,j)=COST(i,j)*crf + MAIN(i,j)
      B(i,j)=(FAT(i)*RFAT(i,j)*CFAT+INJ(i)*RINJ(i,j)*CINJ+
& PDO(i)*RPDO(i,j)*CPDO)/YR(i)
      print'(2f10.2)',C(i,j),B(i,j)
 302  continue
 303  continue
      print*,'PLEASE INPUT THE PROPOSED BUDGET'
      read*,bud
      print*,'-------------------------------------------------
&--------'
      print*,'LOCATION NO.   PROJECT CODE           COST
&       BENEFIT'
      DO 35 I=1,N
      print*,'-------------------------------------------------
&---------'
      DO 30 J=1,AL(I)
      print'(t5, i5, t20, a ,t35, f10.0, t50, f10.0)', I, CODE(I,J)
&     , C(I,J), B(I,J)
 30   CONTINUE
```

```
 35     continue
        NN=1
 5      CALL SORT (C,B,MC,MB,BC,CODE,NN,AL)
        IF (NN .GE. N) GO TO 8
        NN=NN+1
        GO TO 5
 8      print*,'==================================================
&========'
        do 50 I=1,N
        MB(I,1)=B(I,1)
        MC(I,1)=C(I,1)
        BC(I,1)=MB(I,1)/MC(I,1)
        if (AL(i) .eq. 1) go to 50
        do 55 J=2,AL(I)
        MC(I,J)=C(I,J)-C(I,J-1)
        MB(I,J)=B(I,J)-B(I,J-1)
        BC(I,J)=MB(I,J)/MC(I,J)
        PRINT*
55      CONTINUE
50      continue
        do 65 i=1,N
        PRINT*
        PRINT*,'---------------------------------------------------
&-----------------------------------------------'
        print'(t38,a,i5)','LOCATION NUMBER ',I
        print'(t38,a)','.....................'
        print*
        print*,'LOC. NO.    PROJECT CODE            COST        BENEFIT
&    INCRE. COST   INCRE. BENEF.   B/C '
        print*,'================================================
&==========================================='
        do 60 j=1,AL(i)
        print'(i5,t15,a,t30,f10.0,t42,f10.0,t55,f10.0,t70,f10.0,t81,f10.2)',i
&, CODE(i,j), C(i,j), B(i,j), MC(i,j), MB(i,j), BC(i,j)
 60     continue
 65     continue
        print*
        print*
        print*
        print*,'THE FOLLOWING PROJECTS ARE CONSIDERED TO BE UNSUITABLE'
        print*,'----------------------------------------------------
&------------------------------------'
        print F1,'LOC. NO.','PROJ. CODE','COST','BENEFIT',
&'INCRE. COST','INCRE. BENEF.','B/C','  '
        do 200 i=1,N
```

```
      do 190 j=1,AL(i)
              if(BC(i,j) .lt. 1) then
      Print T1,i, CODE(i,j),C(i,j),B(i,j),MC(i,j),MB(i,j),BC(i,j)
      endif
190   continue
200   continue
      print*
      print*
      print*,'THE FOLLOWING PROJECTS ARE CONSIDERED TO BE FEASIBLE
& AND IF FUNDS ARE NOT LIMITED, WOULD BE SELECTED'
      print F1,'LOC. NO','PROJ. CODE','COST','BENEFIT','
&INCRE. COST','INCRE. BENEF.','B/C','  '
      print*,'============================================================
&==============================='
      do 220 i=1,N
      r=0
      do 210 j=1,AL(i)
      if(BC(i,j) .ge. 1) then
      r=r+1
      C(i,r)=C(i,j)
      B(i,r)=B(i,j)
      CODE(i,r)=CODE(i,j)
      MC(i,r)=MC(i,j)
      MB(i,r)=MB(i,j)
      endif
210   continue
      AL(i)=r
220   continue
      print*
      do 212 i=1,N
        if (AL(i) .ge. 2) then
              do 211 j=2,AL(i)
                      if(BC(i,j) .gt. BC(i,j-1)) then
                      BC(i,j)=(MB(i,j)+MB(i,j-1))/(MC(i,j)+MC(i,j-1))
                      BC1(i,j)=BC(i,j)
                      C1(i,j)=C(i,j)
                      endif
                      if( AL(i) .gt. 3) then
                       if(BC(i,j+1) .gt. BC(i,j)) then
                        zz=MB(i,j-1)+MB(i,j)+MB(i,j+1)
                      yy=MC(i,j-1)+MC(i,j)+MC(i,j+1)
                      BC(i,j+1)=zz/yy
                        C1(i,j+1)=C(i,j+1)
                        BC1(i,j+1)=BC(i,j+1)
                       endif
```

```
                        Endif
211                 continue
          Endif
 212    continue
        print*
        print*
        do 47 i=1,N
        do 46 j=1,AL(i)
        print T1,i,CODE(i,j),C(i,j),B(i,j),MC(i,j),MB(i,j),BC(i,j)
 46     continue
 47     continue
        print*
        print*
        print*,'THE PROGRAM RECOMMEND THE FOLLOWING PROJECTS AS
& THE OPTIMAL SELECTION UNDER UNLIMITED FUNDS'
        print*,'------------------------------------------------
&-----------------------------------'
        nl=0
        do 45 i=1,N
        nl=nl+AL(i)
 45     continue
        kk=1
        jj=1
        kkk=AL(1)
        do 14 i=1,N
        do 12 k=kk,kkk
        MMB(k)=MB(i,jj)
        MMC(k)=MC(i,jj)
        BB(k)=B(i,jj)
        BBC(k)=BC(i,jj)
        COD(k)=CODE(i,jj)
        CC(k)=C(i,jj)
        jj=jj+1
 12     continue
        kk=kkk+1
        kkk=kk+AL(i+1)-1
        jj=1
 14     continue
        call sort2 (BBC,MMC,MMB,BB,CC,COD,nl)
        print F1,'INDEX NO.','PROJ. CODE','COST','BENEFIT',
&'INCRE. COST','INCRE. BENEF.','B/C',' '
        print*,'------------------------------------------------
&-----------------------------------'
        do 19 i=1,nl
        print T1,i, COD(i), CC(i), BB(i), MMC(i), MMB(i), BBC(i)
```

```
 19     continue
        print*
        print*
        print*,'THE PROGRAM RECOMMEND THE FOLLOWING PROJECTS
& WHICH ARE WITHIN THE PROPOSED BUDGET'
        print F1,'INDEX NO.','PROJ. CODE','COST','BENEFIT',
& 'INCRE. COST','INCRE. BENEF.','B/C'
        sum=0
        print*,'_______________________________________________
&___________________________________'
        sum1=0
        l=0
        do 68 j=1,nl
        sum=sum+CC(j)
        sum1=sum1+BB(j)
                if(bud-sum) 102,103,88
 88             l=l+1
        print T1,j, COD(j), CC(j),BB(j),sum, sum1,BBC(j)
                if( l .eq. nl) go to 103
 68     continue
 102    sum=sum-CC(j)
 103    extra=bud-sum
        yy=extra*(1+.07)
        print*
        print*
        print'(a,f10.0)','THE PROPOSED BUDGET IS    $',bud
        print*,'-----------------------------------------------------
&-------------------------------'
        print'(a,f10.2)','UNEXPENDED BUDGET IS  $',extra
        print*
        print'(a,f10.2)','NEXT-YEAR VALUE OF UNEXPENDED BUDGET $',yy
        STOP
        END
        SUBROUTINE SORT (AA,BB,CC,DD,EE,FF,NN,AL)
        REAL AA(20,10),BB(20,10),CC(20,10),DD(20,10),EE(20,10)
        INTEGER AL(10)
        CHARACTER*12 FF(20,10), TEMPT5
        REAL TEMPT0,TEMPT1,TEMPT2,TEMPT3,TEMPT4
        KKK=AL(NN)
        DO 100 K=1,KKK-1
        DO 99  KK=1,KKK-k
        IF(AA(NN,KK).GT.AA(NN,KK+1)) THEN
                TEMPT0=AA(NN,KK)
                AA(NN,KK)=AA(NN,KK+1)
                AA(NN,KK+1)=TEMPT0
```

```
                TEMPT1=BB(NN,KK)
                BB(NN,KK)=BB(NN,KK+1)
                BB(NN,KK+1)=TEMPT1
                TEMPT2=CC(NN,KK)
                CC(NN,KK)=CC(NN,KK+1)
                CC(NN,KK+1)=TEMPT2
                TEMPT3=DD(NN,KK)
                DD(NN,KK)=DD(NN,KK+1)
                DD(NN,KK+1)=TEMPT3
                TEMPT4=EE(NN,KK)
                EE(NN,KK)=EE(NN,KK+1)
                EE(NN,KK+1)=TEMPT4
                TEMPT5=FF(NN,KK)
                FF(NN,KK)=FF(NN,KK+1)
                FF(NN,KK+1)=TEMPT5
        ENDIF
99      CONTINUE
100     CONTINUE
        end
        subroutine sort2 (aa,bb,cc,dd,ee,ff,nn)
        real aa(1:*), bb(1:*), cc(1:*),dd(1:*), ee(1:*)
        character*10 ff(30), tt6
        do 18 i=1,nn-1
        m=nn-i
        do 17 j=1,m
        if( aa(j) .lt. aa(j+1)) then
        tt1=aa(j)
        aa(j)=aa(j+1)
        aa(j+1)=tt1
        tt2=bb(j)
        bb(j)=bb(j+1)
        bb(j+1)=tt2
        tt3=cc(j)
        cc(j)=cc(j+1)
        cc(j+1)=tt3
        tt4=dd(j)
        dd(j)=dd(j+1)
        dd(j+1)=tt4
        tt5=ee(j)
        ee(j)=ee(j+1)
        ee(j+1)=tt5
        tt6=ff(j)
        ff(j)=ff(j+1)
        ff(j+1)=tt6
        endif
17      continue
18      continue
        end
```

APPENDIX (B-3) FEASIBILITY ASSESSMENT MODULE (INDEPENDENT MODULE)

