

**A COMPARATIVE STUDY**  
**OF DIFFERENT EVALUATION TECHNIQUES**  
**FOR APPRAISING ALTERNATIVE TRANSPORTATION PLANS**

A Thesis presented to the

DEPARTMENT OF CIVIL ENGINEERING  
UNIVERSITY OF CAPE TOWN

In partial fulfilment of the requirements  
for the degree of Master of Science in Engineering.

by

R. A. CROOK

1981

The University of Cape Town has been given  
the right to reproduce this thesis in whole  
or in part. Copyright is held by the author.

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

## SYNOPSIS

This thesis studies the evaluation element of the general transportation planning process from a broad systems perspective. Evaluation linkages are identified with the other activities of the planning process which, if not recognised and accounted for, can unnecessarily restrict the efficiency of plan evaluation thereby reducing the effectiveness of the evaluation element as an aid to decision making.

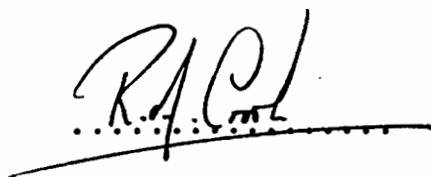
The nature and scope of the evaluation element is examined in some detail. Certain key aspects are discussed; the value framework that is used to assess plan performance, the principles of measurement used therein, and some procedural steps are put forward to guide the selection of appropriate criteria to indicate plan performance.

The latter part of the thesis is devoted to comparing the capabilities and limitations of six different evaluation techniques, namely; cost benefit analysis, cost-effectiveness technique, ranking and rating matrices, utility analysis and goals-achievement matrix.

As a conclusion to the thesis, it is felt that due to the divergent nature of transportation planning each of the foregoing methods without exception, has its relative strengths and weaknesses. The aspects of robustness and weakness of each methodology are shown to be a reflection of certain fundamental paradoxical requirements that run through the whole planning process. It is these conflicting requirements that consequently neutralise any one method from being totally effective. Consequently, for an evaluation to be comprehensive, complex transportation problems should be evaluated in two stages. The primary evaluation should be undertaken with the "most appropriate" methodology followed with a supplementary evaluation augmenting any deficiency in the initial evaluation.

Declaration of Candidate

I, Roger Alan Crook, hereby declare that this thesis is my own work and that it has not been submitted for a degree at another University.

A handwritten signature in black ink, appearing to read 'RAC', is written over a horizontal dotted line. The signature is stylized and cursive.

April 1981

## ACKNOWLEDGEMENTS

I would like to acknowledge the kind assistance of my thesis supervisor, Mr. O.H. Müller of the University of Cape Town and the encouragement of the partners of Hawkins, Hawkins and Osborn, particularly Messers. Louis de Waal and Gerry van Alphen.

Especial thanks to Betsie Burger for deciphering my writing and typing the original draft and to Wendy Thompson for the trouble she has taken in typing the final document. Thanks too, to Marion Smit for drawing most of the Tables and Figures. In addition, thanks is due also to my colleagues; Mike Workman for the getting the word processor package operational, Malcolm Thomson for proof-reading the script and Keith Minter for printing the thesis.

Finally, I am grateful to my wife, Reville, for her patience, support and encouragement during the preparation of this study.



5. ALTERNATIVE METHODS FOR PLAN APPRAISAL	
5.1 Review Criteria .. .. .	5-1
5.2 Classification of Methodologies .. .. .	5-2
5.3 Cost-Benefit Appraisal .. .. .	5-3
5.4 Cost-Effectiveness Technique .. .. .	5-16
5.5 Ranking and Rating Matrices .. .. .	5-30
5.6 Utility Method of Appraisal .. .. .	5-36
5.7 Goals Achievement Matrix .. .. .	5-44
5.8 Supplementary Evaluation Procedures . . . . .	5-54
References for Chapter 5 .. .. .	5-59

6. SUMMARY AND CONCLUSIONS	
6.1 A Synoptic Assessment .. .. .	6-1
6.2 Some Paradoxes of Evaluation .. .. .	6-5
6.3 Some Final Thoughts .. .. .	6-12
References for Chapter 6 .. .. .	6-13

#### APPENDIX A

7. COST-BENEFIT APPROACH TO DETERMINING HIGHWAY COSTS AND BENEFITS	
7.1 Introduction .. .. .	7-1
7.2 Highway Costs .. .. .	7-1
7.3 Road User Benefits .. .. .	7-2
7.4 Closure .. .. .	7-9
References for Chapter 7 .. .. .	7-10

#### APPENDIX B

8. DETAILS OF POST-GRADUATE COURSES COMPLETED . . . . .	8-1
---	-----



## LIST OF TABLES

TABLE 4-1	Typical Schemes versus Measurement Criteria .. .. .	4-14
TABLE 4-2	Ordinal Ranking Array .. .. .	4-15
TABLE 4-3	Cardinal Ranking or Rating Array .. .. .	4-16
TABLE 4-4	Normalised Array . . . . .	4-17
TABLE 4-5	Relative Rating Array .. .. .	4-18
TABLE 4-6	Utility Value Array . . . . .	4-20
TABLE 5-1	Typical Categorisation of Costs and Benefits .. .. .	5-8
TABLE 5-2	Summary of Consequences of Alternative Plans .. .. .	5-21
TABLE 5-3	Rank-based Expected Value Method .. .. .	5-31
TABLE 5-4	Example of Alternative Schemes v Criteria	5-32
TABLE 5-5	Relative Rating Matrix . . . . .	5-33
TABLE 5-6	Utility Matrix .. .. .	5-40
TABLE 5-7	The Goals Achievement Matrix . . . . .	5-46
TABLE 5-8	Excerpt from Newark Planning Balance Sheet . . . . .	5-49
TABLE 5-9	Marginal Analysis .. .. .	5-55
TABLE 6-1	A Relative Appraisal of the Different Evaluation Methodologies .. .. .	6-3
TABLE 6-2	A Summary of the Principle Characteristics of the Six Evaluation Techniques .. .. .	6-4

## 1. INTRODUCTION.

---

### 1.1. Objectives Of The Thesis.

One of the interesting characteristics of transportation planning is that there are usually many different ways of achieving the same goal. Therefore, an important activity in the transportation planning process is the evaluation of alternative plans to determine the "best" plan. To aid the selection and choice process several different evaluation techniques have been specifically developed to appraise alternative plans.

Thus, the main objectives of this thesis are firstly; to examine how the evaluation activity is related to the overall planning process and secondly; to appraise some of the different evaluation methodologies that are currently used to evaluate transportation alternatives.

It is hoped that the achievement of the above objectives will be of practical benefit to my work situation - since a major portion of my work involves the design and evaluation of alternative transportation plans.

### 1.2. Format Of The Thesis.

Although this thesis is concerned with the evaluation of alternative "transportation" plans much of it's content is related to "highway" evaluation aspects. The highway emphasis results from two factors. Most of the evaluation methodologies reviewed in this study were developed initially for evaluating alternative highway plans. In addition the experience of the author is more related to highway planning than the broader transportation planning field. Nevertheless, it is believed that the general principles of evaluation put forward in this thesis are relevant for both highway and the broader transportation planning scene.

The scope and content of the study can be gauged from the following brief outline.

Chapter 1 - sets out the objectives of the study and highlights some of the fundamental aspects of the transportation planning and evaluation process.

Chapter 2 - puts forward the strategy of systems analysis as a suitable conceptual framework to guide and structure the research for this thesis. The basic concepts of problem solving are described.

Chapter 3 - examines the evaluation aspects of the general planning process. How the evaluation element relates to the planning system as a whole and in turn, how it relates to the other individual planning process elements. Several evaluation linkages with other planning elements are identified.

Chapter 4 - endeavours to identify certain fundamental principles upon which the specific evaluation process is founded. The scope of the evaluation process and the principles of measurement used therein are examined.

Chapter 5 - from the preceeding chapters a broad framework is developed within which the different evaluation techniques can be comparatively assessed. Six evaluation methodologies are examined namely; cost benefit analysis, cost-effectiveness technique, ranking and rating matrices, utility matrices and goal-achievement matrix. The main characteristics of each methodology are described and their relative strengths and weaknesses are identified.

Chapter 6 - summarises the performance of the six evaluation methodologies against the review criteria established early in Chapter 5. In addition several fundamental and paradoxial requirements are identified that condition the effectiveness of the evaluation activity in the general planning process.

Appendix A - outlines the cost-benefit approach to determining highway costs and benefits.

It will be seen from the study outline that the thesis has a broad focus, in an attempt to pull together the many diverse factors that are considered relevant to the evaluation activity. However, the broad scope presents a dilemma with respect to the depth of analysis that can be presented and it is hoped that a reasonable balance has been achieved.

### 1.3. Fundamental Transportation Problems.

In evaluating transportation planning problems it is important to recognise that there are two fundamental categories of problems, convergent and divergent problems. (Schumacher, 1977). A convergent problem is one in which alternative solutions are posed and intelligently analysed until a design gradually emerges that is simply "the answer". The solutions to convergent problems are generally fairly stable with time, because they obey certain engineering laws or relationships. Some examples of convergent problems in transportation planning would be: the capacity performance relationships of highway and rail facilities, the engineering design of the physical transport facilities etc.

Conversely, divergent problems when studied (by different analysts, also intelligently) produce "answers" that contradict one another. The more money that is thrown at the problem, in the form of research grants, the more the answers tend to diverge. In Chapter 3 it will be shown that some of the fundamental values used to measure the worth of alternative plans, are pairs of opposites. For example, most transportation strategies have objectives to provide adequate highway facilities for the increasing number of car-users and at the same time to provide subsidies for public transport in order to ensure there is an "equitable balance of transport". Two opposing aims competing for a share of the same financial resource: hence a divergent problem.

Thus transportation planning in its broadest sense often

requires the engineer or planner to analyse and evaluate proposals against mutually opposing activities or aims. As Schumacher (1977a) comments; divergent problems offend the logical mind which wishes to remove tension by coming down on one side of the issue or the other. In a divergent problem this temptation must be understood and resisted. In addition, a careful distinction must be made between the divergent overall problem and the convergent sub-problems within the whole.

Perhaps, not surprisingly, the evaluation process is different for these two categories of problems and two kinds of decision rules are appropriate to determine the preferred alternative (Solesbury, 1974). In convergent problems an optimising rule is used to choose the best alternative. In this approach an overall criterion function is developed against which all alternatives can be measured. In divergent problems a satisficing rule is more appropriate. Satisficing seeks to identify an alternative that is satisfactory on the grounds that it achieves an acceptable attainment level of maybe several diverse goals. Thus, in the satisficing approach only good solutions to transportation problems are sought and not optimal ones.

In Chapter 5 it will be seen that the different evaluation methodologies use different decision rules, which suggests that certain methodologies may be more appropriate for the different categories of problems.

#### 1.4. The Nature Of Transportation Planning.

Transportation planning in its fullest sense is a creative process. An engineer when planning and evaluating designs uses two distinct mental activities, sometimes separately, sometimes simultaneously, namely analysis and synthesis. (Dickerson and Robertshaw, 1975).

- \* Analysis is the breaking down of a problem into its component parts and understanding the relationships connecting the parts. De Bono (1971) characterises this type of thinking as sequential vertical thinking (or convergent thinking).
- \* Synthesis is the creating of a structure or framework from its component parts. Synthesis is associated with conceptual approaches to problems, the arrangement of information and perceptual choices. De Bono characterises this type of thinking as lateral thinking (or divergent thinking).

Most formal engineering education is orientated towards convergent problem analysis. The student is encouraged to search for specific answers to problem situations, for in analysis the answers are often unique, or at least fall into well defined classes. Conflicting data is usually not present in a single answer problem (if it is, it is ignored) and the unique answer is obtained by a series of rational and logical procedures. Conversely, in transportation planning practice, many engineering problems have a multiplicity of solutions and therefore tend to be synthesis orientated. Alternative

plans are put together in different ways until a creative and acceptable solution is found. Thus the planning process uses conflicting techniques of breaking down (analysis) and the building up (synthesis) in the search for the "best" solution.

Therefore, planning in general and transportation planning in particular, can be viewed as both an art and as a science (Edwards and Beimborn, 1978). Planners who come from the architectural or urban planning backgrounds tend to emphasise the art aspect, ie the planner's creativity and his ability to synthesis and integrate diverse sources of information. Planners of this sort tend to be skeptical of the technical and analysis type of approach to planning and rely more on intuitive judgement than on formalised methods.

Conversely, planners who come from an engineering background favour analytical methods to evaluate the socio-technical data. They tend to use a more quantitative formalised approach to planning, which often includes the use of advanced mathematical-computer modeling techniques to evaluate the alternative plans. This fundamental paradox of planning, being emphasised as an art on the one side and on other side as a science, reflects through the whole planning process.

Another "fundamental" concerning the nature of planning is that analysis and synthesis have an iterative structure. The nature of planning is shown conceptually below in Figure 1-1.

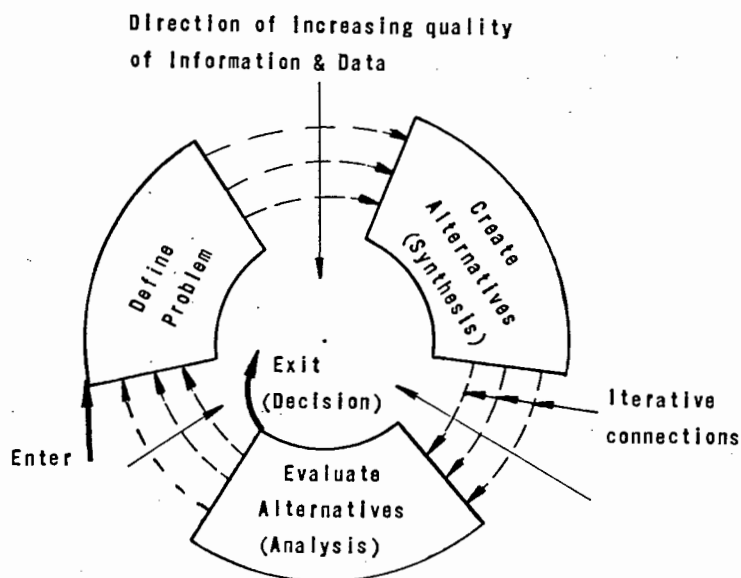


FIGURE 1-1 : THE NATURE OF PLANNING.

The purpose of iteration is to improve the quality information put forward to the decision-maker. This statement implicitly assumes that the better of the quality of

information the better the decision. Obviously any evaluation methodology endeavours to present only the highest quality of information so that an informed decision can be made. Nevertheless it is important to realise that there is a point of diminishing returns where continual reiteration to increase the quality of information has little effect on the quality of the evaluation and thus ultimately the decision. (See Figure 1-2).

Thus in the high information situation of transportation planning and evaluation, it is important that a balance is kept between the quality of the information and its value to the evaluation methodology.

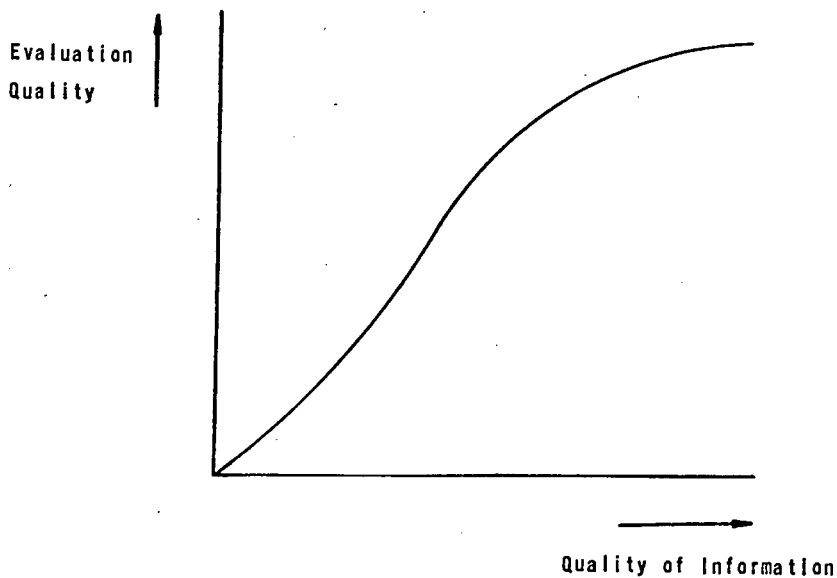


FIGURE 1-2 : QUALITY OF EVALUATION AS A FUNCTION  
OF QUALITY OF INFORMATION.  
(Source : Emery, 1974, p. 396.)

## REFERENCES FOR CHAPTER 1

DE BONO, E. (1971) "Lateral Thinking for Management". McGraw-Hill, pp. 4-13.

DICKERSON, S.L. and ROBERTSHAW, J.E. (1975) "Planning and Design the Systems Approach". Lexington Books. pp. 77-78.

EDWARDS, J.L. and BEIMBORN, E.A. (1978) "Future Relationship between Long and Short Range Urban Transportation Planning". Traffic Quarterly. October 1978. Volume 32.

EMERY, J. (1974) "Cost-benefit Analysis of Information Systems". Systems Analysis Techniques. Editors Cougar, J.D. and Knapp, R.W. Wiley. pp. 395-424.

SCHUMACHER, E.F. (1977) "A Guide for the Perplexed". Sphere Books Ltd., pp. 139-148.

SCHUMACHER, E.F. (1977a) Ibid., p. 147.

SOLESBURY, W. (1974) "Policy in Urban Planning". Pergamon Press, Oxford, pp. 151-152.