```
*       *************************************************************
*       * S. M. SEYED-HOSSEIN, FEASIBILITY ASSESSEMENT MODULE        *
*       * THIS IS AN INDEPENDENT COMPUTER PROGRAM MODULE THAT CAN BE  *
*       * USED BY STATE OR LOCAL GOVERNMENT TO ALLOCATE THE SAFETY .  *
*       * FUNDS TO SELECT THE BEST SET OF SAFETY COUNTERMEASURE.  THE *
*       * DOCUMENTATION CAN BE FOUND IN CHAPTER FIVE AND SIX OF      **
*       * THIS DISSERTATION.  THE PROGRAM CAN BE OBTAINED THROUGH A   *
*       * WRITTEN REQUEST TO THE PROFESSOR L. WEST AT THE UNIVERSITY  *
*       * OF OKLAHOMA, DEPARTMENT OF CIVIL ENGINEERING.               *
*       *************************************************************
*       THE UNIVERSITY OF OKLAHOMA
*       SPRING 1982
*       -----------------------------------------------------------
*       ECN, PDP 11/70 COMPUTER:  UNIX, VERSION 7: FORTRAN, F77
*       -----------------------------------------------------------
*       PROGRAM STATEMENT:
*
*               THIS PROGRAM IS A PART OF PHD DISSERTATION NAMED
*               "MACRO-OPTIMIZATION PROCEDURE FOR ALLOCATING THE
*               SAFETY RESOURCES IN LOCAL JURISDICTION" THAT IS
*               SUPERVISED BY PROFESSOR LEONARD WEST FROM CIVIL
*               ENGINEERING DEPARTMENT AT THE UNIVESITY OF OKLAHOMA
*               IN SPRING 1982.
*                    All THE DOCUMENTATIONS ARE AVAILABLE IN APPENDICES
*               WITH SOME RECOMMENDATION FOR DATA INPUT AND OTHER POSSIBLE
*               ADVANTAGE THAT THIS COMPUTER PROGRAM OFFERS IN COMBINATION WITH
*               OTHER MODULE AS INDICATED IN CHAPTER FIVE.
*       -----------------------------------------------------------
* ...   VARIABLE USED:
*               APT:                INTEREST RATE
*               AL(I      ):        # OF ALTERNATIVES AT EACH LOCATION I
*               BB(I      ):        TRANFORMATION FOR BENEFIT AT LOCATION I
*               BBC(I     ):        TRANSFORMATION FOR BENEFIT/COST
*               BC(I,J    ):        MARGINAL BENEFIT
*               C(I,J     ):        COST OF PROJECT J AT LOCATION I
*               CC(I,J    ):        TRANSFORMATION FOR COST VARIABLES
*               COD(I     ):        TRANSFORMATION FOR PROJECT'S CODE
                CODE(I,J):          CODE OF PROJECT J AT LOCATION I
*               F1                  FIX FORMAT FOR OUT PUT TITLE
*               INT:                INTEREST RATE
*               MMB(I):             TRANSFER FOR MARGINAL COST
*               MMC(I):             TRANSFER FOR MARGINAL COST
*               N:                  NUMBER OF ALTERNATIVES
*               NL:                 NUMBER OF FEASIBLE ALTERNATIVES
*               T1:                 FIXED FORMAT STAEMENT FOR OUT PUT
```

```
*       ----------------------------------------------------------
        real  C(20,10), MC(20,10),B(20,10),BC(20,10), MB(20,10)
        real CC(30), BB(30), MMC(30), MMB(30), BBC(30)
        real C1(20,10), BC1(20,10)
        character*10 COD(30)
        integer AL(20), r
        character T1*60, F1*50
        character T1*60, F1*50
        parameter (F1='(a,t10,a,t28,a,t39,a,t48,a,t62,a,t80;a)')
        parameter (T1='(i5,t11,a,t24,f10.0,t37,f10.0,t48,f10.0,
&t62,f10.0,t76,f10.2)')
        DATA MC,BC,MB /200*0.,200*0.,200*0./
        PRINT*,'PLEASE INPUT THE NUMBER OF LOCATIONS'
        READ*,N
        PRINT*,'INPUT THE NUMBER OF ALTERNATIVES CANDIDATED FOR EACH
&LOCATION'
        READ*,(AL(I), I=1,N)
        PRINT*,'INPUT PROJECT CODE, COST, BENEFIT'
                DO 20 I=1,N
                DO 15 J=1,AL(I)
        READ*,CODE(I,J),C(I,J),B(I,J)
 15             CONTINUE
 20             CONTINUE
        print*,'-----------------------------------------------
&--------'
        print*,'LOCATION NO.   PROJECT CODE           COST
&         BENEFIT'
        DO 35 I=1,N
        print*,'-----------------------------------------------
&---------'
        DO 30 J=1,AL(I)
        print'(t5, i5, t20, a ,t35, f10.0, t50, f10.0)', I, CODE(I,J)
&       , C(I,J), B(I,J)
 30     CONTINUE
 35     continue
        NN=1
 5      CALL SORT (C,B,MC,MB,BC,CODE,NN,AL)
        IF (NN .GE. N) GO TO 8
        NN=NN+1
        GO TO 5
 8      print*,'===============================================
&========'
        do 50 I=1,N
        MB(I,1)=B(I,1)
        MC(I,1)=C(I,1)
```

```
        BC(I,1)=MB(I,1)/MC(I,1)
        if (AL(i) .eq. 1) go to 50
        do 55 J=2,AL(I)
        MC(I,J)=C(I,J)-C(I,J-1)
        MB(I,J)=B(I,J)-B(I,J-1)
        BC(I,J)=MB(I,J)/MC(I,J)
        PRINT*
55      CONTINUE
50      continue
        do 65 i=1,N
        PRINT*
        PRINT*,'------------------------------------------------
&-----------------------------------------------'
        print'(t38,a,i5)','LOCATION NUMBER ',I
        print'(t38,a)','.....................'
        print*
        print*,'LOC. NO.    PROJECT CODE           COST        BENEFIT
&    INCRE. COST   INCRE. BENEF.   B/C '
        print*,'================================================
&================================================'
        do 60 j=1,AL(i)
        print'(i5,t15,a,t30,f10.0,t42,f10.0,t55,f10.0,t70,f10.0,t81,f10.2)',
&, CODE(i,j), C(i,j), B(i,j), MC(i,j), MB(i,j), BC(i,j)
 60     continue
 65     continue
        print*
        print*
        print*
        print*,'THE FOLLOWING PROJECTS ARE CONSIDERED TO BE UNSUITABLE'
        print*,'------------------------------------------------------
&-----------------------------------'
        print F1,'LOC. NO.','PROJ. CODE','COST','BENEFIT',
&'INCRE. COST','INCRE. BENEF.','B/C','  '
        do 200 i=1,N
        do 190 j=1,AL(i)
                 if(BC(i,j) .lt. 1) then
        Print T1,i, CODE(i,j),C(i,j),B(i,j),MC(i,j),MB(i,j),BC(i,j)
        endif
 190    continue
 200    continue
        print*
        print*,'THE FOLLOWING PROJECTS ARE CONSIDERED TO BE FEASIBLE
& AND IF FUNDS ARE NOT LIMITED, WOULD BE SELECTED'
        print F1,'LOC. NO','PROJ. CODE','COST','BENEFIT','
&INCRE. COST','INCRE. BENEF.','B/C','  '
```

```
      print*,'==============================================
&============================='
      do 220 i=1,N
      r=0
      do 210 j=1,AL(i)
      if(BC(i,j) .ge. 1) then
      r=r+1
      C(i,r)=C(i,j)
      B(i,r)=B(i,j)
      CODE(i,r)=CODE(i,j)
      MC(i,r)=MC(i,j)
      MB(i,r)=MB(i,j)
      endif
 210  continue
      AL(i)=r
 220  continue
      print*
      do 212 i=1,N
        if (AL(i) .ge. 2) then
              do 211 j=2,AL(i)
                      if(BC(i,j) .gt. BC(i,j-1)) then
                      BC(i,j)=(MB(i,j)+MB(i,j-1))/(MC(i,j)+MC(i,j-1))
                      BC1(i,j)=BC(i,j)
                      C1(i,j)=C(i,j)
                      endif
                      if( AL(i) .ge. 3) then
                       if(BC(i,j+1) .gt. BC(i,j)) then
                        zz=MB(i,j-1)+MB(i,j)+MB(i,j+1)
                      yy=MC(i,j-1)+MC(i,j)+MC(i,j+1)
                      BC(i,j+1)=zz/yy
                        C1(i,j+1)=C(i,j+1)
                        BC1(i,j+1)=BC(i,j+1)
                       endif
                      Endif
211           continue
        Endif
 212  continue
      print*
      print*
      do 47 i=1,N
      do 46 j=1,AL(i)
      print T1,i,CODE(i,j),C(i,j),B(i,j),MC(i,j),MB(i,j),BC(i,j)
 46   continue
 47   continue
      print*
```

```
 222    print*,'PLEASE INPUT THE PROPOSED BUDGET'
 .      read*,bud
        print*
        print*,'THE PROGRAM RECOMMEND THE FOLLOWING PROJECTS AS
&  THE OPTIMAL SELECTION UNDER UNLIMITED FUNDS'
        print*,'------------------------------------------------
&----------------------------------'
        nl=0
        do 45 i=1,N
        nl=nl+AL(i)
 45     continue
        kk=1
        jj=1
        kkk=AL(1)
        do 14 i=1,N
        do 12 k=kk,kkk
        MMB(k)=MB(i,jj)
        MMC(k)=MC(i,jj)
        BB(k)=B(i,jj)
        BBC(k)=BC(i,jj)
        COD(k)=CODE(i,jj)
        CC(k)=C(i,jj)
        jj=jj+1
 12     continue
        kk=kkk+1
        kkk=kk+AL(i+1)-1
        jj=1
 14     continue
        call sort2 (BBC,MMC,MMB,BB,CC,COD,nl)
        print F1,'INDEX NO.','PROJ. CODE','COST','BENEFIT',
&'CUMULAT.COST','CUMULAT. BENEF.','MAR. B/C'
        print*,'------------------------------------------------
&----------------------------------'
        do 19 i=1,nl
        print T1,i, COD(i), CC(i), BB(i), MMC(i), MMB(i), BBC(i)
 19     continue
        print*
        print*
        print*,'THE PROGRAM RECOMMEND THE FOLLOWING PROJECTS
&  WHICH ARE WITHIN THE PROPOSED BUDGET'
        print F1,'INDEX NO.','PROJ. CODE','COST','BENEFIT',
&'COMULAT. COST','COMULAT. BENEF.','MAR. B/C'
        sum=0
        print*,'________________________________________________
&__________________________________'
```

```
        sum1=0
        l=0
        do 68 j=1,nl
        sum=sum+CC(j)
        sum1=sum1+BB(j)
                if(bud-sum) 102,103,88
102     sum =sum - CC(j)
        sum1=sum1-BB(j)
                go to 68
88      l=l+1
        print T1,l, COD(j), CC(j),BB(j),sum, sum1,BBC(j)
68      continue
103     extra=bud-sum
        yy=extra*(1+.07)
        print*
        print*
        print'(a,f10.0)','THE PROPOSED BUDGET IS   $',bud
        print*,'-----------------------------------------------------------
&----------------------------'
300     continue
        print'(a,f10.2)','UNEXPENDED BUDGET IS  $',extra
        print*
        print'(a,f10.2)','NEXT-YEAR VALUE OF UNEXPENDED BUDGET $',yy
        print*,'\f'
        print*,' IF YOU WANT TO TRY ANOTHER BUDGET LEVEL, ENTER 1'
        read*,nnn
        if (nnn .eq. 1) go to 222
        STOP
        END
        SUBROUTINE SORT (AA,BB,CC,DD,EE,FF,NN,AL)
        REAL AA(20,10),BB(20,10),CC(20,10),DD(20,10),EE(20,10)
        INTEGER AL(10)
        CHARACTER*12 FF(20,10), TEMPT5
        REAL TEMPT0,TEMPT1,TEMPT2,TEMPT3,TEMPT4
        KKK=AL(NN)
        DO 100 K=1,KKK-1
        DO 99  KK=1,KKK-k
        IF(AA(NN,KK).GT.AA(NN,KK+1)) THEN
                TEMPT0=AA(NN,KK)
                AA(NN,KK)=AA(NN,KK+1)
                AA(NN,KK+1)=TEMPT0
                TEMPT1=BB(NN,KK)
                BB(NN,KK)=BB(NN,KK+1)
                BB(NN,KK+1)=TEMPT1
                TEMPT2=CC(NN,KK)
```

```
            CC(NN,KK)=CC(NN,KK+1)
            CC(NN,KK+1)=TEMPT2
            TEMPT3=DD(NN,KK)
            DD(NN,KK)=DD(NN,KK+1)
            DD(NN,KK+1)=TEMPT3
            TEMPT4=EE(NN,KK)
            EE(NN,KK)=EE(NN,KK+1)
            EE(NN,KK+1)=TEMPT4
            TEMPT5=FF(NN,KK)
            FF(NN,KK)=FF(NN,KK+1)
            FF(NN,KK+1)=TEMPT5
      ENDIF
99    CONTINUE
100   CONTINUE
      end
      subroutine sort2 (aa,bb,cc,dd,ee,ff,nn)
      real aa(1:*), bb(1:*), cc(1:*),dd(1:*), ee(1:*)
      character*10 ff(30), tt6
      do 18 i=1,nn-1
      m=nn-i
      do 17 j=1,m
      if( aa(j) .lt. aa(j+1)) then
      tt1=aa(j)
      aa(j)=aa(j+1)
      aa(j+1)=tt1
      tt2=bb(j)
      bb(j)=bb(j+1)
      bb(j+1)=tt2
      tt3=cc(j)
      cc(j)=cc(j+1)
      cc(j+1)=tt3
      tt4=dd(j)
      dd(j)=dd(j+1)
      dd(j+1)=tt4
      tt5=ee(j)
      ee(j)=ee(j+1)
      ee(j+1)=tt5
      tt6=ff(j)
      ff(j)=ff(j+1)
      ff(j+1)=tt6
      endif
17    continue
18    continue
      end
```

APPENDIX (B-4) DYNAMIC PROGRAMMING COMPUTER CODE FOR RESOURCE ALLOCATION

```
/*tag    usr=(sseyedho,rje)
//seye job        ,'seyed           ',class=j time=(2,30)
/*jobparm d=rmt1
// exec watfiv
//sysin dd *
c       **********************************************************
c       * THIS PROGRAM DEVELOPES THE DYNAMIC PROGRAMMING TECHNIQUE   *
c       * TO BE USED FOR THE COMPARISON PURPOSE AND MODEL.CALIBRATION*
c       * THE ALABAMA DEPARTMENT OF TRANSPORTATION COMPUTER CODE HAS *
c       * BEEN MODIFIED AND USED IN THIS DISSERTATION.               *
c       **********************************************************
        DIMENSION ORET(50,301),ODEC(50,301),NIN(50),NDE(51)
        DIMENSION NOD(50,301),C(50,31),R(31),CO(30),RO(30)
        DIMENSION CX(50,31),RX(31),XNO1(50)
 1      CONTINUE
        IST=0
        VRET=0.0
        READ(5,4) NSTG,NBJ,XINC,K1,K2,XNO2,IPUNCH
 4      FORMAT(2I4,F6.0,2I4,F10.0,I2)
        IF(NSTG) 2,999,2
 2      CONTINUE
        DO 5 I=1,NSTG
 5      NIN(I)=301
 3      FORMAT(20I4)
        WRITE(6,101)
        DO 15 I=1,NSTG
        C(I,1)=0.
        READ(5,100) NDEC,(CX(I,IC),IC=1,NDEC),XNO1(I)
 100    FORMAT(I3,7F10.0/8F10.0/8F10.0)
        NDE(I)=NDEC
        DO 301 IC=1,NDEC
        ICP1=IC+1
        C(I,ICP1)=CX(I,IC)
 301    CONTINUE
 15     CONTINUE
        WRITE(6,200) XNO2
 200    FORMAT(8X,'DPM RUN CODE',F6.0//)
        WRITE(6,201)NSTG,NBJ,XINC,K1,K2
 201    FORMAT(5X,'STAGES----MAXIMUM---INCREMENT---LIMIT---ULIMIT'
     :,/,2I9,F13.2,2I9,//,'----STAGE   INPUTS----DECISIONS')
        DO 203 I=1,NSTG
        WRITE(6,202)I,NIN(I),NDE(I)
 202    FORMAT(I9,I8,I10)
 203    CONTINUE
        WRITE(6,101)
```

```
      WRITE(6,200) XNO2
      WRITE(6,204)
204   FORMAT (1H,'   STAGE   DECISION   COST   RETURN  REF NO',
     :'      COST/BEN')
      IPAP=0
      NSP1=NSTG+1
      NDE(NSP1)=0
      DO 10 I=1,NSTG
      R(1)=0.
      READ(5,100) NDEC,(RX(IC),IC=1,NDEC),XNO1(I)
      DO 302 IC=1,NDEC
      ICP1=IC+1
      R(ICP1)=RX(IC)
302   CONTINUE
      NDEC=NDE(I)+1
      DO 206 IC=1,NDEC
      IX=IC-1
      RECB=R(IC)
      IF(R(IC).EQ.0.0) RECB=1
      CBEN=C(I,IC)/RECB
      WRITE(6,205) I,IX,C(I,IC),R(IC),XNO1(I)    ,CBEN
205   FORMAT(I6,I9,F11.0,F11.0,F7.0,F10.4)
206   CONTINUE
      IPAP=IPAP+NDEC
      IP1=I+1
      IPC=IPAP+NDE(IP1)
      IF(IPC.LT.50) GO TO 303
      WRITE(6,101)
      WRITE(6,200) XNO2
      WRITE(6,204)
      IPAP=0
303   CONTINUE
      NINP=NIN(I)
      DO 20 J=1,NINP
      XIN=(J-1)*XINC
      DUM=-10000000000.*NBJ
      NDEC=NDE(I)+1
      DO 30 K=1,NDEC
      CALL XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
      IF(KICK) 901,901,902
902   GO TO 30
901   CONTINUE
      VRET=R(K)
      IF(I-1) 7,7,8
7     TEST=VRET
```

```
      GO TO 11
8     TEST=VRET+ORET(I-1,IST)
      GO TO 11
11    IF(NBJ*(DUM-TEST)) 13,12,12
13    DUM=TEST
      ODEC(I,J)=TDEC
      ORET(I,J)=DUM
      NOD(I,J)=K
12    GO TO 29
29    CONTINUE
30    CONTINUE
20    CONTINUE
10    CONTINUE
      NINP=NIN(NSTG)
      NOPC=40/NSTG
      KKK=NOPC
      ICORO=0
      DO 40 M=K1,NINP,K2
      ICORO=ICORO+1
      J=M
      XIN=(J-1)*XINC
      IF(KKK.NE.NOPC) GO TO 67
      WRITE(6,101)
      WRITE(6,200) XNO2
      WRITE(6,16)
16    FORMAT('  ',         5X,'BUDGET  LOCATION ',4X,'ALT-NUM',
     :5X,'COST',5X,'RETURN')
      KKK=0
67    KKK=KKK+1
      WRITE(6,18) XIN
18    FORMAT('O',1X,F12.2)
      CO(ICORO)=XIN
      DO 45 L=1,NSTG
      I=NSTG+1-L
      XIN=(J-1)*XINC
      TDEC=ODEC(I,J)
      KK=(NOD(I,J)-1)
      NO1=XNO1(I)
      WRITE(6,17) I,NO1,KK,ODEC(I,J),ORET(I,J)
17    FORMAT('  ',12X,I3,1X,I4,6X,I4,2F12.0,F10.4)
      K=NOD(I,J)
      CALL XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
      J=IST
45    CONTINUE
      RO(ICORO)=ORET(NSTG,M)
```

```
 40      CONTINUE
         IIX=30
         IF(IPUNCH.EQ.0) GO TO 998
C        WRITE(7,100) IIX,(CO(I),I=1,30),XNO2
C        WRITE(7,100),IIX,(RO(I),I=1,30),XNO2
 998     WRITE(6,101)
 101     FORMAT('1')
         GO TO 1
 999     STOP
         END
         SUBROUTINE XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
         DIMENSION C(50,31)
         TDEC=C(I,K)
         OUT=XIN-TDEC
         IF(OUT) 10,20,20
 10      KICK=1
         GO TO 30
20       KICK=0
         IST=(OUT/XINC) +1.5
 30      RETURN
         END
$EXEC
  17   1  1000  11  10      9000
   4      200.      7136.     29645.    36781.
   1     8000.
   1   100000.
   2      750.       800.
   1     6000.
   1   100000.
   1     5000.
   1   100000.
   2     6500.      8000.
   3      800.      2200.      3600.
   1     1000.
   1     2200.
   2     5000.     35000.
   2     4500.     14700.
   1     2800.
   1     1200.
   1     1400.
   4    20802.     71322.    118870.   128380.
   1    14157.
   1    34395.
   2    14030.      5393.
   1    21853.
```

APPENDIX (B-4) DYNAMIC PROGRAMMING COMPUTER CODE FOR RESOURCE ALLOCATION