## CHAPTER 2 RESEARCH APPROACH

2.1 INTRODUCTION .. .. .	2-1
2.2 NEED FOR SYSTEMS ANALYSIS .. .. .	2-1
2.3 THE SYSTEMS ANALYSIS PROCESS .. .. .	2-2
2.3.1 The System .. .. .	2-3
2.3.2 The Environment .. .. .	2-3
2.3.3 System Consequences .. .. .	2-4
2.4 SYSTEM MODEL-BUILDING .. .. .	2-5
2.4.1 Why Model The System .. .. .	2-5
2.4.2 The Classification of Models .. .. .	2-5
2.4.3 Characteristics of a Model .. .. .	2-7
2.5 ANALYSIS AND EVALUATION .. .. .	2-7
2.6 SYNTHESIZING OF ALTERNATIVES .. .. .	2-8
2.6.1 Some Principles of Creative Thinking .. .. .	2-9
2.6.2 Aids to the Synthesis of Alternatives .. .. .	2-9
2.7 SYSTEMS ANALYSIS AS A FRAMEWORK FOR ANALYSIS AND SYTHESIS .. .. .	2-10
REFERENCES FOR CHAPTER 2 .. .. .	2-12

## 2. RESEARCH APPROACH.

---

### 2.1. Introduction.

The transportation planning process is an adaptive process, changing and evolving to the current demands of society. In recent years the techniques used in highway/transportation planning have become more wide ranging and comprehensive in an attempt to measure more and more factors that now appear to be relevant. Thus the simplified model of the planning process, "survey, analysis and plan" is no longer satisfactory.

To accommodate the new breadth of issues now associated with planning transportation systems, a more comprehensive methodology or framework must be incorporated into the planning process. Many eminent transportation engineers (Manheim, 1967 & 1969; Hutchinson, 1974; Stopher and Meyburg, 1976) suggest that such a methodology is systems analysis. In fact, to put it more strongly, it can be considered that the planning process is being restructured and engineering systems analysis embodies the essence of the change.

Therefore, it is thought appropriate that a general description of systems analysis be undertaken. It is hoped that this overview will fulfill two objectives:

- \* A general understanding of system analysis will provide a useful general strategy for analysing evaluation problems.
- \* To provide a guiding framework within which this thesis will be prepared.

### 2.2. Need For Systems Analysis.

One of the fundamental characteristics of systems analysis is that it can be applied to any problem that is susceptible to solution by a series of decisions. Since planning is characterised by a series of decisions, the systems approach has been found to be a useful methodology around which to structure a framework for investigating complex transportation planning problems.

Systems analysis does not lend itself to brief one sentence definitions. It has its roots based in the fields of operations research and general system theories. Ackoff (1974) describes the systems approach to problems as a process that focuses on systems taken as a whole, not on their parts taken separately. Such an approach is concerned with total performance even when a change in only one or a few of its parts is contemplated, because there are some properties of systems that can only be treated adequately from a holistic point of view. Aristotle's statement, "the

whole is more than the sum of its parts" perhaps captures the spirit of intent of systems analysis.

### 2.3. The Systems Analysis Process.

Thomas and Schofer (1970) suggest that the essential property of system analysis is that it provides a conceptual framework within which an analyst is assisted to think more broadly and comprehensively about his problems. This broad process is shown diagrammatically in Figure 2-1 below.

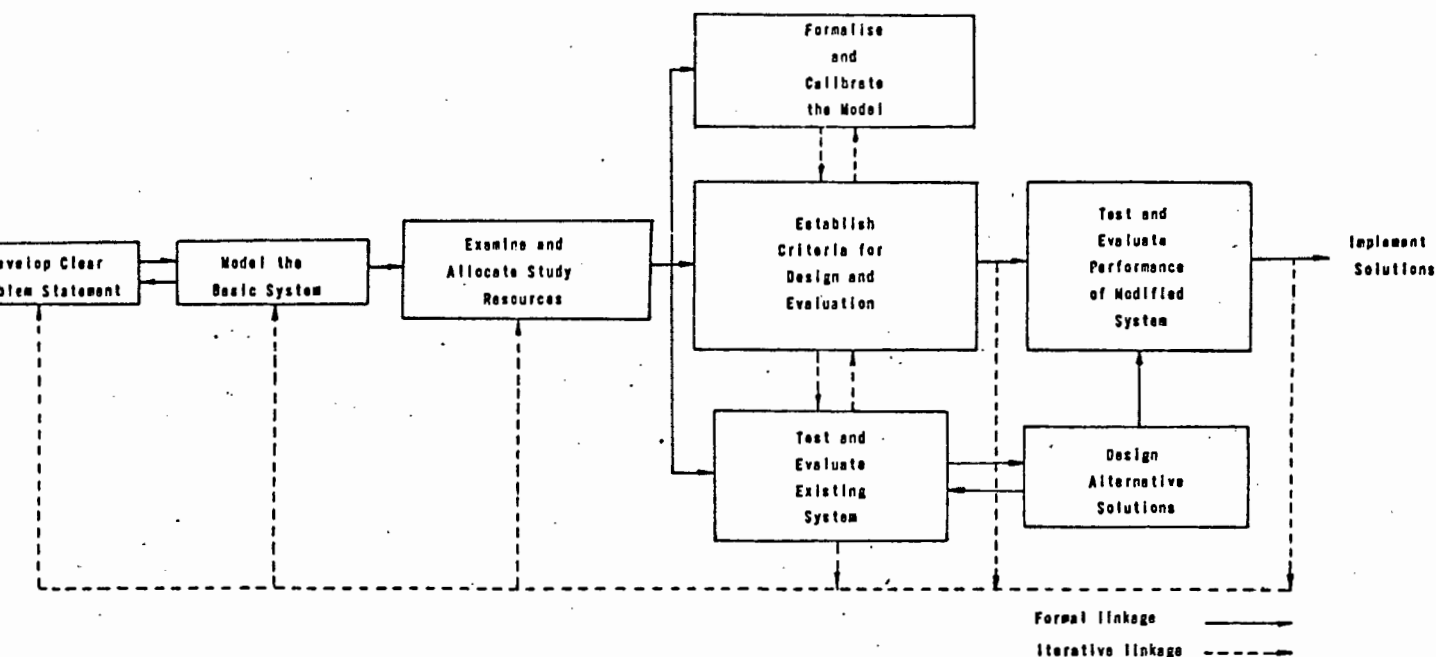


FIGURE 2-1  
A MODEL OF THE SYSTEMS ANALYSIS PROCESS  
(Source : Thomas and Schofer, 1970, p. 7)

It will be seen from Figure 2-1 that the initial emphasis focuses on developing a clear understanding of the problem. The importance of this initial step can hardly be overemphasised, for all subsequent activities will be guided by the analysts understanding and definition of the problem. Wortman (1976) states that in dealing with complex problems, such as those associated with transportation planning, there is a natural tendency to immediately pose alternative solutions without first establishing the exact nature and scope of the problem. In addition, there is the danger of confusing and not distinguishing between the symptoms and the root causes of a problem.

In developing a comprehensive view of the problem the analyst will determine:

- \* The purpose and function of the system.
- \* The components or elements of the system.
- \* The interaction that occurs among the different elements within the system.
- \* The system effects or consequences on the outside environment.

### 2.3.1. The System.

Ackoff (1974a) defines a system as a set of interrelated elements, meaningfully connected and satisfactorily bounded, which interact for a common purpose or function.

Expanding on this definition it may be said that the connections within the system shape the structure of the system, they may be time dependent or space dependent or both. Further, if a system is to be studied effectively, some boundaries must be established. The experience of the analyst together with the goals and objectives of the study are used to establish the boundaries.

As Thomas and Schofer (1970a) point out, there is a danger for the inexperienced analyst to try to connect every possible interaction; for in a sense all systems are sub-systems within larger systems. For instance, a transportation system can be part of a national, regional or local system. Thus the hierarchy of systems can often be extended into higher-order or lower-order systems. However, in practice the level of analysis will be constrained by either some resource and/or lack of knowledge type of constraint or boundary.

Dickerson and Robertshaw (1975) have categorised some axioms of systems:

- \* A system is identified by its function.
- \* Any system is a sub-system of a broader system.
- \* An element may function as part of more than one system, that is, it may serve many functions.

### 2.3.2. The Environment.

Thomas and Schofer (1970b) define the environment of a system as the collection of elements or activities outside the system under study, that affects and/or is affected by that system. Thus the system and its environment form a complementary set, the two parts being inter-related within a conceptual boundary.

Some examples of things that are frequently part of the transportation environment are; land-use patterns,

physiographic factors, climate, limited physical resources, policies, etc. If the engineer decides (or tries) to control any of these, they become part of the system. Conversely, anything which can affect the system but which cannot be controlled by the planner is part of the environment of the system. Thus the "total system" refers to the system under study plus its environment. This is shown schematically below in Figure 2-2.

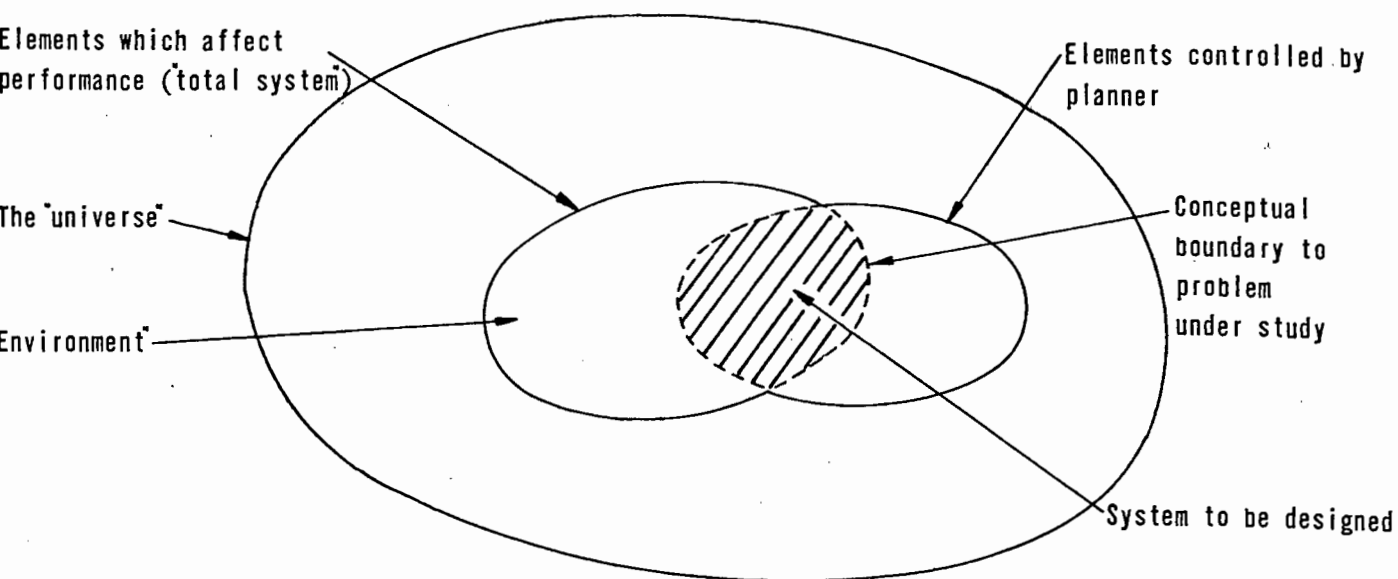


FIGURE 2-2 : A SCHEMATIC REPRESENTATION OF SYSTEM AND ITS ENVIRONMENT.  
(Source : Dickerson and Robertshaw - p. 21).

Thus in terms of the environment a system may be classified into two groups, (Carter and Homburger, 1978).

- \* An open system : one in which a change in the environment produces a change in the system and vice versa. Most traffic engineering systems are of this category.
- \* A closed system : one in which the environment does not have any influence on the system.

### 2.3.3. System Consequences.

Thomas and Schofer (1970c) define the interface between the system and the environment as the area where all the interaction between the two takes place. This interaction may take the form of inputs entering and outputs leaving the system. The effects of the inputs and outputs of a system on its environment are called the system consequences.

Particularly relevant to highway planning, is the connotation that consequences must be associated with time and place characteristics. For example, the construction of a new highway may be the output of the transportation planning process, however increased residential housing and commercial activities alongside its corridor may be the concomitant consequences.

Thus it may be summarised:

- \* Environmental impacts (consequences) result from the presence and operation of systems.
- \* Consequences are associated with temporal and spatial characteristics.

#### 2.4. System Model-building.

Formal modeling is basic to the systems approach to planning and design. The formulation and selection of the appropriate model is one of the key steps in the evaluation of alternatives. Therefore, it is appropriate that some general comments on the modeling process be made.

##### 2.4.1. Why Model The System.

In systems analysis the development of a model is undertaken very near the beginning of the study. The primary purpose of developing a model is so that the analyst may develop a better understanding of the system and its structure. To develop a model the analyst must establish system boundaries, define the environment, determine system elements - their function and relationship within the model. Models allow the analyst to lay out concisely his knowledge of the relevant aspects of the system under study. It also serves to show where the analyst's knowledge is weak and where he has ignored important components or interactions. This is one way in which systems analysis tends to reduce the narrowness discussed earlier.

Modeling a system also provides the analyst with the opportunity to manipulate some of the values of the input variables and to observe the effects on the output variables. Thus, by carrying out a sensitivity analysis, the analyst can determine which are the important or sensitive elements of the system. Conversely, the analysis may show that some elements have little effect on the output variables and in such cases the model can be simplified by their removal.

##### 2.4.2. The Classification Of Models.

Generally, models used in transportation planning are simplified representations of reality. For in the systems analysis approach, a model can be defined as a representation

of a real world system which is used to predict the performance of a system.

There are three fundamental types of models:

- \* Mathematical
- \* Physical
- \* Conceptual

Mathematical or algebraic models are the most familiar types of models. Only the simplest and best understood systems can be completely described by mathematical models. Unfortunately in transportation systems, the linkages of the different elements cannot be completely quantified and it is necessary to seek a means of modeling other than by algebraic specification.

Sometimes physical models in the form of scale drawings or models are more useful for systems studies. However, not all elements, activities and relationships are physical in nature and therefore defy specification.

The third category of models is the conceptual or block diagram model. A good example of this type of model is the block organisation chart of a business firm, showing the elements (individuals) and structure (organisation) of the firm. Figure 2-1 is also an example of this type of model.

In the systems approach to problem solving it is often useful to classify models in another way. Data for model-building is obtained from two sources: data from the real world and data from the analyst's value judgements. The former is objective, whereas the latter is subjective. Thus models can be further classified according to these two sources.

- \* A descriptive model essentially describes facts and relationships. Consequently it is free of value judgements and is a simple statement of facts. Some examples of descriptive models are Newton's laws, a map or a graph of traffic volume-versus-time interval.
- \* A prescriptive (or normative) model is one that prescribes the expected value (or worth or utility) for each alternative. Some examples of prescriptive models are statistical tests and safety factors.

In appraising the value of different transportation alternatives the systems analyst will always try to develop a prescriptive model, since it contains a set of criteria for making a decision. However, the prescriptive model will usually have descriptive "sub-model" parts. Therefore, the analyst must be aware of the prescriptive and descriptive nature of the different parts of his model and due to their subjective nature he must carefully scrutinise the former, least he be accused of allowing the model to make the decision.

Luce and Raiffa (1957) comment that regardless of the type of model used, the mere process of recording it on paper in a consistent and systemised form will provide a clear understanding worth as much, if not more, than any subsequent numerical manipulation.

#### 2.4.3. Characteristics Of A Model.

As discussed previously the basic purpose of modeling is to represent the system under study, so that the relevant elements may be manipulated to determine their effect on the behaviour of the system. Thus, if a model fulfills the foregoing criteria, it can be said to be a good model.

Dickerson and Robertshaw (1975a) have summarised the characteristics of a good model as follows:

- \* Adequately represents the system structure.
- \* Includes all important design criteria.
- \* Easily interpreted and applied.
- \* Low cost to produce and apply alternative tests.
- \* Agrees with observation.

However, even with good models the analyst must be aware of certain dangers or pitfalls that are always present. All models are incomplete or underspecified and thus give rise to two basic errors (Jackson and Burrell, 1977).

- \* Specification Errors : arise from the simplification in a model of the phenomenon that is being represented. An example would be representing a complex non-linear relationship by a simple linear expression.
- \* Measurement Errors : arise from inaccurate assessment of a variable. An example would be an under-reporting of the number of accidents on a section of highway.

Another common failing of modeling is that the analyst may leave out certain factors that are significant but are difficult to quantify. For example, until recently travel demand models only took into account the transportation system attributes of time and cost; and left out other important attributes such as comfort, convenience and reliability which were difficult to quantify. (Spear, 1975)

#### 2.5. Analysis And Evaluation.

Referring to Figure 2-1 it will be seen that following the basic modeling process, the resources allocated to the study are examined. The study resources affect the depth and scope

of the analysis. Thus, the analyst must try to ensure that the different elements of the systems analysis process are in balance with the resource constraints and that these constraints are relevant and sensible.

Several inter-related elements now follow in the analysis process:

- \* Formalise and calibrate models.
- \* Establish criteria for design and evaluation.
- \* Test and evaluate the existing systems.
- \* Test and evaluate alternative systems.

The model will represent the interactions and relationships between the different system elements that together reflect the problem statement. The establishment of criteria are used to measure the performance of the system and any alternatives that may be proposed. The criteria used to measure system performance should reflect the goals and objectives that have been established for the study. (A further discussion of goals, objectives and criteria is presented in Section 3.5 of the thesis). The testing and evaluating of the existing system will demonstrate whether the model adequately represents the system structure and whether the design criteria represent a reliable basis for judging system performance. The above steps may have to be cycled through a number of times until through a process of interactive linkages (see Figure 2-1) the different elements of the process are in harmony or balance and the need for modification is no longer required.

## 2.6. Synthesizing Of Alternatives.

Another key activity in the systems analysis process is the design of alternative solutions. In this activity, alternative systems must be conceived and designed that will improve the performance of the existing system. This difficult task requires the analyst to be creative and imaginative. Creativity and imagination are elements of synthesis. As mentioned in Section 1.4, in problem solving, use is made of both analysis and synthesis techniques.

A key element in creativity is the ability to generate ideas. Dickerson and Robertshaw (1975b) cite as one of the major reasons for the low quality in designs is the failure on the part the designer to generate many alternative solutions to a problem. Thus, the ability of an evaluation technique to compare the relative merits of alternative designs is ultimately conditioned by the quality of the plans put forward for appraisal. Consequently, a "good" plan cannot be chosen from a "poor" set of alternatives.

### 2.6.1. Some Principles Of Creative Thinking.

In Section 1.4 it was suggested that creative synthesis, or lateral thinking is a complementary, yet distinct thinking process to the traditional logical vertical thinking. De Bono (1971) defines lateral thinking as a specific way of using information in order to bring about creative ideas to a problem situation.

According to De Bono the principles of creative thinking can be summarised as follows:

- \* To generate many innovative and maybe wild ideas.
- \* To defer evaluation of alternative ideas (ie potential solutions).
- \* To recognise dominant or polarizing ideas.
- \* To search for different ways of looking at things.
- \* To relax the rigid control of vertical thinking.
- \* To use chance and other methods in order to introduce discontinuity of thought.

The above principles give weight to the statement made by Weinstein and Angrist (1970) that the two major enemies of new ideas can be (surprisingly) logic and commonsense.

### 2.6.2. Aids To The Synthesis Of Alternatives.

The function of synthesis is to create alternatives that rank high on the evaluation scale. There is no formalised method that will produce these alternatives although there are certain techniques which have been shown to enhance the creative process and are increasingly being used in the general planning process.

It is beyond the scope of this study to go into these techniques in any detail, but it is important to understand how they relate to the planning process in general and the evaluation element in particular.

Dickerson and Robertshaw (1975c) suggest the following techniques as aids to creative thinking:

- \* Morphological methods (ordered characteristics)
  - Alternative branching
  - Matrix construction
- \* Brainstorming methods (spontaneous or random characteristics)
  - Checklists
  - Analogies
  - Gordon Technique
  - Delphi Technique

## Lateral Thinking Techniques

- \* Historical data (past experience)

regardless of which techniques are used as aids for creative thinking, it must be remembered that by definition they are only aids for thinking. Thinking and formulating the problem is probably the most important aspect in the whole system analysis process (Figure 2-1). Bailey (1970), who has made a comprehensive study of the creative aspects of problem solving, suggests that the analyst must develop a constructive discontent for the system and environment that is to be analysed. Thus, preconditioning the use of any of the techniques used in systems analysis, there must be a personal discontent developed by the analyst, for only then will there be a commitment and motivation to find a creative solution.

### 2.7. Systems Analysis As A Framework For Analysis & Synthesis

It is hoped that the foregoing brief overview has demonstrated that systems analysis is a co-ordinated set of procedures which are eminently suited to the analysis and synthesis of fundamental planning and design issues.

De Neufville and Stafford (1971) have summarised some of the functional characteristics of using systems analysis from the planning and evaluation standpoint:

- \* It is a general problem-solving procedure that uses a rational basis for decision-taking.
- \* It considers the total system and yet allows a logical progression from the general to the specific to be used.
- \* It sharpens the designer's awareness of his objectives by forcing him to make explicit statements about what they are and how they are to be measured.
- \* It establishes procedures for generating a large number of possible solutions and for determining efficient methods to search through them.
- \* In generating alternative solutions it encourages creativity and innovation by subjecting all ideas, and alternatives to the same open, impartial evaluation.
- \* It assembles optimization techniques which can select favourable alternatives.
- \* It suggests strategies of decision-making which can be used in the evaluation and selection of possible alternatives.

Obviously, the above positive attributes must be tempered with the thought that systems analysis is not the panacea for solving all transportation problems, be they convergent or

divergent in nature. In common with all evaluation techniques and analytical tools, their effectiveness is totally dependent on the user. Fortunately, the limitations and common sources of error in the use of systems analysis have been well documented (Quade, 1968). However, to quote Thomas and Schofer; "the essential property of systems analysis is that it provides an organised framework within which the analyst may think more broadly and comprehensively about his problems."

## REFERENCES FOR CHAPTER 2

ACKOFF, R.L. (1974) "Towards a System of System Concepts". System Analysis Techniques. Editors Cougar, J.D. and Knapp, R.W. Wiley pp. 27-38

ACKOFF, R.L. (1974a) Ibid., p. 28.

BAILEY, R.L. (1970) "Disciplined Creativity for Engineers". Ann Arbor Science Publishers Inc. pp. 88-89.

CARTER, E.C. and HOMBURGER, W.S. (1978) "Introduction to Transportation Engineering". Institute of Transportation Engineers, Inc. Reston. p. 225.

DE BONO, E. (1971) "Lateral thinking for Management". McGraw-Hill, pp. 47-51.

DE NEUFVILLE, R and STAFFORD, J.H. (1971) "System Analysis for Engineers and Managers". McGraw-Hill. pp. 1-16.

DICKERSON, S.L. and ROBERTSHAW, J.E. (1975) "Planning and Design the Systems Approach". Lexington Books. p. 19.

DICKERSON, S.L. and ROBERTSHAW, J.E. (1975a) Ibid., p. 93.

DICKERSON, S.L. and ROBERTSHAW, J.E. (1975b) Ibid., p. 78.

DICKERSON, S.L. and ROBERTSHAW, J.E. (1975c) Ibid., p. 89.

HUTCHINSON, B.G. (1974) "Principles of Urban Transport Systems Planning." McGraw-Hill.

JACKSON, R.I. and BURRELL, R.C. (1977) "Guidelines for Urban Transportation Studies". The Professional Engineer Volume 6. No. 1.

LUCE, R.D. and RAIFFA, H. (1957) "Games and Decisions". Wiley.

MANHEIM, M.L. (1967) "Principles of Transportation Systems Analysis". Highway Research Record, No. 180.

MANHEIM, M.L. (1969) "Search and Choice in Transportation in Transport Systems Analysis". Highway Research Record, No. 293.

\* QUADE, E.S. (1968) "Pitfalls and Limitations. Systems Analysis and Policy Planning". Elsevier Publishing Company Inc. pp. 345-363.

SPEAR, B.D. (1975) "Generalised Attribute Variable for Models of Mode Choice Behaviour". Transportation

Research Board.

STOPHER, P.R. and MEYBURG, A.H. "Transportation Systems Evaluation", Lexington Books.

THOMAS, E.N. and SCHOFER, J.L. (1970) "Strategies for the Evaluation of Alternative Transportation Plans". National Co-operative Highway Research Program (NCHRP). Report 96. Highway Research Board.

THOMAS, E.N. and SCHOFER, J.L. (1970a). Ibid., pp. 4-5.

THOMAS, E.N. and SCHOFER, J.L. (1970b). Ibid., p. 10.

THOMAS, E.N. and SCHOFER, J.L. (1970c). Ibid., p. 11.

WEINSTEIN, A.S. and ANGRIST, S.W. (1970). "Introduction to the Art of Engineering". Allyn and Bacon Inc., Boston. p. 4.

WOHL, M. and MARTIN, B.V. "Traffic Systems Analysis for Engineers and Planners", McGraw-Hill.

\* Publication not available to the author.

## CHAPTER 3 EVALUATION IN THE PLANNING PROCESS

3.1 THE DESIGN PROCESS - A FORMALISED FRAMEWORK ..	3-1
3.2 A MODEL OF A GENERAL PLANNING PROCESS .. .. .	3-3
3.3 DATA COLLECTION, ANALYSIS AND FORECASTING . . .	3-5
3.4 DETERMINATION OF CONSTRAINTS AND OBJECTIVES ..	3-6
3.4.1 Classifying Constraints .. . . . . . . . . . .	3-6
3.4.2 Determination of Objectives . . . . . . . . . .	3-7
3.5 VALUE, GOALS AND OBJECTIVES .. . . . . . . . . .	3-7
3.5.1 Fundamental Transportation Values and Goals	3-8
3.5.2 The Hierarchical Structure .. . . . . . . . . .	3-9
3.5.3 The Relative Importance of Goals and Objectives .. .	3-11
3.6 FORMULATION OF OPERATIONAL CRITERIA FOR DESIGN .. .	3-11
3.7 PLAN DESIGN AND THE TESTING OF ALTERNATIVE PLANS .. .	3-12
3.8 EVALUATION AND DECISION-TAKING . . . . . . . . . .	3-12
REFERENCES FOR CHAPTER 3 .. . . . . . . . . . . . . . . .	3-14

### 3. EVALUATION IN THE PLANNING PROCESS.

---

#### 3.1. The Design Process - A Formalised Framework.

Although the principal subject of this study is the "evaluation process", in accordance with the proposed systems approach, it would appear beneficial to our understanding, to first derive the relationship between the parts of the design process (or system) and the evaluation element, before analysing in detail the evaluation phase.

Lichfield et al (1975) have defined the planning process as a course of activity that is intended to increase understanding of the nature of problems. This requires the examination of all possible existing alternative solutions and their relative merits.

The far-reaching consequences and high cost of transportation infrastructure requires that analysis and synthesis of alternative designs take place in a rational and formalised framework. Ideally, the framework should be capable of including the often complex and large number of variables that are now associated with transportation engineering problems. The framework or design process must also recognise the dynamic nature of design situations and permit full accounting of both present and future conditions in searching for, analysing and evaluating design alternatives.

As Wohl and Martin (1967) point out, the formalisation of the design process should not be thought of as reducing all variables to a common denominator but rather as a process that permits consistent evaluation of different design solutions against a common set of design variables, value scales and objective functions. Wohl and Martin have formalised the transportation engineering design process as shown in block diagram form in Figure 3-1.

Perhaps not surprisingly, it will be noted that the specific tasks or steps formalised above are in a similar sequence to the systems analysis process shown in Figure 2-1. The other systems characteristic to be noted is the interactive feedback linkages, which allow the whole structure to be refined in the light of new information.

Lichfield et al (1975a) have formalised a more general planning design model which is shown in Figure 3-2. This general model of the planning process was obtained by Lichfield from studying about one hundred normative and descriptive models used in planning studies in the United Kingdom and United States during the past decade. It will, therefore form a good basis to understand in a general way, what inter-relationships exist between evaluation and the other planning activities.

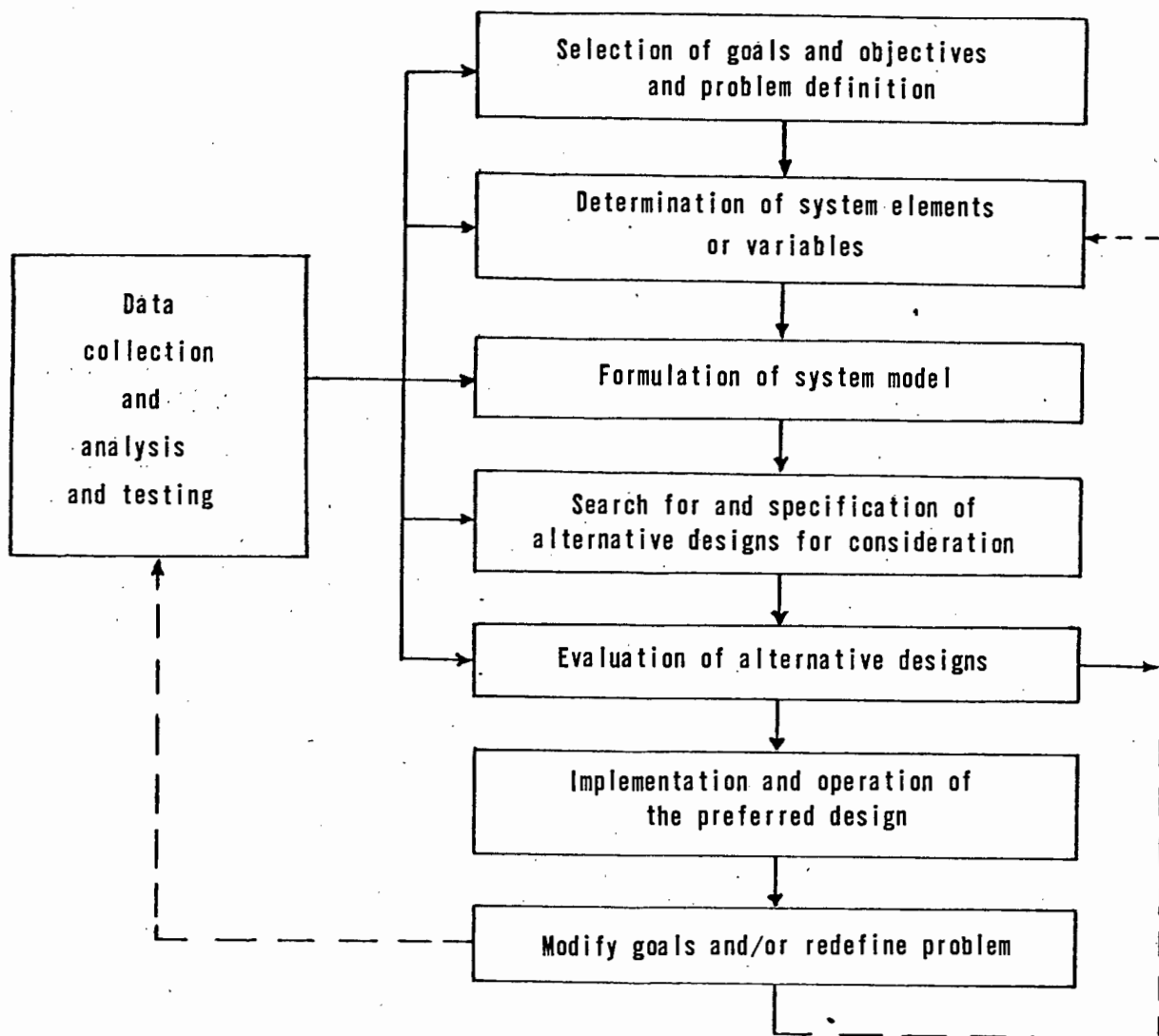


FIGURE 3-1 DESIGN PROCESS FOR TRAFFIC ENGINEERING.  
(Source : Wohl and Martin, 1967, p. 8)

Thus the aim of this section of the study is two-fold.

- \* It is believed that an understanding of how evaluation principles and methods relate to the general planning process will improve the quality of decisions made.
- \* Improvements to the quality of plan designs are likely if the principles of plan assessment and the nature of the measures to be used in the evaluation are known in advance of those whose task it is to design, ie to integrate the design elements with the evaluation element.

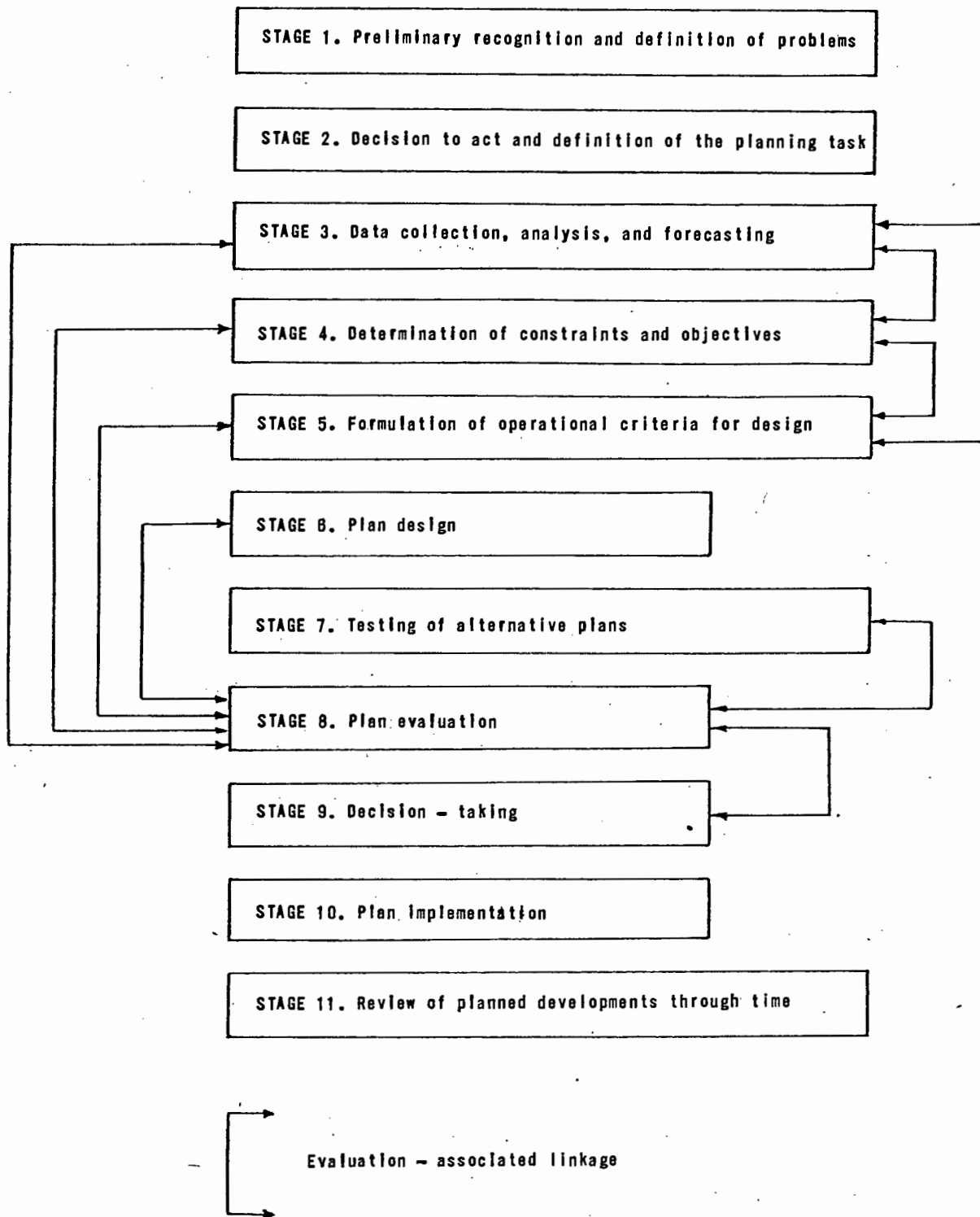


FIGURE 3-2 : CONCEPTUAL MODEL OF THE PLANNING PROCESS SHOWING EVALUATION ASSOCIATED LINKAGES. (Source : Lichfield et al, (1975) p. 40)

3.2. A Model Of A General Planning Process.

From Lichfield's review of literature a general model has been developed. The model is presented at two levels of detail, in Figure 3-2 the eleven main activities are outlined and in Figure 3-3 each activity is broken down into its constituent elements.