```
/*tag    usr=(sseyedho,rje)
//seye job        ,'seyed           ',class=j time=(2,30)
/*jobparm d=rmt1
// exec watfiv
//sysin dd *
c       **************************************************************
c       * THIS PROGRAM DEVELOPES THE DYNAMIC PROGRAMMING TECHNIQUE   *
c       * TO BE USED FOR THE COMPARISON PURPOSE AND MODEL CALIBRATION*
c       * THE ALABAMA DEPARTMENT OF TRANSPORTATION COMPUTER CODE HAS *
c       * BEEN MODIFIED AND USED IN THIS DISSERTATION.               *
c       **************************************************************
        DIMENSION ORET(50,301),ODEC(50,301),NIN(50),NDE(51)
        DIMENSION NOD(50,301),C(50,31),R(31),CO(30),RO(30)
        DIMENSION CX(50,31),RX(31),XNO1(50)
 1      CONTINUE
        IST=0
        VRET=0.0
        READ(5,4) NSTG,NBJ,XINC,K1,K2,XNO2,IPUNCH
 4      FORMAT(2I4,F6.0,2I4,F10.0,I2)
        IF(NSTG) 2,999,2
 2      CONTINUE
        DO 5 I=1,NSTG
 5      NIN(I)=301
 3      FORMAT(20I4)
        WRITE(6,101)
        DO 15 I=1,NSTG
        C(I,1)=0.
        READ(5,100) NDEC,(CX(I,IC),IC=1,NDEC),XNO1(I)
 100    FORMAT(I3,7F10.0/8F10.0/8F10.0)
        NDE(I)=NDEC
        DO 301 IC=1,NDEC
        ICP1=IC+1
        C(I,ICP1)=CX(I,IC)
 301    CONTINUE
 15     CONTINUE
        WRITE(6,200) XNO2
 200    FORMAT(8X,'DPM RUN CODE',F6.0//)
        WRITE(6,201)NSTG,NBJ,XINC,K1,K2
 201    FORMAT(5X,'STAGES----MAXIMUM---INCREMENT---LIMIT---ULIMIT'
      :,/,2I9,F13.2,2I9,//,'----STAGE   INPUTS----DECISIONS')
        DO 203 I=1,NSTG
        WRITE(6,202)I,NIN(I),NDE(I)
 202    FORMAT(I9,I8,I10)
 203    CONTINUE
        WRITE(6,101)
```

```
      WRITE(6,200) XNO2
      WRITE(6,204)
204   FORMAT (1H,'   STAGE   DECISION   COST   RETURN   REF NO';
     :'      COST/BEN')
      IPAP=0
      NSP1=NSTG+1
      NDE(NSP1)=0
      DO 10 I=1,NSTG
      R(1)=0.
      READ(5,100) NDEC,(RX(IC),IC=1,NDEC),XNO1(I)
      DO 302 IC=1,NDEC
      ICP1=IC+1
      R(ICP1)=RX(IC)
302   CONTINUE
      NDEC=NDE(I)+1
      DO 206 IC=1,NDEC
      IX=IC-1
      RECB=R(IC)
      IF(R(IC).EQ.0.0) RECB=1
      CBEN=C(I,IC)/RECB
      WRITE(6,205) I,IX,C(I,IC),R(IC),XNO1(I)    ,CBEN
205   FORMAT(I6,I9,F11.0,F11.0,F7.0,F10.4)
206   CONTINUE
      IPAP=IPAP+NDEC
      IP1=I+1
      IPC=IPAP+NDE(IP1)
      IF(IPC.LT.50) GO TO 303
      WRITE(6,101)
      WRITE(6,200) XNO2
      WRITE(6,204)
      IPAP=0
303   CONTINUE
      NINP=NIN(I)
      DO 20 J=1,NINP
      XIN=(J-1)*XINC
      DUM=-10000000000.*NBJ
      NDEC=NDE(I)+1
      DO 30 K=1,NDEC
      CALL XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
      IF(KICK) 901,901,902
902   GO TO 30
901   CONTINUE
      VRET=R(K)
      IF(I-1) 7,7,8
7     TEST=VRET
```

```
        GO TO 11
8       TEST=VRET+ORET(I-1,IST)
        GO TO 11
11      IF(NBJ*(DUM-TEST)) 13,12,12
13      DUM=TEST
        ODEC(I,J)=TDEC
        ORET(I,J)=DUM
        NOD(I,J)=K
12      GO TO 29
29      CONTINUE
30      CONTINUE
20      CONTINUE
10      CONTINUE
        NINP=NIN(NSTG)
        NOPC=40/NSTG
        KKK=NOPC
        ICORO=0
        DO 40 M=K1,NINP,K2
        ICORO=ICORO+1
        J=M
        XIN=(J-1)*XINC
        IF(KKK.NE.NOPC) GO TO 67
        WRITE(6,101)
        WRITE(6,200) XNO2
        WRITE(6,16)
16      FORMAT('  ',          5X,'BUDGET  LOCATION ',4X,'ALT-NUM',
     :5X,'COST',5X,'RETURN')
        KKK=0
67      KKK=KKK+1
        WRITE(6,18) XIN
18      FORMAT('O',1X,F12.2)
        CO(ICORO)=XIN
        DO 45 L=1,NSTG
        I=NSTG+1-L
        XIN=(J-1)*XINC
        TDEC=ODEC(I,J)
        KK=(NOD(I,J)-1)
        NO1=XNO1(I)
        WRITE(6,17) I,NO1,KK,ODEC(I,J),ORET(I,J)
17      FORMAT('  ',12X,I3,1X,I4,6X,I4,2F12.0,F10.4)
        K=NOD(I,J)
        CALL XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
        J=IST
45      CONTINUE
        RO(ICORO)=ORET(NSTG,M)
```

```
 40      CONTINUE
         IIX=30
         IF(IPUNCH.EQ.0) GO TO 998
C        WRITE(7;100) IIX,(CO(I),I=1,30),XNO2
C        WRITE(7,100),IIX,(RO(I),I=1,30),XNO2
 998     WRITE(6,101)
 101     FORMAT('1')
         GO TO 1
 999     STOP
         END
         SUBROUTINE XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
         DIMENSION C(50,31)
         TDEC=C(I,K)
         OUT=XIN-TDEC
         IF(OUT) 10,20,20
 10      KICK=1
         GO TO 30
 20      KICK=0
         IST=(OUT/XINC) +1.5
 30      RETURN
         END
$EXEC
  17    1  1000   11   10.      9000
  4       200.       7136.     29645.     36781.
  1      8000.
  1    100000.
  2       750.        800.
  1      6000.
  1    100000.
  1      5000.
  1    100000.
  2      6500.       8000.
  3       800.       2200.      3600.
  1      1000.
  1      2200.
  2      5000.      35000.
  2      4500.      14700.
  1      2800.
  1      1200.
  1      1400.
  4     20802.      71322.    118870.    128380.
  1     14157.
  1     34395.
  2     14030.       5393.
  1     21853.
```

```
 1     20238.
 1       600.
 1    136009.
 2     13104.     15470.
 3      4590.     16830.     21674.
 1     10560.
 1      1296.
 2      2496.      7680.
 2      3450.      8050.
 1      1512.
 1      6790.
 1      7210.
/*eof
```

## APPENDIX (C-1) OPTIMALITY ASSESSMENT COMPUTER PROGRAM

***NOTE FOR LARGE-SCALE PROBLEMS THE DIMENSIONS SHOULD BE MODIFIED.

```
C       ************************************************************
C       * S. M. SEYED-HOSSEIN, OPTIMALITY ASSESSEMENT MODULE        *
C       * MAY 1982, UNIVERSITY OF OKLAHOMA, SUPERVISED BY PROFESSOR *
C       * L. WEST, AT CIVIL ENGINEERING DEPARTMENT.                 *
C       * THIS IS AN INDEPENDENT COMPUTER MODULE THAT CAN BE USED BY *
C       * FEDERAL, STATE, AND LOCAL GOVERNMENT TO SOLVE THEIR       *
C       * MULTI-OBJECTIVE SAFETY PROBLEMS.  THIS PROGRAM IS A SLIGHTLY*
C       * MODIFIED VERSION OF "LINEAR GOAL PROGRAMMING PACKAGE"     *
C       * WRITTEN BY PAULA S. BERSHADER AT PENNSYLVANIA STATE       *
C       * UNIVERSITY.  THE PROCESS FOR SAFETY FORMULATION CAN BE FOUND*
C       * IN CHAPTER SIX OF THIS DISSERTATION.                      *
C       * THE PROGRAM HAS BEEN WRITTEN AND INTERACTIVELY GUIDES THE *
C       * USER TO INPUT THE REQUIRED DATA.  HOWEVER, UNDERSTANDIND  *
C       * THE FORMULATION PROCESS IS NECESSARY BEFORE USING THIS    *
C       * PROGRAM.                                                  *
        * FOR LARGE SCALE PROBLEMS, THE DIMENTIONS FOR ARRAY SHOULD *
        * BE INCREASED                                              *
C       ************************************************************
      COMMON        TL(20,10),   TT(10,30),   TE(20,30),   TI(10,30),
     1              TB(20),      TA(10),      JCOL(30,2),  JROW(20,2),
     2              NOBJ,        NPRI,        NVAR,        NCOL,
     3              NROW,        INSW
      DATA          IMAX/200/
      DATA          NPRB/0/
        WRITE(6,200)
200     FORMAT('THIS PROGRAM IS A SLIGHTLY MODIFIED VERSION OF'/
     1         '''LINEAR GOAL PROGRAMMING PACKAGE'' WRITTEN BY'/
     2         'PAULA S. BERSHADER WHILE AT THE PENNSYLVANIA STATE'/
     3         'UNIVERSITY IN 1975.  THE READ FORMATS HAVE BEEN'/
     4         'CHANGED TO ALLOW EASIER INPUT OF DATA.')
        WRITE(6,101)
101     FORMAT('**************************************************'/
     1         '**************************************************'/
     2         '**************************************************'/
     3         '**************************************************'/
     4         '**************************************************')
        WRITE(6,202)
202     FORMAT('ENTER THE FOLLOWING VALUES ON A SINGLE LINE '/
     1         'SEPARATED BY COMMAS:  TOTAL NUMBER OF OBJECTIVES,'/
     2         'NUMBER OF PRIORITIES, NUMBER OF DECISION VARIABLES,'/
     3         'NUMBER OF TERMS IN THE ACHIEVEMENT FUNCTION, 1 FOR'/
     4         'PURE INTEGER SOLUTION OR 0 FOR NORMAL L.G.P..')
   25 READ (5,30,END=40,ERR=21) NOBJ,NPRI,NVAR,NTAP,INSW
      IF (NOBJ .LT. 1 .OR. NPRI .LT. 1 .OR. NVAR .LT. 1) GO TO 22
      IF (NOBJ .GT. 20 .OR. NPRI .GT. 10 .OR. NVAR .GT. 10) GO TO 22
        NCOL = NOBJ + NVAR
      DO 1 NV = 1,NVAR
      JCOL(NV,1) = 2
    1 JCOL(NV,2) = NV
      DO 2 NO = 1,NOBJ
         NC = NO + NVAR
      JCOL(NC,1) = 3
      JCOL(NC,2) = NO
      JROW(NO,1) = 4
    2 JROW(NO,2) = NO
        WRITE(6,102)
102     FORMAT('**************************************************'/
     1         '**************************************************'/
     2         '**************************************************'/
     3         '**************************************************')
        WRITE(6,204)
204     FORMAT('NEXT ENTER THE COEFFICIENTS OF THE JTH DECISION VARIABLE'/
     1         'IN THE ITH OBJECTIVE.  ENTER THESE VALUES ON A SINGLE'/
```

```
     2          'LINE SEPARATED BY COMMAS.  DO NOT INCLUDE THE COEFFI-'/
     3          'CIENTS OF THE DEVIATION VARIABLES.  FOR EXAMPLE:'/
     4                   'X1 + 4X2 + N1 - P1 = 6'/
     5                    'X1 - 2X2 + N2 - P2 = 4'/
     6                   '3X1 + 6X2 + N3 - P3 = 9'/
     7          'THE VALUES WOULD BE KEYED IN AS FOLLOWS:'/
     8                  .'1,4,1,-2,3,6')
      READ (5,31,END=20,ERR=21) ((TE(NO,NV),NV=1,NVAR),NO=1,NOBJ)
      DO 3 NOR = 1,NOBJ
      DO 3 NO  = 1,NOBJ
         NOC = NO + NVAR
      TE(NOR,NOC) = 0
      IF (NO .EQ. NOR) TE(NOR,NOC) = -1
    3 CONTINUE
        WRITE(6,103)
  103   FORMAT('************************************************'/
     1          '************************************************'/
     2          '************************************************'/
     3          '************************************************')
        WRITE(6,206)
  206   FORMAT('NEXT ENTER THE RIGHT HAND SIDE VALUES FOR EACH'/
     1          'OBJECTIVE.  ENTER THE VALUES ON A SINGLE LINE'/
     2          'SEPARATED BY COMMAS.  FOR EXAMPLE CONSIDER:'/
     3                 ' X1 + 4X2 + N1 - P1 = 6'/
     4              'X1 -2X2 + N2 - P2 = 4'/
     5                 '3X1 + 6X2 + N3 - P3 = 9'/
     6          'THE VALUES WILL BE KEYED IN AS:'/
     7                 '6,4,9')
      READ (5,31,END=20,ERR=21) (TB(NO),NO=1,NOBJ)
      DO 6 NP = 1,NPRI
      DO 4 NO = 1,NOBJ
    4 TL(NO,NP) = 0
      DO 5 NC = 1,NCOL
    5 TT(NP,NC) = 0
    6 CONTINUE
        WRITE(6,104)
  104   FORMAT('************************************************'/
     1          '************************************************'/
     2          '************************************************'/
     3          '************************************************')
        WRITE(6,208)
  208   FORMAT('NOW ENTER THE PRIORITY LEVELS FOR THE ASSOCIATED'/
     1          'DEVIATION VARIABLES, + OR - TIMES THE SUBSCRIPT OF'/
     2          'THE ASSOCIATED DEVIATION VARIABLE.(IE + FOR N, -'/
     3          'FOR P.), AND WEIGHTING FACTOR FOR THE ASSOCIATED'/
     4          'DEVIATION VARIABLE.  YOU MUST USE ONE LINE FOR EACH'/
     5          'DEVIATION VARIABLE APPEARING IN THE ACHIEVEMENT'/
     6          'FUNCTION.  FOR EXAMPLE:'/
     7                  'MIN A = [(2P1 + 3P2),(N3)]'/
     9                      ' X1 + 4X2 + N1 - P1 = 6'/
     9                      ' X1 - 2X2 + N2 - P2 = 4'/
     1                      '3X1 + 6X2 + N3 - P3 = 9'/
     2          'THE INPUT WOULD BE:'/
     3                      '1,+1,2'/
     4                      '1,+2,3'/
     5                      '2,-3,1')
      DO 7 NT = 1,NTAP
      READ (5,32,END=20,ERR=21) IPRI,ISUB,WHTP
      CALL PLACE (IPRI, ISUB, WHTP)
    7 CONTINUE
         NPRB = NPRB + 1
      WRITE (6,34) NPRB
         NCPL = 0
         NPRT = 0
    8 NROW = 0
         IVAL = 0
```

```
  9 IF (NROW .EQ. NPRI) GO TO 11
       NROW = NROW + 1
    CALL CINDX(0)
 10 CALL TEST (NEVC, NDVB)
       IVAL = IVAL + 1
    IF (IVAL .GE. IMAX) GO TO 19
    IF (NEVC .LE. 0) GO TO 9
    CALL PERM (NEVC,NDVB)
    GO TO 10
 11 CALL INTST (NSW)
    IF (NSW .EQ. 0) CALL POUT (NPRT,NCPL)
    CALL ALTST (NPRT,NCPL)
    IF (NPRT .NE. 0) GO TO 25
    CALL FCPL (ISW)
    IF (ISW .EQ. 0) GO TO 25
       NCPL = NCPL + 1
    GO TO 8
 19 WRITE (6,38) IMAX
    GO TO 25
 20 WRITE (6,35)
    GO TO 40
 21 WRITE (6,36)
    GO TO 40
 22 WRITE (6,37)
 30 FORMAT (5I5)
 31 FORMAT (8F10.0)
 32 FORMAT (2I5,F10.0)
 34 FORMAT (1H1,/////,'PROBLEM',I4,' READ IN SUCCESSFULLY')
 35 FORMAT (//,'**DATA STREAM ERROR--MISSING DATA CARDS**')
 36 FORMAT (//,'DATA STREAM ERROR -- UNREADABLE DATA CARD**')
 37 FORMAT(//,'**INPUT VARIABLE EXCEEDS ALLOWABLE DIMENSION RANGE**')
 38 FORMAT (//, ' **  ALGORITHM DID NOT FINISH ',I5, ' ITERATIONS **')
 40 CONTINUE
    STOP
    END
    SUBROUTINE PLACE (IPRI, ISUB, WHTP)
     COMMON       TL(20,10),   TT(10,30),   TE(20,30),   TI(10,30),
   1              TB(20),      TA(10),      JCOL(30,2),  JROW(20,2),
   2              NOBJ,        NPRI,        NVAR,        NCOL,
   3              NROW,        INSW
    IF (IPRI .LT. 1 .OR. IPRI .GT. NPRI) GO TO 2
    IF (ISUB .EQ. 0 .OR. IABS(ISUB) .GT. NOBJ) GO TO 2
    IF (ISUB .GT. 0) GO TO 1
       ISUB = -ISUB
    IF (TL(ISUB,IPRI) .NE. 0) GO TO 3
    TL(ISUB,IPRI) = WHTP
    RETURN
  1    ICOL = ISUB + NVAR
    IF (TT(IPRI,ICOL) .NE. 0) GO TO 3
    TT(IPRI,ICOL) = WHTP
    RETURN
  2 WRITE (6,4)
    GO TO 6
  3 WRITE (6,5)
  4 FORMAT (//,'**SUBSCRIPT OUT-OF-RANGE WHILE READING SUBSCRIPTS**')
  5 FORMAT (//,'**OVERWRITE ATTEMPTED IN A STUB**')
  6 STOP
    END
    SUBROUTINE CINDX (ISW)
    COMMON        TL(20,10),   TT(10,30),   TE(20,30),   TI(10,30),
   1              TB(20),      TA(10),      JCOL(30,2),  JROW(20,2),
   2              NOBJ,        NPRI,        NVAR,        NCOL,
   3              NROW,        INSW
     I = 1
    IF (ISW .NE. 1) I = NROW
    DO 3 NP = I,NROW
```

```
      TA(NP) = 0
      DO 1 NO = 1,NOBJ
    1 TA(NP) = TA(NP) + TB(NO) * TL(NO,NP)
      DO 2 NC = 1,NCOL
      TI(NP,NC) = -TT(NP,NC)
      DO 2 NO = 1,NOBJ
      TI(NP,NC) = TI(NP,NC) + TE(NO,NC) * TL(NO,NP)
    2 CONTINUE
    3 CONTINUE
      RETURN
      END
      SUBROUTINE TEST (NEVC,NDVR)
      COMMON         TL(20,10),   TT(10,30),   TE(20,30),   TI(10,30),
     1               TB(20),      TA(10),      JCOL(30,2),  JROW(20,2),
     2               NOBJ,        NPRI,        NVAR,        NCOL,
     3               NROW,        INSW
         NEVC = 0
      IF (TA(NROW) .LE. 0) RETURN
         VEVC = 0
       NRMW = NROW - 1
      DO 3 NC = 1,NCOL
      IF (TI(NROW,NC) .LE. 0) GO TO 3
      IF (NROW .EQ. 1) GO TO 2
      DO 1 N = 1,NRMW
      IF (TI(N,NC) .LT. 0) GO TO 3
    1 CONTINUE
    2 IF (TI(NROW,NC) .LE. VEVC) GO TO 3
         NEVC = NC
         VEVC = TI(NROW,NC)
    3 CONTINUE
      IF (NEVC .EQ. 0) RETURN
         NDVR = 0
      DO 7 NR = 1,NOBJ
      IF (TE(NR,NEVC) .LE. 0) GO TO 7
         V = TB(NR)/TE(NR,NEVC)
      IF (NDVR .EQ. 0) GO TO 6
      IF (V-VDVR)6,4,7
    4 DO 5 NP = 1,NPRI
      IF (TL(NR,NP) - TL(NDVR,NP)) 7,5,6
    5 CONTINUE
    6    VDVR = V
         NDVR = NR
    7 CONTINUE
      IF (NDVR .GE. 1) RETURN
      WRITE (6,8)
    8 FORMAT (//,'**PROGRAM TERMINATED-FAILED PIVOT-COMPUTATION**')
      STOP
      END
      SUBROUTINE PERM (NEVC,NDVR)
      COMMON         TL(20,10),   TT(10,30),   TE(20,30),   TI(10,30),
     1               TB(20),      TA(10),      JCOL(30,2),  JROW(20,2),
     2               NOBJ,        NPRI,        NVAR,        NCOL,
     3               NROW,        INSW
      DO 1  I = 1,2
            J = JCOL(NEVC,I)
      JCOL(NEVC,I) = JROW(NDVR,I)
    1 JROW(NDVR,I) = J
      DO 2 NP = 1,NPRI
         TEMP = TL(NDVR,NP)
      TL  (NDVR,NP) = TT(NP,NEVC)
    2 TT(NP,NEVC) = TEMP
          PIV = TE(NDVR,NEVC)
          PIB = TB(NDVR)
      DO 31 NO = 1,NOBJ
      IF (NO .EQ. NDVR) GO TO 31
          PIX = TE(NO,NEVC)/PIV
```