1. Preliminary recognition and definition of problems.
  - 1.1 Surveillance and analysis of relevant problems.
  - 1.2 Comparison of existing and forecast conditions, in order to identify problems requiring examination.
  - 1.3 Assessment of problem significance.
2. Decision to act and definition of the planning task.
  - 2.1 Decision to investigate the problems and alternative courses of action.
  - 2.2 Definition of the purpose of the planning task.
  - 2.3 Formulation of goals for the plan.
  - 2.4 Formulation of approach to the study and to the design and evaluation of alternative plans.
3. Data collection, analysis, and forecasting.
  - 3.1 Collection and analysis to the planning problems.
  - 3.2 Forecasting the scope for change in urban and regional developments.
  - 3.3 Determination of evaluation data requirements.
4. Determination of constraints and objectives.
  - 4.1 Determination of constraints.
  - 4.2 Determination of objectives for the plan.
5. Formulation of operational criteria for design.
  - 5.1 Formulation of measures for the objectives.
  - 5.2 Collection of evidence on the relative importance of objective achievements.
6. Plan design.
  - 6.1 Selection of one or more design methods.
  - 6.2 Use of design criteria to prepare alternative plans.
7. Testing of alternative plans.
  - 7.1 Testing of internal consistency.
  - 7.2 Assessment of feasibility with respect to constraints.
8. Plan evaluation.
  - 8.1 Measurement of levels of achievement of objectives.
  - 8.2 Appraisal of the evidence produced.
  - 8.3 Setting down of findings in a logical framework.
  - 8.4 Making of recommendation to decision-takers.
9. Decision-taking.
  - 9.1 Collaboration and debate among decision-takers.
  - 9.2 Collective choice of the preferred plan.
10. Plan implementation.
  - 10.1 Establishment of machinery for implementation.
  - 10.2 Initiation of planned developments.
11. Review of planned developments through time.
  - 11.1 Observation of consequences of the adopted plan.
  - 11.2 Comparison with predicted outcomes and appraisal of the significance of any unanticipated consequences.
  - 11.3 Identification of new problems arising.

For convenient simplification, the model activities and elements have been set out as a linear, sequential process. In practice it is recognised as desirable to recycle through certain activities, in the light of what has been learned. It is also likely that many of the planning activities will be undertaken simultaneously.

It is now necessary to identify and amplify certain threads within the general planning process, those activities which are linked and therefore have a bearing on the evaluation activity. In the above planning process stages 1 and 2 are preliminaries to the main activities of planning and stages 10 and 11, which follow the decision, do not normally involve the planning team. Thus it is stages 3 - 9 which will be studied to identify any evaluation-associated linkages.

### 3.3. Data Collection, Analysis And Forecasting.

If cognisance is not taken of the evaluation-associated linkages with this stage of planning, a situation can arise where the choice of data collected and the unit measures of performance used in the analysis will not be consistent with the units of measure in the evaluation phase (De Neufville and Stafford, 1978). For example, if one was planning a mass transportation system, how should cost be analysed so that cheapness can be evaluated. In rands per passenger - km? Rands per ride? or Rands per vehicle km? Each could be used as a measure of evaluation. For instance, if the units of analysis were cost per passenger-km, the evaluation would favour alternatives with long, high-density hauls where overheads could be shared over many trips. The use of cost per ride as an index would favour the evaluation of a dense, closely spaced alternative. Finally, costs per vehicle as a unit of analysis would favour the evaluation of alternatives with small vehicles or carriages.

Therefore, the choice of units of performance in the data collection and analysis phase should be thought of as linkages which can condition the evaluation stage.

The data collection element can be made more cost-effective in certain instances where preliminary evaluation work is carried out in association with it, thereby influencing the kind of data collected. The evaluation linkage may take the form of attitudinal surveys to determine the nature of the preferences of community groups or sectors within the study area.

In major planning studies there is sometimes a subtle separation of responsibility between those responsible for the collecting of data, analysis and the preparing of alternative plans, and those responsible for their comparative evaluation. For example, specialist economic consultants are a common occurrence. Therefore, those who undertake the evaluation exercise must participate throughout the early stages of the planning process, in order to avoid any internal inconsistencies between the data collection and analysis phase and that of the evaluation phase.

### 3.4. Determination Of Constraints And Objectives.

There is a fundamental dilemma between the two terms constraints and objectives, since the purpose of planning constraints is to set limits on the way planning objectives may be realised.

In adopting a systems approach to planning it will be recalled that boundaries or constraints, must always be established. Further it will be remembered that the objectives of the study are used to establish the boundaries.

#### 3.4.1. Classifying Constraints.

It will be noted from Figure 3-2 that constraints (and objectives) are determined primarily at the time that operational criteria are developed. Constraints represent certain pre-conditions that alternative plans must meet in order that they may proceed further along the evaluation process. Constraints can be classified into three classes. (Dickerson and Robertshaw 1975).

- \* An effectiveness limit, that is a lower bound, placed upon some aspect of the effectiveness or performance of the system. Planning standards fall into this category of constraint and are taken as the constraints that previous experience have shown to be useful and reasonable to achieve. A level of service 'C' would be an example of an effectiveness limit for traffic performance in a highway design problem.
- \* A cost constraint is an upper limit placed on the use of resources. For example, budget constraints, natural resource constraints and time constraints are imposed on most planning problems.
- \* A design constraint is a limitation on a physical aspect or operational characteristic of the design. An example of this would be the request that an urban highway be designed to accommodate some form of bus priority in peak travel hours.

Following the above considerations, it should be added that constraints are not determined fully and irrevocably at the beginning of the study, but by a process of iteration. It is the analyst's duty to establish the validity of the constraints (ie boundaries) and once established, they should reflect in turn the relevance or importance of the objectives for the design and evaluation.

The primary purpose of constraints is therefore, to imbibe a concept of resource-effectiveness into the design and evaluation stages by limiting the area and hence, the costs within which the search for alternatives may take place.

### 3.4.2. Determination Of Objectives.

If the evaluation phase of the planning process is defined as that element which attempts to measure and compare the ability of alternative plans to achieve stated objectives, the importance of the linkage between evaluation and objectives can hardly be over-stressed (Scott Rutherford et al 1973). Objectives constitute a central part in the process of plan generation and evaluation and have an operational significance greater than any of the other linkages.

Firstly, an objective serves as a guideline and focal point for the development of alternative designs. Secondly, objectives form the very basis of evaluation, since an objective should lead to criteria for evaluating the alternative projects in the final decision process. It is this second aspect; the relationship between objectives and evaluation that will be discussed in more detail in the following paragraphs.

### 3.5. Values, Goals And Objectives.

Values, goals and objectives and criteria are words to which planners often refer without agreement (or understanding) as to the distinction between them or the functional relationship between them. Wachs and Schofer (1969) suggest the main reason for confusion among the terms mentioned is that all the words are high-level abstractions. Thus there is a difficulty in referencing these terms to something tangible in a physical sense and to one another in a functional sense. Wachs and Schofer have formulated the following definitions:

- \* Values form a set of certain irreducibles which form the basic desires and drives governing the behaviour of people and groups of people. Thus, it is possible to identify a societal or cultural value framework in planning. Examples of values adopted in planning are economy, safety, equity, mobility, amenity, etc.
- \* Goals are generalised statements which broadly relate the physical environment to values but to which no test for fulfillment may be readily applied, because they are also high-level abstractions. Examples of goals in planning; to provide equal opportunity of access, to expand and improve the public transport service in the metropolitan area at a reasonable rate, etc.
- \* Objectives are specific statements which are attainable and measureable because of their reference to a physical world. Examples of objectives; to increase the vehicle capacity of a highway, to spread peak traffic demand, to reduce public transport user costs.
- \* Criteria are specific measures or tests which reflect the degree of attainment of particular objectives. The

well known criteria of travel time and road-users cost are examples of criteria that are often used to measure the performance of different highway facilities.

- \* Standards are the minimum acceptable levels of criteria measures or tests. From Section 3.4.1 a standard can also be considered as a form of constraint and therefore a standard is useful in routinizing the evaluation of alternatives. The consideration of only those alternative alignments of a highway that can attain a design speed of 100km/hr, is an example of the use of a criterion as a standard and a constraint. However, as Teitz (1968) comments, one must guard against technical performance standards unnecessarily constraining the evaluation and the analyst must always ensure that they are relevant and appropriate measures of performances.

### 3.5.1. Fundamental Transportation Values And Goals.

One can classify goals in transportation planning into three principle categories (Marglin,1967).

- \* Goals concerned with economic and resource efficiency - ie the maximisation of returns on investments regardless of to whom they may accrue or at whose cost. These goals are related to the value function "efficiency".
- \* Goals concerned with redistribution of income ie the promotion of the welfare of a particular sector of the community or a certain area of the country. These goals are related to the value function "equity".
- \* Goals concerned with the fulfillment of desires which cannot be satisfactorily justified through their economic worth. Environmental goals, such as the conservation of fauna and flora, wilderness areas, and aesthetic considerations are examples. These goals can be related to many different value functions and unfortunately, do not lend themselves to neat categorisation. However, they are usually related to such abstract values as "freedom", "health", "safety", "amenity", "diversity" and "ownership". Generally speaking in transportation planning, these goals are related to "social and environmental amenity".

From the above categorisation it will be realised that many transportation strategies will have values and goals that are not mutually supporting and quite often will be in polar-like opposition, particularly when the problems they are addressing are of a divergent nature. The divergent nature of transportation values merely reflects the fundamental yet conflicting needs of human society. For example society needs stability and change; tradition and innovation; public interest and private interest; freedom and order; efficiency and equity; etc. As Schumacher (1977) comments society's

health depends on the simultaneous pursuit of the above mutually opposing values. Similarly, many transportation strategies will reflect these opposing societal values and thus, ideally the framework of an evaluation methodology should be able to accommodate these divergent values.

However, some attempts at formulating goals have proved to be of little value in guiding the planning process, not so much that the goals were in polar-like conflict, but rather because they were too abstract or utopian. Thomson (1974) suggests that goals, as a general guide, should attempt to remove deficiencies where facilities fall below peoples conscious desires rather than aim to provide new and better facilities which have not yet entered into their conscious expectation. The concept of appropriate technology as expounded by Schumacher echoes the above statement. (Schumacher, 1973).

### 3.5.2. The Hierarchical Structure.

Another characteristic of values and goals that has an important evaluation linkage is that they have a hierarchical nature. Figure 3-4 shows the possible interrelationships among values, goals, objectives and criteria for the evaluation of alternative plans.

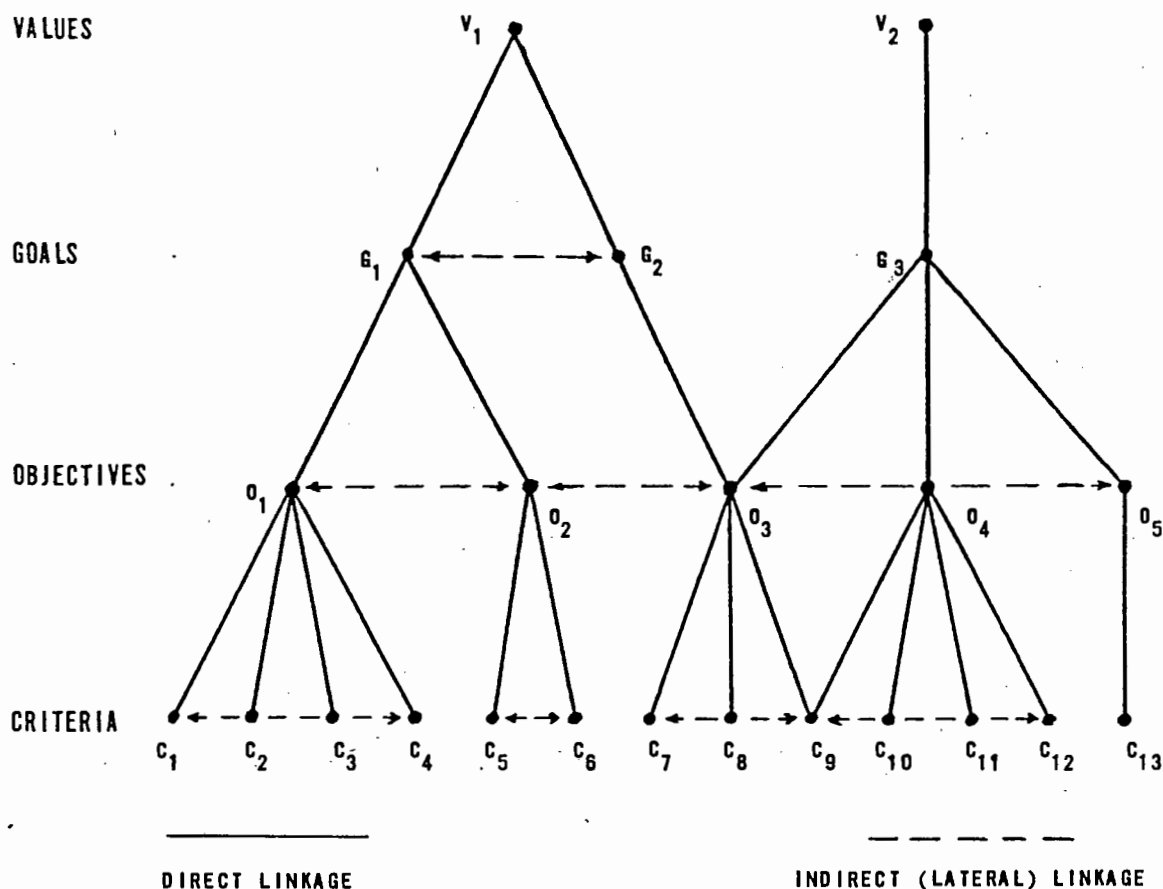


FIGURE 3-4 HIERARCHICAL INTER-RELATIONSHIP AMONG VALUES, GOALS, OBJECTIVES AND CRITERIA. (Based on Wachs and Schofer, 1969).

The following observations can be made from the conceptual model shown above:

- \* Some criteria (C9 for example) may measure the attainment of two or more objectives (O3 & O4 for example).
- \* Similarly some objectives (O3 for example) might partially contribute to the satisfaction of two or more goals (G2 & G3 for example).
- \* One goal could contribute to the satisfaction of more than one value.
- \* In the physical evaluation of alternative systems it is possible that a high attainment of one criterion pre-determines a low attainment of another criterion, with both criteria relating to the same objective (for C5 & C6 relating to O2).
- \* For reasons of simplicity only vertical relationships in the structure have been developed, but in reality there are also lateral linkages. For example, the lateral linkages between such values as safety and economy may present a conflicting interaction lower down in the structure, where trade-offs between criteria must be considered. The above example of conflicting criteria C5 & C6 is also evidence of a lateral interrelationship.

From these observations the following conclusions may be drawn that are relevant to our understanding of the evaluation process:

- (i) It is of paramount importance that the analyst takes account of the hierarchical value structure when using goal-orientated evaluation techniques, such as cost-effectiveness analysis and plan ranking schemes. For even when objectives or criteria are explicitly stated as being of equal importance or weight, because of the complex inter-relationship, this importance or weight may not be reflected through the hierarchy (in either direction, to say the goals and values), unless the analyst clearly understands the value structure of the study.
- (ii) At each level within the hierarchical structure it is possible to have a lateral inter-relationship which gives rise to complementary elements or conflicting elements. The analyst should give consideration to the fact that complementary elements have an additive effect through the structure (double counting). However, if conflicting elements are present, then an effort should be made to reformulate the particular goals and objectives, to minimise internal conflicts (Craven et al, 1979). Where this is not possible, consideration must be given to trade-offs between the conflicting

objectives or criteria.

- (iii) For the value hierarchy to serve as an effective guide for developing and evaluating alternative projects, goals and objectives should be established at the beginning of the planning cycle. Thus the generation of alternative plans will occur within a logical and consistent framework and the evaluation of these plans in terms of the degree to which they fulfill objectives will become a much simpler process.

Thus even given a well defined set of clear goals, the determination of planning objectives and criteria for subsequent evaluation is still a complex and daunting task, though hopefully the foregoing thoughts will make the evaluation part more effective.

### 3.5.3. The Relative Importance Of Goals And Objectives

Figure 3-4 and Section 3.5.1 showed that goals and objectives are not necessarily mutually supporting, nor usually is their relative weight or importance to one another constant or equal. Therefore, one of the key activities linked to the evaluation stage is the determination of the relative importance or weight of goals, objectives and criteria.

How the relative weight of goals and objectives can be determined will be discussed in Section 4.3.2. What requires emphasis here, is that since the development of objectives constitutes a central part in the evaluation process, then how the relative weights of the objectives are determined is of paramount importance to the evaluation stage of the planning process.

### 3.6. Formulation Of Operational Criteria For Design.

In the conceptual model (Figure 3-2) it will be noted that the determination of the design criteria stage is formally linked back to both the data collection, constraints/objectives stages and forward to the evaluation phase. These linkages demonstrate clearly that the formulation of operational criteria for a design is a very important element within the planning system.

The formulation of operational criteria for design is concerned with the translation of planning objectives into some operational form, useful for design. This was discussed in Section 3.5, where it was stressed that the criteria selected for design should also be appropriate for the evaluation stage. The common use of travel time saved in transportation studies is a good example of the selection of a criterion for design that presents consequential difficulties in interpreting the measures of benefit in the evaluation stage (Neuburger, 1971). The problems of placing an economic value on travel time saved are well documented.

(Stopher & Meyburg, 1976).

In general, transportation systems have multiple goals and objectives and evaluation too should therefore be based on multiple criteria. It follows from this statement that there can be no standardised set of criteria on which evaluation can be based. In some studies there will be an emphasis on economic criteria, whereas others will emphasise environmental criteria. However, the emphasis in each case should reflect the value-goal structure of the study.

### 3.7. Plan Design And The Testing Of Alternative Plans.

These two elements of the design process are concerned with the paradoxical aspect of checking the alternative designs for internal and external consistency. The connotation of internal consistency relates back to planning objectives and ensures that the alternative plans generated meet the stated objectives. External consistency ensures feasibility in the sense that all alternative plans generated must meet the planning constraints prior to evaluation.

It should be noted that although the design and testing of alternative elements are linked to the evaluation element, there is a functional distinction between them. The former activity involves the individual analysis of each plan in order to determine whether it is feasible (ie capable of implementation in the form envisaged), whereas evaluation is concerned with comparative analysis. Since it is a waste of time and resources to evaluate impracticable alternatives, the testing of plans should therefore be undertaken prior to evaluation.

The generation of alternative plans is an important element in the planning process, since the engineer can only be confident of evaluating and selecting the preferred plan if a wide range of alternatives is considered.

### 3.8. Evaluation And Decision-taking.

Figure 3-3 shows that the main element in the plan evaluation phase is to measure the levels of achievement of objectives and then to appraise the resulting evidence. The resulting information should then be presented in a rational way to the decision-maker, so that an informed decision can be made. The submission of a set of recommendations to the decision-takers should therefore, be primarily an information document that reveals the implications and trade-offs of the alternative plans. Plan evaluation is therefore, not a decision document. According to Lichfield et al (1975b), the function of evaluation is to provide the best information possible to those whose responsibility it is to make and justify decisions.

We have considered all the evaluation associated linkages prior to that of evaluation, now we must consider the last

linkage which occurs after evaluation, the decision-taking stage.

This chapter of the thesis has shown that the whole planning process is characterised by a series of decisions. The reason for using the systems approach to planning was to ensure that these series of decisions were made in a consistent and rational basis. It has also been shown that the actual basis of a decision depends on the value scale used by the decision maker. Thus two people considering the same problem and data set may arrive at different decisions because they use different value scales.

In practice the decision takers' criteria for choosing between the set of alternative plans evaluated by the planning team is not normally known in advance of evaluation. Moreover, most decision-takers generally reserve the right to interpret proffered evidence on advantages and disadvantages of alternatives in their own way.

It is therefore, a common experience for the engineer to recommend one alternative for implementation and the decisiontaker to select another. This situation occurs because the evaluation linkage was absent or deliberately not used, due to two different value scales having been used as a basis for eventual choice.

The "evaluation dilemma" will be most acute (or at a maximum) where evaluation and decision-taking is carried out in a "closed system". This occurs where there is little opportunity for "triangular" debate between the planning team, the general public and the decision-takers. The "evaluation dilemma" will be least (or at a minimum) in an "open system" when the linkage between evaluation and decision-taking has been recognised. This situation is moving towards the ideal of merging the evaluation and decision taking elements, with connotations of co-determination as the basis of eventual choice. However, if it is recognised that this evaluation dilemma will be present in most choice situations, an effort can be made to minimise it.

## REFERENCES FOR CHAPTER 3

- CRAVEN, D.W., MCGHEE, J.L., MUNDY, R.A. and others (1979). "Market Opportunity Analysis for Short-Range Public Transportation Planning - Goals and Policy Development". National Co-operative Highway Research Program (NCHRP). Report 211. Transportation Research Board. pp. 3-17.
- DE NEUFVILLE, R. and STAFFORD, J.H. (1971) "Systems Analysis for Engineers and Managers". McGraw-Hill p. 8.
- DICKERSON, S.L. and ROBERTSHAW, J.E. (1975). "Planning and Design the Systems Approach". Lexington Books. pp. 42-43
- LICHFIELD, N., KETTLE, P. and WHITBREAD, M. (1975) "Evaluation in the Planning Process". Pergamon Press Ltd., p. 18
- LICHFIELD, N., KETTLE, P. and WHITBREAD, M. (1975a) Ibid., p.40
- LICHFIELD, N., KETTLE, P. and WHITBREAD, M. (1975b) Ibid., pp. 32-47
- \* MARGLIN, S.A. (1967) "Public Investment Criteria". Allen and Unwin, London.
- NEUBURGER, H. (1971) "User Benefit in the Evaluation of Transport and Land Use Plans". Journal of Transport Economics and Policy. Volume 5.
- SCHUMACHER, E.F. (1974) "SMALL IS BEAUTIFUL". Sphere Books.
- SCOTT-RUTHERFORD, G., SCHOFFER, J.L. WACHS, M. and SKUTSCH, M. (1973) "Goal Formulation for Socio-Technical Systems". Journal of the Urban Planning and Development Division of A.S.C.E. Volume U.P.2
- STOPHER, P.R. and MEYBURG, A.N. (1976) "Transportation Systems Evaluation". Lexington Books, pp. 37-66
- TEITZ, M.P. (1968) "Cost-Effectiveness : Systems Approach to Analysis of Urban Services". Journal of American Institute of Planners. Volume 34. No.5
- THOMSON, J.M. (1974) "Modern Transport Economics". Penguin Books, pp. 176-177
- WACHS, M. and SCHOFFER, J.L. (1969) "Abstract Values and Concrete Highways". Traffic Quarterly. pp. 133-156.
- WOHL, M. and MARTIN, B.V. (1967) "Traffic Systems Analysis for Engineers and Planners". McGraw-Hill pp. 6-7
- \* Publication not available to the author.

## CHAPTER 4 THE PROCESS IN EVALUATION

4.1 THE NATURE OF EVALUATION .. .. .	4-1
4.2 SCOPE OF THE EVALUATION PROCESS .. .. .	4-1
4.3 MEASUREMENT OF PLAN PERFORMANCE .. .. .	4-2
4.3.1 A Value Framework .. .. .	4-2
4.3.2 Goals - Objectives - Weights .. .. .	4-5
4.3.3 Concept of Effectiveness .. .. .	4-9
4.4 PRINCIPLES OF MEASUREMENT .. .. .	4-9
4.4.1 Measurement of Plan Criteria .. .. .	4-9
4.4.2 Measurement Scales .. .. .	4-10
4.4.3 Transformation Scaling Procedures. .. .. .	4-13
4.5 THE NULL ALTERNATIVE .. .. .	4-21
4.6 CRITERIA SELECTION TO INDICATE PLAN PERFORMANCE	4-21
REFERENCES FOR CHAPTER 4 .. .. .	4-25

## 4. THE PROCESS IN EVALUATION.

---

### 4.1. The Nature Of Evaluation.

Evaluation, like judgement and criticism are all aspects of the same thing, the result of reasoning. It has been suggested that in planning in general and in evaluation in particular the formalisation for reasoning should be system analysis (Chapter 2). Thus, the purpose of this section will be to attempt to structure the evaluation process by looking at some of the fundamental principles of evaluation, thereby providing a framework by which alternative plans can be appraised.

In Chapter 3 it was shown that the evaluation process does not operate in glorious isolation within the planning process. Several evaluation interfaces or linkages with the other planning activities were identified. It was shown that the planning process is characterised by a series of decisions and that even prior to the evaluation and selection phases, many partial decisions were made. The early synthesis of alternative plans as a result is often made in comparatively large vacuums of information.

To overcome areas with low levels of information, another characteristic of the planning process was identified, that of iteration. The purpose of these iterative linkages is to improve the quality of the output of the individual element in the process and ultimately the quality of the final evaluation and decision-taking elements. Thus, if in the evaluation process a new alternative emerges, it must be possible to return to the preceding activities.

### 4.2. Scope Of The Evaluation Process.

If one is to be effective in examining some of the principle elements of the evaluation process it is necessary to define the scope or boundaries thereof. The evaluation process can be bounded by consideration of two kinds of planning constraints:

- \* Planning Horizon
- \* Time Horizon

Section 2.3.1 stated that one of the characteristics of the systems approach to planning is that any system is a sub-system of a broader system. Therefore in evaluating highway plans it is possible and necessary to distinguish between these different planning systems or levels of planning, eg national, regional, sub area or corridor. Wachs

et al (1974) argue that in fact there are two fundamental levels or scales of planning, namely system or network level planning and a lower localised level; project or facility planning.

The systemwide planning horizon is concerned with broad brush design alternatives and is characterised by a broad planning perspective and a long range time horizon - about 10 to 25 years or longer. The length of highways considered are long, 100 - 1000 kilometres and the planning effort is focused on the evaluation of highway networks or corridors. The corridors of interest are generally wide, making it difficult to specify precisely the total cost or the social and environmental impacts.

The localised planning horizon is concerned with the precise location and design of components of a regional network. It is thus characterised by a localised planning perspective and a short range time horizon of about 1 to 5 years. The length of highway considered is of the order of 1 to 50 kilometres long and the corridor of interest much narrower, say 100 m to 300 m wide. In the evaluation of alternative alignments at this level of planning, precise estimates of facility costs together with social and environmental impacts can be determined.

The nature of planning necessitates that the two planning horizons be functionally linked, but in practice they are often treated as separate and unrelated activities. (Bellomo et al, 1977). A major factor in this level mismatch is the tendency for different levels of government and organisations to have responsibility for distinct scales of transportation planning. When the two levels of planning become functionally separated, as is often the case in transportation planning, it is hardly surprising that often highway - transit plans generate much public controversy.

Evaluation can be conducted at essentially two levels of planning. Each level uses different sorts of information in formulating the alternatives, the values and therefore the criteria used to evaluate plan performance can be very different.

#### 4.3. Measurement Of Plan Performance.

##### 4.3.1. A Value Framework.

One of the fundamental prerequisites for an evaluation process to function is the need for a value framework or scale for measuring the relative worth of the alternative plans. However, different value scales will apply to the

evaluation of plans at different levels of planning.

Wachs et al (1974a) suggest that unitary values generally are applied to systemwide planning and individualistic or sectorial values are applied to localised project planning.

Meyerson and Banfield (1955) define the unitary values as values that are seen as pertaining equally to the general well-being of all members of society, ie it is aggregated and societal in concept. Alternatively, individualistic values, as the term implies, are values that are seen as relevant to individuals or groups, ie it is disaggregate or sectorial in concept. As Wachs comments, a distinction between unitary and individualistic values helps clarify the differences between transportation system planning and the consequences and conflicts associated with the localised planning of individual projects and facilities.

In the transportation planning process, the analysis and forecasting elements often use elaborate mathematical models, such as trip generation, trip distribution, modal split analysis and traffic assignment. The ensuing evaluation of the alternative network is undertaken by comparing cost-benefits or cost-effectiveness indices generated from the output information of the models. Thus the evaluation process compares the measurement of system or network performance based on unitary values without regard to the distribution of the concomitant benefits and disbenefits.

In fact, in the opinion of many eminent engineers and planners, the sophistication of systemwide planning in terms of quantitative models and the ability to predict future system performance has far outstripped the localised planning techniques in their ability to measure and evaluate plan performance at the individual or sectorial level.

A good local example of different value scales being used to evaluate a highway plan is the Kirstenbosch Freeway. Here the engineers and planners considered the Kirstenbosch link as an element of a total system plan which had previously been evaluated primarily in terms of unitary concepts of performance, ie minimum total transportation cost and completing the system arguments.

In contrast with the unitary values of the engineers, the benefits and costs of the facility were perceived as highly disaggregate and sectorial in concept by individuals, groups of ratepayers and environmental interest groups. It was argued that the aesthetic and noise consequences of the elevated freeway on the public gardens and surrounding private properties were unacceptable. Thus the measurement of plan performance has been evaluated using two different value scales; the engineers and planners using the unitary values and the affected citizens using the individualistic values.

Therefore, in hindsight it would appear as if a contributing factor to the Kirstenbosch Freeway controversy was an imbalance between systemwide service requirements and localised disaggregate requirements.

The values "generally" (refer to Section 3.5.1) used for evaluating transportation plans embody the fundamental societal values of:

- \* Efficiency
- \* Equity
- \* Social and environmental amenity

It is suggested that these three values should form the fundamental criteria or frames of reference for evaluating alternative transportation plans.

The value of efficiency is used to determine the proposal that yields the most efficient allocation of resources for society as a whole. Thus the principle of efficiency is generally unitary in concept, concerned with the maximisation of the total system net benefit.

The value of equity is concerned with the fairness of the impact and incidence of the proposed allocation of these resources on society or sectors of society. It can be either unitary or sectorial in concept. In transportation planning, the principle of equity is either sectorial or individualistic in concept and is concerned that each sector or individual receives its fair share of benefits (and/or penalties).

The value of social and environmental amenity is used to determine the impact and consequences of the proposal on the environmental system as a whole and on its constituent sub-systems, eg community groups, ecologically sensitive areas, aesthetic impact, etc. For clarity it should be added that amenity epitomises the positive qualities of convenience, safety, health, beauty, etc, as opposed to the negative qualities of inconvenience, hazard, pollution, ugliness, etc. The value of amenity can thus be either unitary or individualistic in concept.

The value-goal framework, as has been shown in Section 3.5.1, is further complicated by the reality that values and goals are not necessarily mutually supporting, nor is their relative weight or importance to one another always constant with respect to time. For instance, values such as economic efficiency and environmental amenity are often related to different time frames (Munn, 1975). Economic aspects are concerned with maximising gains over a time scale 10 to 20 years, whilst environmental considerations are concerned with

minimising liabilities over a time scale of 50 years and longer.

The two scales of value, that is unitary and sectorial, have given rise to different techniques of evaluation being developed. Since transportation planning is a dynamic process, with the fundamentals remain the same, there is through the passage of time, a change in emphasis. Heightchew (1979) believes that the emphasis and balance of our values in the evaluation framework is a direct function of the "historical mood" of society. The current emphasis in planning is away from unitary value systems and towards group or community value systems. Methodologies such as cost-benefit analysis, which are unitary value orientated, are therefore gaining disfavour (by some!) while methods like goals achievements matrix, which are community orientated, are finding increasing favour.

#### 4.3.2. Goals - Objectives - Weights.

In all evaluation methodologies the primary purpose of developing a comprehensive set of goals and objectives is to give the planning process and the evaluation element, direction and meaning. Section 3.5 showed that study goals and objectives are related in a hierarchical relationship to a framework of fundamental values. It was shown that within the hierarchical structure there may be complementary and conflicting elements. It is also apparent that certain elements may be considered more important or should have greater weight than other elements within the structure. This sub-section, therefore, briefly examines some current approaches that are used to determine goals and objectives and their relative weights.

The determination of planning of goals, objectives and their relative weights is one of the primary phases in the evaluation process. How are they determined? Hill (1967) suggests that one of the following approaches can and has been used:

- (i) The decision-maker can be asked to give relative weights to the goals and objectives
- (ii) The elected members of affected community groups can form a committee to make a community valuation of objectives
- (iii) Individual persons of the affected groups can be interviewed and their relative valuation of objectives can be determined
- (iv) Public hearings can be arranged to determine public-interest group goal formulation and valuation
- (v) The patterns of previous allocations of public

investments can be analysed in order to determine the goals and objectives relative weighting, implicit in previously similar decision situations.

The above range of approaches vary from the one extreme of using a single expert to the other extreme of using a committee. In metropolitan planning studies it is common practice for the goals and objectives (and their relative weights) to be determined by a steering committee. The committee approach is often favoured on the premise that many opinions are more equitable and superior than one. However, as is well known, the committee approach has certain disadvantages and to overcome these shortcomings the Delphi technique is often used, (Dajani and Gilbert, 1975). This method is designed to structure group communication and encourage consensus of opinion of the group of experts by a series of questionnaires interspersed with controlled opinion feed-back.

Although the technique can vary in form, a typical approach would consist of the following distinct phases (Linstone and Turoff, 1975).