```
      TB(NO) = FIX(TB(NO) - PIX * PIB)
    6 DO 3 NC = 1,NCOL
      IF (NC .EQ. NEVC) GO TO 3
      TE(NO,NC) = FIX(TE(NO,NC) - TE(NDVR,NC) * PIX)
    3 CONTINUE
   31 CONTINUE
      DO 4 NC = 1,NCOL
    4 TE(NDVR,NC) = FIX(TE(NDVR,NC)/PIV)
      DO 5 NO = 1,NOBJ
    5 TE(NO,NEVC) = FIX(-TE(NO,NEVC)/PIV)
      TB(NDVR) = FIX(TB(NDVR)/PIV)
      TE(NDVR,NEVC) = FIX(1/PIV)
      CALL CINDX(1)
      RETURN
      END
      FUNCTION FIX (Z)
            X = 1
      DO 1 N = 1,3
      IF (N .NE. 1) X = 10 * X
            F = X * Z
            I = F
            J = I - 2
      DO 1 K = 1,3
            G = J + K
      IF (ABS(F-G) - .005) 2,2,1
    1 CONTINUE
          FIX = Z
      RETURN
    2     FIX = G/X
      RETURN
      END
      SUBROUTINE FCPL (ISW)
      COMMON        TL(20,10),    TT(10,30),    TE(20,30),    TI(10,30),
     1              TB(20),       TA(10),       JCOL(30,2),   JROW(20,2),
     2              NOBJ,         NPRI,         NVAR,         NCOL,
     3              NRCH,         INSW
      IF (NOBJ .EQ. 20) GO TO 10
      CALL INTST (NSW)
      IF (NSW .EQ. 0) GO TO 11
          ISW = 1
        NOBJ = NOBJ + 1
      DO 4 NC = 1,NCOL
            X = TE(NSW,NC)
            I = X
            Y = I
      IF (FIX(X-Y)) 1,2,3
    1 TE(NOBJ,NC) = 1. + X-Y
      GO TO 4
    2 TE(NOBJ,NC) = 0
      GO TO 4
    3 TE(NOBJ,NC) = X-Y
    4 CONTINUE
            X = TB(NSW)
          I = X
            Y = I
      IF (FIX(X-Y)) 5,12,6
    5 TB(NOBJ) = 1. + X-Y
      GO TO 7
    6 TB(NOBJ) = X-Y
    7     NCOL = NCOL + 1
      DO 8 NO = 1,NOBJ
    8 TE(NO,NCOL) = 0
      TE(NOBJ,NCOL) = -1
      DO 9 NP = 1,NPRI
      TT(NP,NCOL) = 0
    9 TL(NOBJ,NP) = 0
```

```
      TL(NOBJ,1) = 1
      JROW(NOBJ,1) = 4
      JROW(NOBJ,2) = NOBJ
      JCOL(NCOL,1) = 3
      JCOL(NCOL,2) = NOBJ
      GO TO 14
   10 WRITE (6,15)
      GO TO 13
   11 WRITE (6,16)
      GO TO 13
   12    NOBJ = NOBJ - 1
      WRITE (6,17)
   13 WRITE (6,18)
         N = 0
      CALL POUT(N,N)
         ISW = 0
   14 RETURN
   15 FORMAT (/,'  FCPL FAILURE - DIMENSION EXCEEDED ')
   16 FORMAT (/,'  FCPL FAILURE - ILLEGAL PATH')
   17 FORMAT (/,'  FCPL FAILURE - ABNORMAL VALUE')
   18 FORMAT (/,'  VALUES AT THE TIME OF FAILURE FOLLOW')
      END
      SUBROUTINE ALTST (NPRT, NCPL)
      COMMON        TL(20,10),     TT(10,30),     TE(20,30),     TI(10,30),
     1              TB(20),        TA(10),        JCOL(30,2),    JROW(20,2),
     2              NOBJ,          NPRI,          NVAR,          NCOL,
     3              NROW,          INSW
      DO 4 NC = 1,NCOL
      DO 1 NP = 1,NPRI
      IF (TI(NP,NC) .NE. 0) GO TO 4
    1 CONTINUE
      DO 3 NO = 1,NOBJ
      IF(TE(NO,NC) .LE. 0) GO TO 3
      IF (TB(NO) .LE. 0) GO TO 3
    2 CALL PERM (NC,NC)
      DO 5 NB = 1,NOBJ
      IF (TB(NB) .LT. 0) GO TO 6
    5 CONTINUE
      CALL INTST (NSW)
      IF(NSW .EQ. 0) CALL POUT (NPRT,NCPL)
    6 CALL PERM (NC,NO)
    3 CONTINUE
    4 CONTINUE
      RETURN
      END
      SUBROUTINE POUT (NPRT,NCPL)
      COMMON        TL(20,10),     TT(10,30),     TE(20,30),     TI(10,30),
     1              TB(20),        TA(10),        JCOL(30,2),    JROW(20,2),
     2              NOBJ,          NPRI,          NVAR,          NCOL,
     3              NROW,          INSW
      DIMENSION     WOUT(20,4)
         NPRT = NPRT + 1
      IF (NPRT .NE. 1) WRITE (6,31) NPRT
      IF (NCPL .NE. 0 .AND. NPRT .EQ. 1) WRITE (6,32) NCPL
   11 DO 12 I = 1,20
      DO 12 J = 1,4
   12 WOUT(I,J) = 0
      DO 13 NP = 1,NPRI
   13 WOUT(NP,1) = FIX(TA(NP))
      DO 14 NO = 1,NOBJ
         IC = JROW(NO,1)
         IR = JROW(NO,2)
   14 WOUT(IR,IC) = FIX (TB(NO))
      WRITE (6,33) NPRI, NVAR, NOBJ, NOBJ
         I = MAX0(NPRI,NVAR,NOBJ)
      DO 20 K = 1,I
```

```
      IF (K .GT. NPRI) GO TO 16
      IF (K .GT. NVAR) GO TO 15
      WRITE (6,34) K,  (WOUT(K,J), J=1,4)
      GO TO 20
   15 WRITE (6,35) K, WOUT(K,1), (WOUT(K,J) ,J=3,4)
      GO TO 20
   16 IF (K .GT. NVAR) GO TO 17
      WRITE (6,36) K, (WOUT(K,J) ,J=2,4)
      GO TO 20
   17 WRITE (6,37) K, (WOUT(K,J) ,J= 3,4)
   20 CONTINUE
   31 FORMAT (/,'  ALTERNATE SOLUTION NUMBER ',I3)
   32 FORMAT (/,'  NUMBER OF CUTTING PLANES USED = ',I3)
   33 FORMAT (/,'  SUBSCRIPT',I6,' TERMS ASTAR',I6,
     1         ' TERMS XSTAR',I6,' TERMS PSTAR',I6,' TERMS WSTAR'/)
   34 FORMAT (I6,4F18.4)
   35 FORMAT (I6,F18.4, 18X,2F18.4)
   36 FORMAT (I6,18X,3F18.4)
   37 FORMAT (I6,36X,2F18.4)
      RETURN
      END
      SUBROUTINE INTST (NSW)
      COMMON      TL(20,10),    TT(10,30),    TE(20,30),    TI(10,30),
     1            TB(20),       TA(10),       JCOL(30,2),   JROW(20,2),
     2            NOBJ,         NPRI,         NVAR,         NCOL,
     3            NROW,         INSW
         NSW = 0
      IF (INSW .EQ. 0) RETURN
      DO 2 NO = 1,NOBJ
      IF (JROW(NO,1) .NE. 2) GO TO 2
           I = TB(NO)
           J = I - 2
      DO 1 K = 1,3
           G = J + K
      IF(ABS(TB(NO)   -G)-.0001) 2,2,1
    1 CONTINUE
      GO TO 3
    2 CONTINUE
       RETURN
    3    NSW = NO
      RETURN
      END
```

APPENDIX (C-1) OPTIMALITY ASSESSMENT COMPUTER PROGRAM

***NOTE FOR LARGE-SCALE PROBLEMS THE DIMENSIONS SHOULD BE MODIFIED.

```
C       ************************************************************
C       * S. M. SEYED-HOSSEIN, OPTIMALITY ASSESSEMENT MODULE       *
C       * MAY 1982, UNIVERSITY OF OKLAHOMA, SUPERVISED BY PROFESSOR *
C       * L. WEST, AT CIVIL ENGINEERING DEPARTMENT.                *
C       * THIS IS AN INDEPENDENT COMPUTER MODULE THAT CAN BE USED BY *
C       * FEDERAL, STATE, AND LOCAL GOVERNMENT TO SOLVE THEIR       *
C       * MULTI-OBJECTIVE SAFETY PROBLEMS.  THIS PROGRAM IS A SLIGHTLY*
C       * MODIFIED VERSION OF "LINEAR GOAL PROGRAMMING PACKAGE"     *
C       * WRITTEN BY PAULA S. BERSHADER AT PENNSYLVANIA STATE       *
C       * UNIVERSITY.  THE PROCESS FOR SAFETY FORMULATION CAN BE FOUND*
C       * IN CHAPTER SIX OF THIS DISSERTATION.                      *
C       * THE PROGRAM HAS BEEN WRITTEN AND INTERACTIVELY GUIDES THE *
C       * USER TO INPUT THE REQUIRED DATA.  HOWEVER, UNDERSTANDIND  *
C       * THE FORMULATION PROCESS IS NECESSARY BEFORE USING THIS    *
C       * PROGRAM.                                                  *
        * FOR LARGE SCALE PROBLEMS, THE DIMENTIONS FOR ARRAY SHOULD *
        * BE INCREASED                                              *
C       ************************************************************
      COMMON        TL(20,10),    TT(10,30),    TE(20,30),    TI(10,30),
     1              TB(20),       TA(10),       JCOL(30,2),   JROW(20,2),
     2              NOBJ,         NPRI,         NVAR,         NCOL,
     3              NROW,         INSW
      DATA          IMAX/200/
      DATA          NPRB/0/
        WRITE(6,200)
200     FORMAT('THIS PROGRAM IS A SLIGHTLY MODIFIED VERSION OF'/
     1         '''LINEAR GOAL PROGRAMMING PACKAGE'' WRITTEN BY'/
     2         'PAULA S. BERSHADER WHILE AT THE PENNSYLVANIA STATE'/
     3         'UNIVERSITY IN 1975.  THE READ FORMATS HAVE BEEN'/
     4         'CHANGED TO ALLOW EASIER INPUT OF DATA.')
        WRITE(6,101)
101     FORMAT('****************************************************'/
     1         '****************************************************'/
     2         '****************************************************'/
     3         '****************************************************'/
     4         '****************************************************')
        WRITE(6,202)
202     FORMAT('ENTER THE FOLLOWING VALUES ON A SINGLE LINE '/
     1         'SEPARATED BY COMMAS:  TOTAL NUMBER OF OBJECTIVES,'/
     2         'NUMBER OF PRIORITIES, NUMBER OF DECISION VARIABLES, '/
     3         'NUMBER OF TERMS IN THE ACHIEVEMENT FUNCTION, 1 FOR'/
     4         'PURE INTEGER SOLUTION OR 0 FOR NORMAL L.G.P..')
   25 READ (5,30,END=40,ERR=21) NOBJ,NPRI,NVAR,UTAP,INSW
      IF (NOBJ .LT. 1 .OR. NPRI .LT. 1 .OR. NVAR .LT. 1) GO TO 22
      IF (NOBJ .GT. 20 .OR. NPRI .GT. 10 .OR. NVAR .GT. 10) GO TO 22
        NCOL = NOBJ + NVAR
      DO 1 NV = 1,NVAR
      JCOL(NV,1) = 2
    1 JCOL(NV,2) = NV
      DO 2 NO = 1,NOBJ
        NC = NO + NVAR
      JCOL(NC,1) = 3
      JCOL(NC,2) = NO
      JROW(NO,1) = 4
    2 JROW(NO,2) = NO
        WRITE(6,102)
102     FORMAT('****************************************************'/
     1         '****************************************************'/
     2         '****************************************************'/
     3         '****************************************************')
        WRITE(6,204)
204     FORMAT('NEXT ENTER THE COEFFICIENTS OF THE JTH DECISION VARIABLE'/
     1         'IN THE ITH OBJECTIVE.  ENTER THESE VALUES ON A SINGLE'/
```