- \* The first phase, the study under discussion, is openly discussed, often in the form of brainstorming. Each individual contributes information which he feels is relevant to the issue under examination. In addition, to ensure group co-operation, the characteristics and different steps in the Delphi technique are explained.
- \* The second phase involves defining terms so that each member of the group understands clearly the issues under discussion. To avoid semantic misunderstanding the objectives must be clearly defined and the generality and specificity of each objective must be stated.
- \* The following phases are controlled by an external co-ordinator who asks each participant to respond anonymously and in private to a list of objectives that have resulted from the foregoing phases. The purpose of the private response is to overcome the major shortcomings of open committee, ie the influence of dominant personalities, organisational status, apparent expertise and the general suppression of disagreement that is associated with the committee approach.
- \* In the fourth phase, the individual responses are edited and recirculated to serve as a basis for response in the next round. Participants are offered the chance to change their previous response. Areas of significant disagreement are thus examined and endeavours are made to expose the reasons for the differences.
- \* Subsequent rounds are repeated until either the spread of responses approaches consensus or the responses remain unchanged showing that the participants are unwilling or unable to compromise further. Stability

in either the form of convergence of opinion or distribution of opinions is usually achieved after 3 or 4 rounds.

Once a list of objectives has been agreed upon the next step would be to determine their relative importance or weight. In developing a set of weights, any of the methods below can be used (ie ranking, rating or partial pair comparisons) in conjunction with the Delphi technique. Again, after successive iterations consensus would usually be reached. With some objective weightings however, consensus is not possible and polarization may occur. If the divergence of opinion cannot be resolved through the restructuring of the objectives then it is necessary for the evaluation techniques to take account of the revealed divergence of opinion.

Leake and Dix (1979) in their recent review of different methods for determining weights to objectives, found 3 methods appropriate in terms of simplicity, reliability and efficiency. The three methods compared were: ranking, rating and partial pair comparisons.

- \* Ranking - each judge would arrange the N criteria (objectives) in order, by assigning the rank of 1 to the most important criterion, 2 to the second in importance and concluding with N for the least important.

The ranking method is often presented in the form of a game, (see Figure 4-1) on the ranking ladder where different objectives can be placed onto their most appropriate rung. The most important objective being placed in position 1 at the top of the ladder.

- \* Rating - each judge is presented with a continuous scale say 0 to 10 for each criterion. A value is assigned for each criterion, the rating need not be an integer and any number of criteria can be assigned the same value. A high value would indicate importance. The rating method, like the ranking method is often presented in game form, see Figure 4-2. The participants would be given, say 50 counters which must be allocated among all the objectives reflecting their relative importance, or preference.
- \* Partial pair comparisons - the basis of this technique is a systematic pair-wise comparison of a set of criteria pairs. The participant is asked to indicate which of the two criteria in each pair is preferred. In partial pair comparisons each criterion is paired only once with every other criterion, hence N criteria result in  $N(N-1)/2$  comparisons or pairs. This method is often presented in the form of a questionnaire. Figure 4-3 gives a typical example of pair comparisons format. This technique produces highly reliable scales (Gordon et al

1
2
3
4
5
6
7
8
9
10

Please mark the objectives below in order of importance. The most important objective should be placed at the top of the ladder. (rung 1)

- A. The public transport system should be easily accessible for people who do not own private transport.
- B. Travellers journey times should be as short as possible.
- C. The cost to build and maintain the transport system should be as low as possible
- D. The out-of-pocket costs (e.g. bus fares, petrol costs etc.) for travellers should be as low as possible.
- E. To reduce energy requirements per person kilometre travelled within the communities.
- F. To provide facilities for modal interchange and co-ordinate services so as to minimise interchange times.
- G. Etc.

FIGURE 4-1 RANKING LADDER

Please rate the objectives below by allocating the number of points that reflect your importance or preference for each objective. Different objectives can be given the same number of points, but you must allocate all 50 points.

Objectives	Your score here
The public transport system should be easily accessible for people who do not own private transport.	
The cost to build and maintain the transport should be as low as possible.	
The out-of-pocket costs (eg. bus fares, petrol costs etc.) for travellers should be as low as possible.	
To provide facilities for modal interchange and co-ordinate services so as to minimise interchange times	
Travellers journey times should be as short as possible	

N.B. Your total score must total 50 points

Σ 50

FIGURE 4 - 2 RATING TABLE

Please tick the box against the objective in each pair that you consider to be the most important on your trip from home to work :

1.	A. Travel journey times should be as short as possible.	<input type="checkbox"/>
	B. Out-of-pocket costs (eg. bus fares, petrol costs) for travellers should be as low as possible.	<input type="checkbox"/>
2.	A. The public transport system should be easily accessible for people who do not own private transport.	<input type="checkbox"/>
	B. The cost to build and maintain the transport system should be as low as possible.	<input type="checkbox"/>

FIGURE 4 - 3 PARTIAL PAIR COMPARISON QUESTIONNAIRE

1979) at the expense of having to make a large number of comparisons, eg 10 objectives would require 45 pair comparisons.

Therefore, regardless of who determines the weighting of the objectives, any of the above three methods can be used to obtain statistically reliable results (Eckenrode, 1965). In Chapter 5 of the thesis it will be shown how the different evaluation methodologies incorporate the aspect of weighting goals, objectives and criteria into their evaluation framework.

Providing one's criteria are of a common metric, the primary purpose of deriving a relative weighting is so that by simple arithmetic a unique answer can be determined in the comparison of alternative plans. In addition, it is well known that different groups of people have different value systems and by applying different sets of weights the effect on the choice of the preferred alternative can also be explored. The Delphi technique is a method that is often used to structure value judgements in goal formulation and their relative weighting. However, as Hill comments, the determination of group objectives and their relative valuation is no simple task requiring the specific allocation of time and resources in a study programme. (Hill, 1968).

#### 4.3.3. Concept Of Effectiveness.

The value-goal-objectives structure with its system of weights provides the fundamental framework in which the alternative plans can be compared and evaluated. Thus each plan can be examined and appraised to determine how well it attains the specified objectives. Kahn (1971) defines the extent to which an alternative satisfies the objectives as its effectiveness. The concept of plan effectiveness is a central aspect of the evaluation process. However, the measurement of plan effectiveness invariably involves both objective and subjective measurements. How these are handled will be discussed in the next section of the thesis.

#### 4.4. Principles Of Measurement.

##### 4.4.1. Incommensurability Of Plan Criteria.

The preceding sections of this chapter have dealt with the aspect of the relative relationship of criteria in the value-goal-objectives hierarchy. However, to effectively evaluate a set of alternative plans the study goals and objectives must be translated into criteria. It will be remembered that plan criteria are specific measurements which are developed by the analyst to reflect the degree to which particular objectives are attained. Thus the ability of the

analyst to measure plan performance is one of the key aspects in undertaking a comparative evaluation.

Evaluation criteria that are commonly used in transportation planning to measure plan performance can be categorised into three fundamental groups:

- \* Costable - criteria whose nature allows a definite cost figure to be derived for them, eg construction cost and road-user cost.
- \* Quantifiable - criteria for which a definite cost figure cannot be ascertained but for which some type of cardinal measure can be determined, eg number of displaced homes, and amount of land accessible for different uses.
- \* Qualitative - criteria that can neither be costed nor cardinally measured but can be described in verbal terms and sometimes ordinally measured, eg social, recreational and aesthetic considerations.

The evaluator wherever possible would prefer all the criteria to be one measurement category, for then all the criteria can be aggregated into one total plan performance index for each scheme being compared. An optimal decision rule can then be applied and thus, if all the criteria are costable then the scheme with the greatest net benefit, is the preferred plan.

However, in the evaluation of alternative transportation plans it is generally not possible for all the relevant measurements to be confined to the costable group of criteria. The evaluation criteria usually contain all three categories, ie costable, quantifiable and qualitative.

One of the principal problems in the measurement of plan evaluation is the incommensurability of measurement units and scales. Since there is no scale of absolute value, (the monetary value scale is probably the best that has been developed to date), there have been various attempts to overcome the problem of incommensurable evaluation criteria by adopting different transformation scoring functions.

#### 4.4.2. Measurement Scales.

The measurement of plan criteria involves assigning a numerical unit or scale to represent the performance or characteristics of a certain parameter. There are, however, various kinds of rules that control the use of numerical scales. The most important rule for any numerical scale is that an isomorphic relationship must be established, ie there must be a direct relationship between the characteristics of

the numerical scale and the characteristics of the parameter being measured. Therefore, the accuracy of measurement of any parameter is conditioned by the ability of the number system to model or represent the observations in the real world.

Hodge (1963) in his review of measurement scales states that there are principally four properties for which numbers are used as models in plan evaluation.

- \* Identity : numbers may serve as labels or names to identify items or class such as in land use classification.
- \* Order : numbers are placed in a consistent and sequential order to reflect the order of items or the position of a specific quality in a series.
- \* Interval : numbers are ordered on a relative continuous scale and reflect the relative differences or distances between items such as one uses in indicating calendar time.
- \* Ratio : the numbers represent an absolute scale that has a unique origin that is real and determinate.

Based on the above four properties of numbers it is possible to classify into four classes the different measurement scales commonly used in plan evaluation. The scales are listed in order of increasing information content.

- \* Nominal scale
- \* Ordinal scale
- \* Interval scale
- \* Ratio scale

#### (i) Nominal Scale.

The nominal scale is the simplest form of measurement and consists of using numbers merely to identify objects or characteristics. This scale forms the basis of all methods of categorisation and is often used in various environmental and land-use classification techniques (Hill, Kaplan and Scott, 1974 and McHarg, 1969). The land-use data bank operated by the Cape Town City Council is actually a nominal scale which attaches numbers to various characteristics of land-use (Morris, 1974).

However, as Hodge states, each class of scale has certain properties which must comply with certain mathematical axioms. For nominal scales these axioms are: Firstly "reflexibility", ie any pair of objects must clearly belong to the same category. Secondly, the relations of equality must be "symmetric", ie if  $a = b$  then  $b = a$ . Thirdly, the relations of equality must be "transitive", ie if  $a = b$  and  $b = c$  then  $a = c$ . Thus, the above three rules form the mathematical basis of a nominal scale.

Therefore, when using the nominal scale the analyst must remember that these numbers have no inherent meaning, and thus, they cannot be aggregated. The only meaningful numerical property they have is identity and the only legitimate arithmetic operation is counting.

(ii) Ordinal Scale.

The ordinal scale permits the analyst to order or rank different objects or characteristics, ie one is able to say scheme A is better than scheme B, and scheme B is better than scheme C, etc. Therefore the only numerical property measured is that of order, the relative difference between A and B is not measured.

Ordinal scales must comply with the three axioms of nominal scales and in addition a further rule of "transitivity", ie if  $a < b$  and  $b < c$  then  $a < c$ . Thus like nominal scales, ordinal scales are not amenable to arithmetic manipulation, since the only numerical property that is measured is the quality of order or rank. It will be shown in the following section that if the limitation of the ordinal scale is not realised grave errors can be made in the evaluation and selection phase.

(iii) Interval Scale.

The interval scale has a higher information content than the previous scales, in that it is possible to determine not only the order but also how large the relative difference is between the objects or characteristics being measured. The interval scale values are open to most arithmetic operations and can be statistically tested. The temperature scales, Fahrenheit and Centigrade and the measurement of noise in decibels are examples of interval scales.

(iv) Ratio Scale.

The ratio scale is similar to the interval scale except the numbers represent a scale with an absolute zero, rather than a relative or arbitrary zero as occurs in interval scales. The ratio scale values are open to most mathematical operations and can be statistically tested. The physical scales are the most common examples of ratio scales, eg length, mass, time and money.

The purpose of measurement in plan evaluation is to maximise the information content presented to a decision-maker in the choice situation. The foregoing has shown that the interval and ratio scales are the higher order scales with respect to accuracy of measurement and mathematical manipulation and should therefore be used whenever practicable.

Thus in the evaluation of alternative transportation plans the analyst endeavours to measure all plan criteria in appropriate physical units, eg length, time, decibels, money, etc. However, the incommensurability of these physical units present the analyst with problems of comparability. For instance how important is the difference in the traffic noise level in relation to construction cost or the difference in the number of houses displaced relative to the area of parkland taken.

To overcome the problem of comparing items measured in different units, several techniques have been developed which attempt to transform the different physical units into units of relative value. However, in establishing a common metric the limitation of the measurement scales has not always been recognised by the analyst. In certain techniques the basic mathematical axioms of the scale have been infringed which then invalidates the ensuing evaluation. Kazanowski (1968) has found that common errors introduced in the search for units of relative value follow a sequential pattern which he has termed the "ranking - weighting - utility fallacy". On account of their common use and their importance in plan evaluation a brief description of these transformation scaling procedures is relevant.

#### 4.4.3. Transformation Scaling Procedures.

When alternative plans are being evaluated on the basis of either quantifiable criteria that do not have a common metric or by both quantifiable or unquantifiable criteria, a tabular display approach is usually used. The criteria selected for the evaluation are identified at the tops of the columns and normally are arranged in decreasing importance of criteria, from left to right (see Table 4-1). The alternative plans are then listed vertically, with the alternative that meets the first (the most significant) criterion the best listed first, and so on. This is sometimes known as the "north-west corner" rule.

To demonstrate the different transformation scaling procedures, consider the typical tabular array of alternative schemes versus measurement criteria, Table 4-1. It will be noticed that criteria 1 to 4 are ratio scales whilst criterion 5 is a nominal scale.

TABLE 4-1 : TYPICAL SCHEMES VERSUS MEASUREMENT CRITERIA.

CRITERIA SCHEME	1 CAPITAL COST ( Rands - Millions)	2 HOUSEHOLDS DISPLACED (No)	3 OPEN SPACE AND PARK LAND TAKE (ha)	4 HOUSEHOLDS AFFECTED BY NOISE > 75d.B(A)	5 AESTHETIC IMPACT
A	10.0	120	12,2	50	Poor
B	11.1	80	15,0	60	Poor
C	14,2	110	10,1	55	Good
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

The first problem in evaluating the alternative scheme performances is that there is no common metric and hence it is often decided to reduce the complexity by ranking the schemes. The purpose of introducing the "lower" ordinal scale of measurement is to overcome the problem of incommensurability of the performance criteria.

It is a simple matter to objectively rank in order of preference criterion 1 to 4. However, criterion 5 (which is qualitative in nature and therefore only nominally measured) must for compatibility of scales be transformed to the higher ordinal scales. Thus, for example, the analyst (or group of experts) must subjectively distinguish between Plan A and Plan B, which have both been nominally categorised as having a poor aesthetic impact. In general, non quantifiable factors are ranked by applying judgement on the basis of a pairwise comparison of the alternatives.

This transformation allows integers of order to be entered in Table 4-1 to give the ordinal ranking of each alternative-performance set, (Table 4-2).

TABLE 4-2 : ORDINAL RANKING ARRAY.

CRITERIA SCHEME	1	2	3	4	5
A	1	3	2	1	3
B	2	1	3	3	2
C	3	2	1	2	1
⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮

The tabular ordinal array (Table 4-2) presents the original information (Table 4-1) in a mathematically convenient and compact way. However, as Luce and Raiffa (1957) so aptly comment, this convenient and compact display is a source of potential trouble, since the analyst must exercise an almost inhuman self-control not to read into these numbers those properties which numbers usually enjoy. Section 4.4.2 showed that the only numerical property that is measured in this array is the quality of order or rank and it is therefore meaningless to add or multiply the individual indices.

The above limitations of the ordinal scale<sup>o</sup> give rise to certain evaluation drawbacks. Firstly, since no arithmetic addition or multiplication is permissible, numerical weights cannot be used in ranking methods. Secondly, the ranking scores cannot be unified into a single numerical value of plan performance. The only legitimate procedure of evaluation, therefore, is to compare each alternative on a pairwise comparison basis.

From Table 4-2 it can be seen that if all the criteria are of equal weight, then by pairwise comparison:

Plan A is better than plan B  
 Plan C is better than plan A  
 therefore select plan C

The resulting preferred order of plans would be Plan C, Plan A and Plan B.

The major disadvantages of the ranking array is that it fails to distinguish the incremental differences between alternatives and it cannot accommodate a numerical weighting system. (Carter et al, 1973). Therefore, not surprisingly recent research efforts have focused on rating and utility

methods to transform plan performance into commensurate units.

The simplest rating scale is the cardinal ranking (or rating) scale. Here, each scheme is comparatively assessed and scored on a continuous interval scale (usually 0 to 10) for each criterion. This scale can also accommodate a numerical weighting system. Table 4-3 illustrates the new array, where the preferred order of plans would be Plan A, Plan B, Plan C, etc. (Note, high scores are better than low scores).

TABLE 4-3 : CARDINAL RANKING OR RATING ARRAY.

SCHEME	CRITERION	1	2	3	4	5	PLAN RATING
	WEIGHT	6	3	4	2	5	
A		8	2	6	6	3	105
B		6	7	3	4	4	97
C		1	3	7	5	7	88
⋮		⋮	⋮	⋮	⋮	⋮	⋮
⋮		⋮	⋮	⋮	⋮	⋮	⋮
⋮		⋮	⋮	⋮	⋮	⋮	⋮

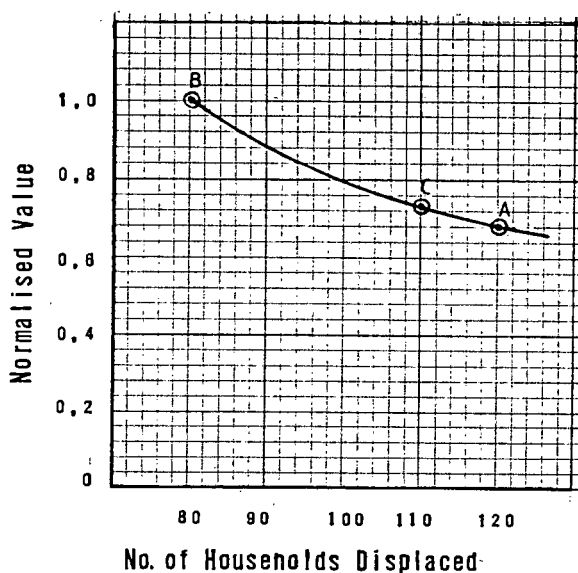
However, the cardinal rating method too has certain drawbacks. The subjectiveness of the scoring is inexact and there is uncertainty whether a criterion should be scored 8 : 6 : 1 or 8 : 6 : 2 or 8,6 : 5,6 : 2,3. The subjectiveness of the scoring thus introduces too much spread into the plan rating scores.

To control the spread in the plan score, the next step is to use a type of transformation function to rationalise the individual scores. A commonly used function is the normalised transformation function. In this procedure the score of plan performance is relative to the best alternative; ie the best alternative is assigned the relative value 1,0 and all other alternatives are in direct proportion less than one. The transformation function used to produce normalised values is shown in Figure 4-4. The resultant evaluation array is shown in Table 4-4 where the preferred order of plans would be Plan C, Plan B, Plan A.

TABLE 4-4 : NORMALISED ARRAY.

SCHEME	CRITERION	1	2	3	4	5	PLAN RATING
	WEIGHT	6	3	4	2	5	
A		1,0	0,67	0,83	1,00	0	13,33
B		0,90	1,00	0,67	0,83	0,25	13,99
C		0,70	0,73	1,00	0,91	1,0	17,21
.		.	.	.	.	.	.
.		.	.	.	.	.	.
.		.	.	.	.	.	.

FIGURE 4-4  
NORMALISED TRANSFORMATION  
FUNCTION



It will be noted that the normalised function is non-linear and is asymptotic to the base with a bias towards 1.0. Thus the spread in the values is controlled relative to the best alternative for each specific criterion.

A major drawback of the normalised array is that assumptions have to be made about non-quantifiable criteria in order for them to be normalised.

In order to score non-quantifiable criteria, the analyst would have to use a "relative" quality judgement scale such as shown in Figure 4-6. However, it will be seen that this is a different type of transformation function and there is now not a uniform transformation scale used for all criteria.

Hence, a normalised array cannot handle in a consistent manner the plan criteria that are both quantitative and qualitative in character.

An alternative to the normalised value transformation function is the relative rating transformation function as suggested by Jessiman and others (1967). This function has a linear form, with the best alternative again receiving the value 1,0 but the worst alternative receiving no value. Each other alternative receives a value which is linearly proportional its position relative to the best and worst alternative. Figure 4-5 shows the transformation function and Table 4-5 shows the relative rating array. In this array the preferred order of plans would be Plan C, Plan A, Plan B.

TABLE 4-5 : RELATIVE RATING ARRAY.

SCHEME	CRITERION	1	2	3	4	5	PLAN RATING
	WEIGHT	6	3	4	2	5	
A		1,0	0	0,57	1,0	0,0	10,28
B		0,74	1,0	0	0	0,25	8,69
C		0	0,25	1,0	0,5	1,0	10,75
⋮		⋮	⋮	⋮	⋮	⋮	⋮
⋮		⋮	⋮	⋮	⋮	⋮	⋮
⋮		⋮	⋮	⋮	⋮	⋮	⋮

FIGURE 4-5  
RELATIVE RATING FUNCTION  
FOR QUANTITATIVE CRITERION

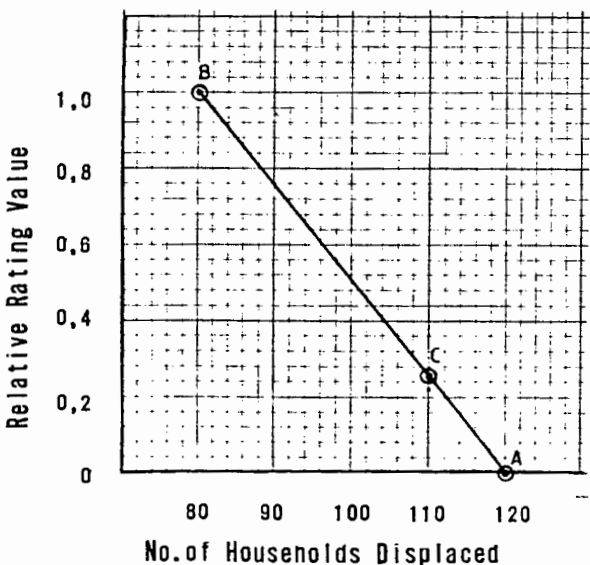
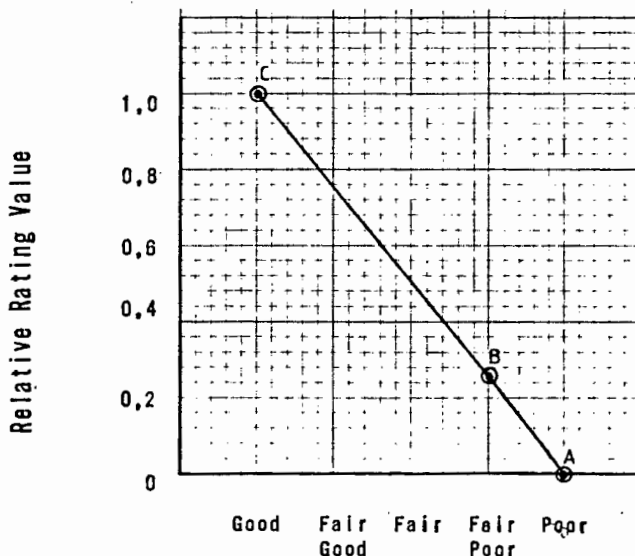


FIGURE 4-6  
RELATIVE RATING FUNCTION  
FOR QUALITATIVE CRITERION



For non-quantifiable criterion, eg criterion 5, aesthetic impact the analyst could legitimately use a quality judgement scale such as that shown in Figure 4-6. The relative rating transformation function can thus accommodate both quantitative and qualitative criterion.

One obvious drawback is that the best alternative receives a maximum value of 1,0 even though it may be far from perfect and conversely the worst alternative receives a value of zero, even though it may be almost as good as the best alternative, eg criterion 4.

Lin and Hoel (1977) have shown that another drawback of this transformation scale is that when a new alternative is added to the original set of alternative plans a change in the preference order of the plans from the original evaluation can occur, even if the new alternative is an inferior alternative. This shortcoming, is a result of the relative scale that is used.

In order to overcome the above problems, utility functions are often proposed to evaluate alternative schemes within each criterion. The concept of utility is a measure of the worth or satisfaction that an individual or group attach to some object or consequence. The utility function is based on ratio scales and therefore, does not have a relative or arbitrary datum, since the upper and lower bounds of the scale are predetermined. The utility transformation function has the advantage of not being affected by the addition (or deletion) of another alternative. However, like everything in evaluation, there is a trade-off and the above advantage must be weighed against the fact that it is far more difficult to define the different utility functions than the simple-to-use relative rating scale.

The analyst must first establish the maximum and minimum desirable or acceptable limits between which each criterion value can range. The second step, once the upper and lower bounds of the function have been determined, is to decide on the shape of the function that best describes the utility of the specific plan consequence. Baxa (1978) reports that presently, both steps are established by subjective judgement, at best based on intuition - past experience and at worst on a relative rating function.

Figures 4-7 and 4-8 demonstrate typical utility transformation functions, which in turn produce the utility array, Table 4-6. In this array the preference order of plans would be Plan C, Plan A, Plan B.

TABLE 4-6 : UTILITY VALUE ARRAY.

SCHEME	CRITERION	1	2	3	4	5	PLAN RATING
	WEIGHT	6	3	4	2	5	
A		0,81	0,78	0,27	0,80	0,0	9,88
B		0,72	0,90	0,18	0,60	0,08	9,34
C		0,49	0,81	0,35	0,70	1,0	13,17
.		.	.	.	.	.	.
.		.	.	.	.	.	.
.		.	.	.	.	.	.

FIGURE 4-7:NON-LINEAR UTILITY FUNCTION FOR NUMBER OF HOUSEHOLDS DISPLACED

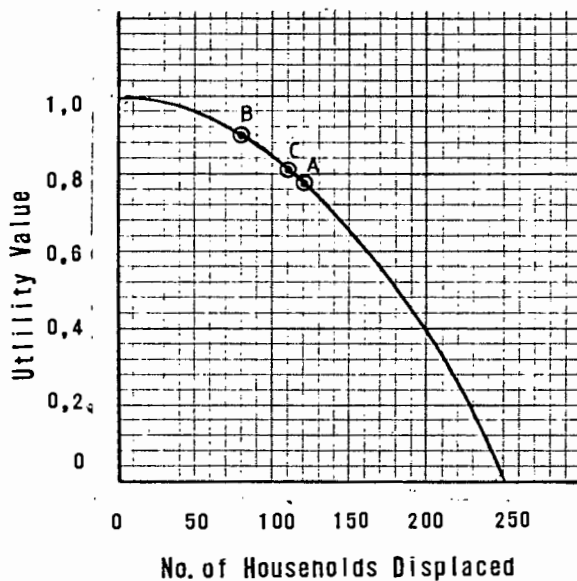
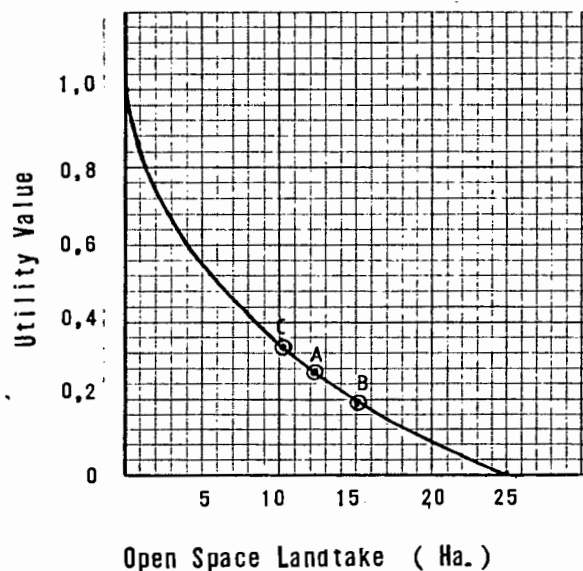


FIGURE 4-8:NON-LINEAR UTILITY FUNCTION FOR OPEN SPACE LANDTAKE



Although, as Figures 4-7 and 4-8 have shown, defining the utility function can be problematic, it does force the analyst to think of the complete range of values of an objective within which all the plan alternatives must fall. It is suggested that this thought process can aid certain aspects of creative thinking (see Section 2.6.1) which in turn can aid the generation of further (better) alternatives.

However, it can be seen that the utility function too has its limitations. There is still a high degree of subjectivity associated with this approach since in most cases the absolute upper and lower bounds of the utility scale are not referenced to a true ratio scale. Even when agreement is

reached between the analysts with respect to the determination of zero and unity on the utility scale, such agreement provides no assurance of any third party's agreement (eg decision maker).

This section has shown that unless the basic rules of numbers and measurement scales are recognised, the ensuing evaluation may not be valid. Similarly, the transformation value functions used in all the relative value - utility based evaluation techniques have related measurement scale limitations, which if not understood can provide fallacious information for decision making. It is clear that whatever transformation scale is used, it is not possible to measure everything and subjective judgement is still needed in the evaluation process. The manner in which value judgements are structured into the various evaluation methodologies will be examined in Chapter 5.

#### 4.5. The Null Alternative.

The plan evaluation process centres around comparing the ability of a set of mutually exclusive alternatives to achieve a set of common objectives. One alternative that should be considered in any set of alternatives is the do-nothing or null alternative. The null alternative generally represents the consequences of the continued operation of the highway or transit facility without improvement. Thus the null alternative is not to be confused with a no-change situation.

The inclusion of the null alternative in the evaluation is important for two reasons. Firstly, it provides a base condition against which the other alternatives can be compared. The provision of a common comparative base is also a practical way of overcoming some of the limitations of the rating-utility transformation functions mentioned in the previous section. Secondly, it demonstrates to the decision maker the consequences of not implementing any of the new proposals - ie of doing nothing.

#### 4.6. Criteria Selection To Indicate Plan Performance.

Section 3.5 demonstrated how general statements of goals and objectives can be interpreted into qualitative and quantitative criteria to measure plan performance.

Thus once the analyst has established by consultation the hierarchical goal structure, a set of criteria can be drawn up to measure plan performance. It would be useful if a set of rules or procedural steps could be applied to structure the use of criteria in the evaluation process. Beimborn (1976) suggests the following procedures:

- (i) Certain criteria have minimum threshold values that must be met, eg engineering standards and only alternative plans that comply with these standard criteria should be designed and thus evaluated.
- (ii) The analyst should endeavour for reasons of simplicity to eliminate criteria whenever possible. The analyst is primarily interested in evaluating the differences between alternatives, for if all the alternative plans are equal or about equally successful at meeting certain criteria, those criteria will not affect the decision and can therefore be eliminated.
- (iii) If a plan falls below any other plan in all the criteria used then that plan can be eliminated from the evaluation. Beimborn terms this as the elimination of plans by the principle of dominance.
- (iv) If a pair or set of criteria are similar in the consequence that they measure, they should be combined into a single criterion. Often in practice, under the guise of comprehensiveness, many criteria fall into this category and if not combined, lead to a measure of "double counting" or bias in the evaluation.
- (v) Criteria can be measured in absolute totals, averages, or as a net change over a basic scale. When an interval scale is used as a criterion of measurement, the analyst must always check that it is significant when compared to total or average scales of measurement. For example; is a relative time saving of two minutes in a total journey time of 120 minutes a significant criterion of measurement? Only the experience and judgement of the analyst(s) can determine whether it is significant. In the comparison of plans against a certain criterion, it may also not always be appropriate to interpret the comparison on a linear basis. For example; is the criterion of a 10 minute travel time saved twice as good as a 5 minute travel time saved?
- (vi) Following from point (iv), the analyst must guard against developing a surfeit of criteria. The adoption of many criteria on the grounds of comprehensiveness must be weighed against the increasing complexity of the ensuing comparative evaluation. Kazanowski (1968) suggests that most selections are based on relatively few criteria (eg cost and some performance attribute, eg capacity). He puts forward the following relationship (Figure 4-9) between the number of criteria and their importance to a decision. It should be noted that criteria referred to are disaggregate in nature.

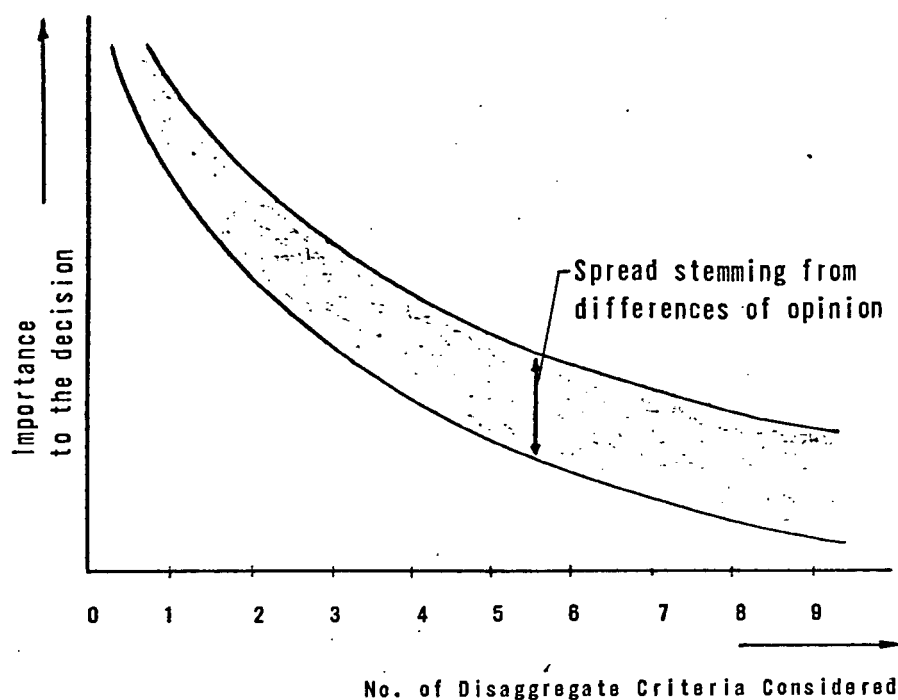


FIGURE 4-9 : GENERAL RELATIONSHIP BETWEEN IMPORTANCE TO A DECISION AND NUMBER OF CRITERIA CONSIDERED.  
(Source: Kazanowski, 1968 p. 134)

As the number of factors to be considered increases, the quality of an individual decision would be expected to increase more slowly. Thomas and Schofer (1970) have hypothesized the relationship between the quality of a decision and the number of criteria (Figure 4-10). They suggest that as more and more (disaggregate) criteria are developed there is a point of diminishing returns, beyond which the decision making process can become overloaded with data. Emery (1974) has shown that a similar relationship exists between quality of evaluation as a function of the quality of information used in the evaluation. (See Figure 1-2). Gilbert and Jessop (1978) and Grigg (1978), from their respective research, suggest that no more than about seven groups (criterion) of information can be reasonably distinguished and compared by humans. This limitation must be recognised when alternative plans are being evaluated against a set of incommensurable or disaggregate criteria.