```
     2          'LINE SEPARATED BY COMMAS.  DO NOT INCLUDE THE COEFFI-'/
     3          'CIENTS OF THE DEVIATION VARIABLES.  FOR EXAMPLE:'/
     4                    'X1 + 4X2 + N1 - P1 = 6'/
     5                     'X1 - 2X2 + N2 - P2 = 4'/
     6                    '3X1 + 6X2 + N3 - P3 = 9'/
     7          'THE VALUES WOULD BE KEYED IN AS FOLLOWS:'/
     8                    '1,4,1,-2,3,6')
      READ (5,31,END=20,ERR=21)  ((TE(NO,NV),NV=1,NVAR),NO=1,NOBJ)
      DO 3 NOR = 1,NOBJ
      DO 3 NO  = 1,NOBJ
         NOC = NO + NVAR
      TE(NOR,NOC) = 0
      IF (NO .EQ. NOR) TE(NOR,NOC) = -1
    3 CONTINUE
        WRITE(6,103)
103     FORMAT('*************************************************'/
     1          '*************************************************'/
     2          '*************************************************'/
     3          '*************************************************')
        WRITE(6,206)
206     FORMAT('NEXT ENTER THE RIGHT HAND SIDE VALUES FOR EACH'/
     1          'OBJECTIVE.  ENTER THE VALUES ON A SINGLE LINE'/
     2          'SEPARATED BY COMMAS.  FOR EXAMPLE CONSIDER:'/
     3                   ' X1 + 4X2 + N1 - P1 = 6'/
4                  'X1 -2X2 + N2 - P2 = 4'/
     5                   '3X1 + 6X2 + N3 - P3 = 9'/
     6          'THE VALUES WILL BE KEYED IN AS:'/
     7                   '6,4,9')
      READ (5,31,END=20,ERR=21)  (TB(NO),NO=1,NOBJ)
      DO 6 NP = 1,NPRI
      DO 4 NO = 1,NOBJ
    4 TL(NO,NP) = 0
      DO 5 NC = 1,NCOL
    5 TT(NP,NC) = 0
    6 CONTINUE
        WRITE(6,104)
104     FORMAT('*************************************************'/
     1          '*************************************************'/
     2          '*************************************************'/
     3          '*************************************************')
        WRITE(6,208)
208     FORMAT('NOW ENTER THE PRIORITY LEVELS FOR THE ASSOCIATED'/
     1          'DEVIATION VARIABLES, + OR - TIMES THE SUBSCRIPT OF'/
     2          'THE ASSOCIATED DEVIATION VARIABLE.(IE + FOR N, -'/
     3          'FOR P.), AND WEIGHTING FACTOR FOR THE ASSOCIATED'/
     4          'DEVIATION VARIABLE.  YOU MUST USE ONE LINE FOR EACH'/
     5          'DEVIATION VARIABLE APPEARING IN THE ACHIEVEMENT'/
     6          'FUNCTION.  FOR EXAMPLE:'/
     7                  'MIN A = [(2P1 + 3P2),(N3)]'/
     9                        ' X1 + 4X2 + N1 - P1 = 6'/
     9                        ' X1 - 2X2 + N2 - P2 = 4'/
     1                        '3X1 + 6X2 + N3 - P3 = 9'/
     2          'THE INPUT WOULD BE:'/
     3                        '1,+1,2'/
     4                        '1,+2,3'/
     5                        '2,-3,1')
      DO 7 NT = 1,NTAP
      READ (5,32,END=20,ERR=21) IPRI,ISUB,WHTF
      CALL PLACE (IPRI, ISUB, WHTF)
    7 CONTINUE
        NPRB = NPRB + 1
      WRITE (6,34) NPRB
        NCPL = 0
        NPRT = 0
    8 NROW = 0
        IVAL = 0
```

```
 9 IF (NROW .EQ. NPRI) GO TO 11
      NROW = NROW + 1
   CALL CINDX (0)
10 CALL TEST (NEVC, NDVR)
      IVAL = IVAL + 1
   IF (IVAL .GE. IMAX) GO TO 19
   IF (NEVC .LE. 0) GO TO 9
   CALL PERM (NEVC,NDVR)
   GO TO 10
11 CALL INTST (NSW)
   IF (NSW .EQ. 0) CALL POUT (NPRT,NCPL)
   CALL ALTST (NPRT,NCPL)
   IF (NPRT .NE. 0) GO TO 25
   CALL FCPL (ISW)
   IF (ISW .EQ. 0) GO TO 25
      NCPL = NCPL + 1
   GO TO 8
19 WRITE (6,38) IMAX
   GO TO 25
20 WRITE (6,35)
   GO TO 40
21 WRITE (6,36)
   GO TO 40
22 WRITE (6,37)
30 FORMAT (5I5)
31 FORMAT (8F10.0)
32 FORMAT (2I5,F10.0)
34 FORMAT (1H1,////,'PROBLEM',I4,' READ IN SUCCESSFULLY')
35 FORMAT (//,'**DATA STREAM ERROR--MISSING DATA CARDS**')
36 FORMAT (//,'DATA STREAM ERROR -- UNREADABLE DATA CARD**')
37 FORMAT(//,'**INPUT VARIABLE EXCEEDS ALLOWABLE DIMENSION RANGE**')
38 FORMAT (//, ' **  ALGORITHM DID NOT FINISH ',I5, ' ITERATIONS **')
40 CONTINUE
   STOP
   END
   SUBROUTINE PLACE (IPRI, ISUB, WHTF)
    COMMON       TL(20,10),    TT(10,30),    TE(20,30),    TI(10,30),
  1              TB(20),       TA(10),       JCOL(30,2),   JROW(20,2),
  2              NOBJ,         NPRI,         NVAR,         NCOL,
  3              NROW,         INSW
   IF (IPRI .LT. 1 .OR. IPRI .GT. NPRI) GO TO 2
   IF (ISUB .EQ. 0 .OR. IABS(ISUB) .GT. NOBJ) GO TO 2
   IF (ISUB .GT. 0) GO TO 1
      ISUB = -ISUB
   IF (TL(ISUB,IPRI) .NE. 0) GO TO 3
   TL(ISUB,IPRI) = WHTF
   RETURN
 1    ICOL = ISUB + NVAR
   IF (TT(IPRI,ICOL) .NE. 0) GO TO 3
   TT(IPRI,ICOL) = WHTF
   RETURN
 2 WRITE (6,4)
   GO TO 6
 3 WRITE (6,5)
 4 FORMAT (//,'**SUBSCRIPT OUT-OF-RANGE WHILE READING SUBSCRIPTS**')
 5 FORMAT (//,'**OVERWRITE ATTEMPTED IN A STUB**')
 6 STOP
   END
   SUBROUTINE CINDX (ISW)
   COMMON       TL(20,10),    TT(10,30),    TE(20,30),    TI(10,30),
  1             TB(20),       TA(10),       JCOL(30,2),   JROW(20,2),
  2             NOBJ,         NPRI,         NVAR,         NCOL,
  3             NROW,         INSW
    I = 1
   IF (ISW .NE. 1) I = NROW
   DO 3 NP = I,NROW
```

```
      TA(NP) = 0
      DO 1 NO = 1,NOBJ
    1 TA(NP) = TA(NP) + TB(NO) * TL(NO,NP)
      DO 2 NC = 1,NCOL
      TI(NP,NC) = -TT(NP,NC)
      DO 2 NO = 1,NOBJ
      TI(NP,NC) = TI(NP,NC) + TE(NO,NC) * TL(NO,NP)
    2 CONTINUE
    3 CONTINUE
      RETURN
      END
      SUBROUTINE TEST (NEVC,NDVR)
      COMMON        TL(20,10),   TT(10,30),   TE(20,30),   TI(10,30),
     1              TB(20),      TA(10),      JCOL(30,2),  JROW(20,2),
     2              NOBJ,        NPRI,        NVAR,        NCOL,
     3              NROW,        INSW
         NEVC = 0
      IF (TA(NROW) .LE. 0) RETURN
         VEVC = 0
        NRMW = NROW - 1
      DO 3 NC = 1,NCOL
      IF (TI(NROW,NC) .LE. 0) GO TO 3
      IF (NROW .EQ. 1) GO TO 2
      DO 1 N = 1,NRMW
      IF (TI(N,NC) .LT. 0) GO TO 3
    1 CONTINUE
    2 IF (TI(NROW,NC) .LE. VEVC) GO TO 3
         NEVC = NC
         VEVC = TI(NROW,NC)
    3 CONTINUE
      IF (NEVC .EQ. 0) RETURN
         NDVR = 0
      DO 7 NR = 1,NOBJ
      IF (TE(NR,NEVC) .LE. 0) GO TO 7
            V = TB(NR)/TE(NR,NEVC)
      IF (NDVR .EQ. 0) GO TO 6
      IF (V-VDVR)6,4,7
    4 DO 5 NP = 1,NPRI
      IF (TL(NR,NP) - TL(NDVR,NP)) 7,5,6
    5 CONTINUE
    6    VDVR = V
         NDVR = NR
    7 CONTINUE
      IF (NDVR .GE. 1) RETURN
      WRITE (6,8)
    8 FORMAT (//,'**PROGRAM TERMINATED-FAILED PIVOT-COMPUTATION**')
      STOP
      END
      SUBROUTINE PERM (NEVC,NDVR)
      COMMON        TL(20,10),   TT(10,30),   TE(20,30),   TI(10,30),
     1              TB(20),      TA(10),      JCOL(30,2),  JROW(20,2),
     2              NOBJ,        NPRI,        NVAR,        NCOL,
     3              NROW,        INSW
      DO 1  I = 1,2
            J = JCOL(NEVC,I)
      JCOL(NEVC,I) = JROW(NDVR,I)
    1 JROW(NDVR,I) = J
      DO 2 NP = 1,NPRI
         TEMP = TL(NDVR,NP)
      TL (NDVR,NP) = TT(NP,NEVC)
    2 TT(NP,NEVC) = TEMP
          PIV = TE(NDVR,NEVC)
          PIB = TB(NDVR)
      DO 31 NO = 1,NOBJ
      IF (NO .EQ. NDVR) GO TO 31
          PIX = TE(NO,NEVC)/PIV
```

```
      TB(NO) = FIX(TB(NO) - PIX * PIB)
    6 DO 3 NC = 1,NCOL
      IF (NC .EQ. NEVC) GO TO 3
      TE(NO,NC) = FIX(TE(NO,NC) - TE(NDVR,NC) * PIX)
    3 CONTINUE
   31 CONTINUE
      DO 4 NC = 1,NCOL
    4 TE(NDVR,NC) = FIX(TE(NDVR,NC)/PIV)
      DO 5 NO = 1,NOBJ
    5 TE(NO,NEVC) = FIX(-TE(NO,NEVC)/PIV)
      TB(NDVR) = FIX(TB(NDVR)/PIV)
      TE(NDVR,NEVC) = FIX(1/PIV)
      CALL CINDX(1)
      RETURN
      END
      FUNCTION FIX (Z)
            X = 1
      DO 1 N = 1,3
      IF (N .NE. 1) X = 10 * X
            F = X * Z
            I = F
            J = I - 2
      DO 1 K = 1,3
            G = J + K
      IF (ABS(F-G) - .005) 2,2,1
    1 CONTINUE
          FIX = Z
      RETURN
    2     FIX = G/X
      RETURN
      END
      SUBROUTINE FCPL (ISW)
      COMMON        TL(20,10),   TT(10,30),   TE(20,30),   TI(10,30),
     1              TB(20),      TA(10),      JCOL(30,2),  JROW(20,2),
     2              NOBJ,        NPRI,        NVAR,        NCOL,
     3              NROW,        INSW
      IF (NOBJ .EQ. 20) GO TO 10
      CALL INTST (NSW)
      IF (NSW .EQ. 0) GO TO 11
          ISW = 1
        NOBJ = NOBJ + 1
      DO 4 NC = 1,NCOL
            X = TE(NSW,NC)
            I = X
            Y = I
      IF (FIX(X-Y)) 1,2,3
    1 TE(NOBJ,NC) = 1. + X-Y
      GO TO 4
    2 TE(NOBJ,NC) = 0
      GO TO 4
    3 TE(NOBJ,NC) = X-Y
    4 CONTINUE
            X = TB(NSW)
          I = X
            Y = I
      IF (FIX(X-Y)) 5,12,6
    5 TB(NOBJ) = 1. + X-Y
      GO TO 7
    6 TB(NOBJ) = X-Y
    7    NCOL = NCOL + 1
      DO 8 NO = 1,NOBJ
    8 TE(NO,NCOL) = 0
      TE(NOBJ,NCOL) = -1
      DO 9 NP = 1,NPRI
      TT(NP,NCOL) = 0
    9 TL(NOBJ,NP) = 0
```

```
   TL(NOBJ,1)  = 1
   JROW(NOBJ,1) = 4
   JROW(NOBJ,2) = NOBJ
   JCOL(NCOL,1) = 3
   JCOL(NCOL,2) = NOBJ
   GO TO 14
10 WRITE (6,15)
   GO TO 13
11 WRITE (6,16)
   GO TO 13
12    NOBJ = NOBJ - 1
   WRITE (6,17)
13 WRITE (6,18)
        N = 0
   CALL POUT(N,N)
       ISW = 0
14 RETURN
15 FORMAT (/,'  FCPL FAILURE - DIMENSION EXCEEDED ')
16 FORMAT (/,'  FCPL FAILURE - ILLEGAL PATH')
17 FORMAT (/,'  FCPL FAILURE - ABNORMAL VALUE')
18 FORMAT (/,'  VALUES AT THE TIME OF FAILURE FOLLOW')
   END
   SUBROUTINE ALTST (NPRT, NCPL)
   COMMON         TL(20,10),    TT(10,30),    TE(20,30),    TI(10,30),
  1               TB(20),       TA(10),       JCOL(30,2),   JROW(20,2),
  2               NOBJ,         NPRI,         NVAR,         NCOL,
  3               NROW,         INSW
   DO 4 NC = 1,NCOL
   DO 1 NP = 1,NPRI
   IF (TI(NP,NC) .NE. 0) GO TO 4
 1 CONTINUE
   DO 3 NO = 1,NOBJ
   IF(TE(NO,NC) .LE. 0) GO TO 3
   IF (TB(NO) .LE. 0) GO TO 3
 2 CALL PERM (NC,NO)
   DO 5 NB = 1,NOBJ
   IF (TB(NB) .LT. 0) GO TO 6
 5 CONTINUE
   CALL INTST (NSW)
   IF(NSW .EQ. 0) CALL POUT (NPRT,NCPL)
 6 CALL PERM (NC,NO)
 3 CONTINUE
 4 CONTINUE
   RETURN
   END
   SUBROUTINE POUT (NPRT,NCPL)
   COMMON         TL(20,10),    TT(10,30),    TE(20,30),    TI(10,30),
  1               TB(20),       TA(10),       JCOL(30,2),   JROW(20,2),
  2               NOBJ,         NPRI,         NVAR,         NCOL,
  3               NROW,         INSW
   DIMENSION      WOUT(20,4)
      NPRT = NPRT + 1
   IF (NPRT .NE. 1) WRITE (6,31) NPRT
   IF (NCPL .NE. 0 .AND. NPRT .EQ. 1) WRITE (6,32) NCPL
11 DO 12 I = 1,20
   DO 12 J = 1,4
12 WOUT(I,J) = 0
   DO 13 NP = 1,NPRI
13 WOUT(NP,1) = FIX(TA(NP))
   DO 14 NO = 1,NOBJ
        IC = JROW(NO,1)
        IR = JROW(NO,2)
14 WOUT(IR,IC) = FIX (TB(NO))
   WRITE (6,33) NPRI, NVAR, NOBJ, NOBJ
         I = MAX0(NPRI,NVAR,NOBJ)
   DO 20 K = 1,I
```

```
      IF (K .GT. NPRI) GO TO 16
      IF (K .GT. NVAR) GO TO 15
      WRITE (6,34) K,  (WOUT(K,J), J=1,4)
      GO TO 20
   15 WRITE (6,35) K, WOUT(K,1), (WOUT(K,J) ,J=3,4)
      GO TO 20
   16 IF (K .GT. NVAR) GO TO 17
      WRITE (6,36) K, (WOUT(K,J) ,J=2,4)
      GO TO 20
   17 WRITE (6,37) K, (WOUT(K,J) ,J=3,4)
   20 CONTINUE
   31 FORMAT (/,'  ALTERNATE SOLUTION NUMBER ',I3)
   32 FORMAT (/,'  NUMBER OF CUTTING PLANES USED = ',I3)
   33 FORMAT (/,'  SUBSCRIPT',I6,' TERMS ASTAR',I6,
     1          ' TERMS XSTAR',I6,' TERMS PSTAR',I6,' TERMS NSTAR'/)
   34 FORMAT (I6,4F18.4)
   35 FORMAT (I6,F18.4,18X,2F18.4)
   36 FORMAT (I6,18X,3F18.4)
   37 FORMAT (I6,36X,2F18.4)
      RETURN
      END
      SUBROUTINE INTST (NSW)
      COMMON        TL(20,10),   TT(10,30),   TE(20,30),   TI(10,30),
     1              TB(20),      TA(10),      JCOL(30,2),  JROW(20,2),
     2              NOBJ,        NPRI,        NVAR,        NCOL,
     3              NROW,        INSW
         NSW = 0
      IF (INSW .EQ. 0) RETURN
      DO 2 NO = 1,NOBJ
      IF (JROW(NO,1) .NE. 2) GO TO 2
           I = TE(NO)
           J = I - 2
      DO 1 K = 1,3
           G = J + K
      IF(ABS(TB(NO)   -G)-.0001) 2,2,1
    1 CONTINUE
      GO TO 3
    2 CONTINUE
       RETURN
    3    NSW = NO
      RETURN
      END
```

APPENDIX (C-2) PROCEDURE FOR INPUT DATA

PROCEDURE FOR DATA INPUT (OPTIMALITY ASSESSMENT MODULE)

LINES (CARDS) VARIABLES USED & LOCATIONS

(ALL VARIABLES IN FREE FORMATS)

1 NOBJ NPRI NTAF INSW

2 C(I,J)...COEFFICIENTS OF THE JTH DECISION VARIABLE IN THE ITH OBJECTIVE

.

. ( NOT MORE THAN 8 VARIABLES IN A ROW )

a (th) card or line

a+1 B(I) ... RIGHT-HAND SIDE VALUE FOR EACH OBJECTIVE (GOALS)

.

.

b

b+1 IPRI ... PRIORITY-LEVEL FOR ASSOCIATED DEVIATION VARIABLE

.

.

c+1 ISUB + OR - TIMES THE SUBSCRIPT OF THE ASSOCIATED DEVIATION

.

d

d+1 WHTF ... WEIGHTING FACTOR FOR THE ASSOCIATED DEVIATION VARIABLE

```
*       NOBJ    TOTAL NUMBER OF OBJECTIVES
*       NPRI    NUMBER OF PRIORITIES
*       NVAR    NUMBER OF DECISION VARIABLE
*       NTAF    NUMBER OF TERMS IN ACHIEVEMENT FUNCTION
*       ISW     ONE, IF PURE INTEGER SOLUTION DESIRABLE
*                ZERO, IF NORMAL LINEAR GOAL PROGRAMMING
DESIRABLE.
```

## EXAMPLE FOR DEMONSTRATING THE INPUT DATA PROCESS

MINIMIZE: ZZ= { 2 D1 + 3D2, D3, D4}

BUD1 + BUD2 -D1 =10

BUD1 -D2 = 4

5 BUD1 + 3 BUD2 + D3 = 56

BUD1 + BUD2 + D4 = 12

The following data can be provided and located according to the previous instruction in free format.

LINES (CARDS)

| | | | | | |
|---|---|---|---|---|---|
| (1) | 4 | 3 | 2 | 4 | 0. |
| (2) | 1 | 5 | 3 | 1 | 1 |
| (3) | 10 | 4 | 56 | 12 | |
| (4) | 1 | +1 | 2 | | |
| (5) | 1 | +2 | 3 | | |
| (6) | 2 | -3 | 1 | | |
| (7) | 3 | -4 | 1 | | |