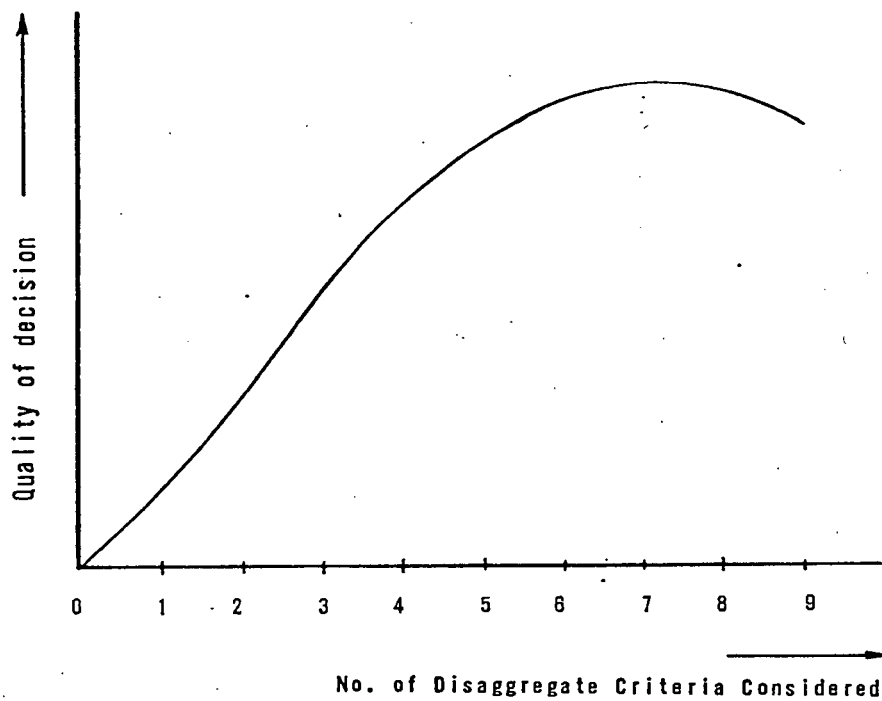


FIGURE 4-10 : GENERAL RELATIONSHIP BETWEEN QUALITY OF DECISION AND NUMBER OF CRITERIA CONSIDERED.  
(Source : Thomas and Schofer, 1970, p. 64)

## REFERENCES FOR CHAPTER 4

- BAXA, J.V. (1978). "An Evaluation Procedure for Short Term Planning". National Institute for Transport and Road Research. CSIR. Report TPRR9.
- BEIMBORN, E.A. (1976) "Structured Approach to the Evaluation and Comparison of Alternative Transportation Plans". Transportation Research Record, No 619.
- BELLOMO, S.J., MEHRA, J.J., STOWERS, J.R. and others (1977). "Evaluating Options in Statewide Transportation Planning /Programming. National Co-operative Highway Research Program (NCHRP). Report 179. Transportation Research Board. pp. 65-70
- CARTER, E.C., HALL, J.W. and HAEFNER, L.E. "Incorporating Environmental Impacts in the Transportation System Evaluation Process". Highway Research Board No. 467.
- DAJANI, J.S. and GILBERT, G. (1975) "Delphi Predictions and Cross Impact Simulation". Journal of the Urban Planning and Development Division of A.S.C.E. Vol UPl.
- \* ECKENRODE, R.T. (1965) "Weighting Multiple Criteria" Management Science. Volume 12. No. 3.
- GILBERT, D. and JESSOP, A. (1978) "Taxonomic Evaluation" Transportation. Elsevier:Amsterdam Vol. 7
- GORDON, M.E. WILEY, J.W. and SULLIVAN, T.D. (1979) "Scaling the Desirability of Consequences of Transportation Plans: An Application of the Constant-Sum Paired Comparison Procedure". Institute of Transportation Engineers Journal. Volume 48. No. 7.
- GRIGG, A.O. (1978) "A Review of Techniques for Scaling Subjective Judgements". Transport and Road Research Laboratory Report No. SR 379
- HEIGHTCHEW, R.E. (1979) "T.S.M. Revolution or Repetition?" Institute of Transportation Engineers Journal. Volume 48. No. 9.
- HILL, M. (1967) "A Method for the Evaluation of Transportation Plans". Highway Research Report, No. 180.
- HILL, M. (1968) "A Goals-Achievement Matrix for Evaluating Alternative Plans". Journal of American Institute of Planners. Volume 34 No. 1.
- HILL, KAPLAN and SCOTT (1974) "Land Use Evaluation : National Route 2, Section 8 and 9 (Nature's Valley to Elands River).
- HODGE, G. (1963) "The Use and Mis-use of Measurement scales in City Planning". Journal of American Institute of Planners. Volume 29. No. 2.

- JESSIMAN, W., BRAND, D., TUMMINIA, A. and BRUSSEE, C.R. (1967) "A Rational Decision-Making Technique for Transportation Planning". Highway Research Record 180.
- KAHN, A.M. (1971) "Cost-Benefit Analysis of Information Acquisition in Transportation Planning". Environment and Planning Journal. Volume 3.
- KAZANOWSKI, A.D. (1968) "Cost-Effectiveness - the Economic Evaluation of Engineered Systems". Editor J. Morley-English. Wiley. pp. 140-144.
- KAZANOWSKI, A.D. (1968a) Ibid., p.134
- LEAKE, G.R. and DIX, M. (1979) "Weighting Transportation Objectives Using the Method of Pair Comparisons". Traffic Engineering and Control. May 1979 pp. 246-252.
- LIN, F. and HOEL, L.A. (1977) "Structure of Utility-Based Evaluation Approaches". Transportation Engineering Journal Division of A.S.C.E. Volume T.E. 2.
- LINSTONE, H.A. and TUROFF, M. (Editors) (1975) "The Delphi Method : Techniques and Applications". Addison-Wesley Publishing Co. Inc. pp. 402-405
- LUCE, R.D. and RAIFFA, H. (1957) "Games and Decisions". Wiley, p.12
- McHARG, I.L. (1969) "Design with Nature". Natural History Press.
- \* MEYERSON, M. and BANFIELD, E.C. (1955) "Politics, Planning and the Public Interest". The Free Press, Illinois. pp. 322-329
- MORRIS, S.S. (1974) "A Systems Approach to Metropolitan Management". Construction in Southern Africa. August 1974.
- MUNN, R.E. (Editor). (1975) "Environmental Impact Assessment, Principles and Procedures". Scope 5 Report. Toronto, Canada. pp. 20-21
- THOMAS, E.N. and SCHOFER, J.L. (1970) "Strategies for the Evaluation of Alternative Transportation Plans". National Co-operative Highway Research Program (NCHRP) Report 96. Highway Research Board pp. 63-64
- WACHS, M., HUDSON, B.M. and SCHOFER, J.L. (1974) "Integrating Localised and Systemwide Objectives in Transportation Planning". Traffic Quarterly pp. 159-184
- WACHS, M., HUDSON, B.M. and SCHOFER, J.L. (1974a) Ibid., pp. 161-165
- \* Publications not available to the author.

## CHAPTER 5 ALTERNATIVE METHODS FOR PLAN APPRAISAL

5.1 REVIEW CRITERIA .. .. .	5-1
5.2 CLASSIFICATION OF METHODOLOGIES .. .. .	5-2
5.3 COST BENEFIT APPRAISAL .. .. .	5-3
5.3.1 Characteristics of the Method .. .. .	5-3
5.3.2 Capabilities and Limitations .. .. .	5-8
5.3.3 Closure .. .. .	5-12
5.3.4 Broaden Scope of COBA .. .. .	5-13
5.4 COST EFFECTIVENESS TECHNIQUE .. .. .	5-16
5.4.1 Characteristics of the Method .. .. .	5-17
5.4.2 Capabilities and Limitations .. .. .	5-26
5.4.3 Closure .. .. .	5-28
5.5 RANKING AND RANKING MATRICES .. .. .	5-30
5.5.1 Rank-based Expected Value Method .. .. .	5-30
5.5.2 Capabilities and Limitations .. .. .	5-31
5.5.3 Relative Rating Matrix Method .. .. .	5-31
5.5.4 Capabilities and Limitations .. .. .	5-33
5.5.5 Closure .. .. .	5-35
5.6 UTILITY METHOD OF APPRAISAL .. .. .	5-36
5.6.1 Characteristics of the Method .. .. .	5-36
5.6.2 Capabilities and Limitations .. .. .	5-39
5.6.3 Closure .. .. .	5-42
5.7 GOALS ACHIEVEMENT MATRIX .. .. .	5-44
5.7.1 Characteristics of the Method .. .. .	5-44
5.7.2 Capabilities and Limitations .. .. .	5-48
5.7.3 Closure .. .. .	5-52
5.8 SUPPLEMENTARY EVALUATION PROCEDURES .. .. .	5-54
5.8.1 Marginal Analysis .. .. .	5-54
5.8.2 Contingency Analysis .. .. .	5-55
5.8.3 Equity Analysis .. .. .	5-57
REFERENCES FOR CHAPTER 5 .. .. .	5-59

## 5. ALTERNATIVE METHODS FOR PLAN APPRAISAL.

---

### 5.1. Review Criteria.

The preceding chapters have explored the main characteristics of evaluation and the linkages between evaluation and the other planning activities. This chapter appraises the different methodologies that are currently used for evaluating highway/transportation plans.

The purpose of this part of the thesis is two-fold:

- \* To determine the principle capabilities and limitations of the different methodologies used in the evaluation phase of the planning process.
- \* It is hoped that by understanding each method's respective strengths and weaknesses the appropriate technique will be selected for the different aspects of evaluation that present themselves in the transportation planning scene.

In order to appraise the different evaluation methodologies, the first step must be to establish a comparative base, ie a set of desirable attributes or review criteria. Chapter 4 identified certain key attributes upon which the whole "internal" rationale of the evaluation process is based.

- \* Planning and time horizons
  - (i) Flexibility - can the methodology handle evaluation at different levels of planning or is it designed to evaluate at one specific level of planning?
- \* Value framework represented
  - (i) Comprehensiveness - can the full range of values be accommodated, eg efficiency, equity and environmental amenity?
  - (ii) Weighting of criteria - can a specific weighting system be used and how are the weights applied?
- \* Treatment of incommensurable criteria
  - (i) Transformation measurement scales - with the conversion of the different factors to a common scale, are the principle axioms of measurement obeyed?
  - (ii) Non-quantitative criteria - how are the qualitative criteria evaluated and how is their subjective judgement structured into the methodology?

In addition to the above key aspects, Jain et al. (1977) suggests that certain "external" review criteria are also pertinent, namely:

- \* Resource requirements
  - (i) Data requirements - does the methodology require data that is easy or difficult to obtain ?
  - (ii) Manpower requirements-are special skills required?
  - (iii) Costs - are some methods more costly to use than others ?
- \* Replicability
  - (i) Ambiguity - what is the relative ambiguity in the methodology? How are value judgements incorporated into the methodology?
  - (ii) Analyst bias - to what degree will different analysts using the same methodology tend to produce widely differing results ?
- \* Information transfer
  - (i) Presentation - is the format of the methodology presented primarily as a decision document or an information document ?
  - (ii) Format - is the information matrix or package presented to the decision maker in a comprehensive and clear manner ?

The appraisal of the different methodologies will take the format of a general descriptive survey of the method's characteristics and the evaluation principles upon which it is based. The above review criteria will then be used to assess the scope and character of each method and identify its relative strengths and weaknesses.

## 5.2. Classification Of Methodologies.

The evaluation methods that are currently used for evaluating transportation plans can be categorised into the following groups:

- \* Cost benefit group of techniques
- \* Cost-effectiveness technique
- \* Ranking and rating matrices
- \* Utility matrices
- \* Goal-achievement matrix
- \* Supplementary evaluation techniques

An overview of the attributes of each approach will now be undertaken.

### 5.3. Cost Benefit Appraisal.

The transportation sector as a whole contributes some 12% of the gross national product of the Republic (Schoeman, 1980). Furthermore, the nature of transportation facilities are typically big, costly and their provision is not undertaken lightly or completed quickly. It is therefore not surprising that appropriately sophisticated methods of economic evaluation have been developed.

Section 4.3.1 demonstrated that there is a direct linkage between an evaluation methodology and the value system adopted. The cost-benefit analysis techniques are characterised by their ability to evaluate alternative plans against the value of economic efficiency. On account of the nature of transport infrastructure, economic efficiency has traditionally been the principal criterion used to evaluate and select alternative plans.

Cost-benefit analysis was developed into a practical methodology in the United States in the 1950's as an outgrowth from the disciplines of engineering economy and water resource management (Barrell and Hills, 1972). It was soon adopted for evaluating other public sector investments, particularly highways and is often referred to as the traditional method of highway evaluation.

#### 5.3.1. Characteristics Of The Method.

##### (a) Cost and Benefits

Morley English (1968) describes cost as one element of value foregone in order to obtain a greater benefit or worth. This statement immediately poses the question; to whom should alternatives be worthwhile when assessed by a public body? In general, the consideration of costs and benefits are viewed from the public (national) standpoint. Although it is not unusual in practice for the standpoint to be narrowed down to the promoting agency's viewpoint - with the criterion of systems (facility) efficiency dominating the evaluation. However, regardless of which viewpoint is taken, the cost-benefit technique values the worth of the different factors relevant to the evaluation on the "willingness to pay" concept. Stopher and Meyburg (1976) state that factors that should be considered in the evaluation are those that the public are willing to pay or trade-off against other items of value where conflicts arise. Thus costs and benefits should only be included in the analysis if there is evidence that society is prepared to forego certain resources (costs) to achieve stated objectives (benefits). Conversely, a lack of willingness to pay for a certain objective indicates a lack of real value or worth for that objective and it is therefore not considered relevant to the cost-benefit analysis.

To aid analysis, Thomson (1974) places costs and benefits in

the following categories.

- \* Direct effects - are those which accrue to the users of facility or other people in direct physical contact with it. For example on the benefit side, cost-savings to the users of the new or improved facility. On the cost side, would be the adverse effects upon nearby property owners, residents, traders, etc.
- \* Transmitted effects - are costs and benefits which are second order effects, originating as a consequence of the direct effects. These effects are often related to the two-way linkage between transportation development patterns and urban development. For example, the effect of new highway construction on land market values. The effect can be beneficial in that the new highway may encourage the development of new industrial sites; or adverse environmental effects such as noise, vibrations, poor aesthetics, etc, can badly effect residential properties that are adjacent to a busy road corridor.
- \* Transferred effects - are those that have been transferred from one location to another because of a certain transportation plan being implemented. For example, the immediate gain in trading that usually results from the creation of a pedestrian mall would normally be balanced by a concomitant loss in trade elsewhere.

Thus, in cost-benefit analysis, costs and benefits are used as performance indicators to demonstrate the consequences of alternative plans. The traditional approach in highway planning is for the engineer to endeavour to maximise system worth by means of his design. System worth, usually reflects unitary values and is considered to be the algebraic difference between the project's benefits and costs. Simply, if the benefits are assessed to be greater than the costs then the project is considered worth-while. The preferred alternative in cost-benefit analysis is the plan with the greatest net benefit.

The traditional cost-benefit approach for highway evaluation confines its boundaries of analysis to the category of direct effects. (Some reasons for this "closed system" approach are put forward in Section 5.3.4). Transmitted and transferred effects are traditionally treated as externalities, ie the benefits are enjoyed free of charge whilst the cost will be suffered without compensation.

#### (b) Time Value of Money.

The cost-benefit group of techniques are characterised by their ability to evaluate the flow of costs and benefits that accrue to a project during its life time - for major facilities, 20 years or more - by collapsing all the evaluation criteria into a common monetary matrix. This ability to collapse the complex time frames associated with project costs and benefits is achieved by the well known process of discounting. The use of an appropriate

discount rate permits the costs and benefits to be valued according to the year of their occurrence.

Several cost-benefit techniques have been developed which recognise the ability of money to earn income over time. The more common methods of economic analysis used in transportation planning to evaluate alternative designs are:

- \* Benefit-cost ratio method
- \* Rate-of-return method
- \* Net present value method.

Each of the above methods in different ways aggregates and compares the stream of discounted benefits with the stream of discounted costs.

However, it is not the purpose of this thesis to compare the advantages and disadvantages of the above methods, since this has been done by many eminent authors. Both Wohl and Martin (1967) and Stopher and Meyburg (1976a) from their comparative studies of the above techniques, consider the net present value method to be the best method of economic analysis.

Therefore, the net present value (N.P.V.) method of appraising costs and benefits will be compared with the review criteria (Section 5.1) and consequently with the other evaluation methodologies. Thus the next section will describe the N.P.V. method in a little more detail.

#### (c) Net Present Value Method.

Winfrey (1969) describes the net present value (N.P.V.) method as a method which gives the algebraic difference in the present worths of both outward cash flows (eg construction costs) and inward flows of income (eg road-user benefits). Therefore, when choosing among mutually exclusive alternatives, the alternative with the greatest net present value is the one with the greatest economy. Further, any alternative with a net present value less than zero is not economically justifiable.

The net present value of any alternative, X, at discount rate,  $i$ , for a period of analysis,  $n$ , is:

$$NPV_x = \sum_n \text{discounted benefits}_i - \sum_n \text{discounted costs}_i$$

In the United States of America, Britain and France, where systematic methods of economic appraisal have been developed and implemented for many years, the N.P.V. method is the preferred method of economic analysis (Leitch, 1978). It's widespread use has evolved on account of certain advantageous characteristics it has compared with the benefit-cost ratio method and the rate of return method. Wohl and Martin (1967a) suggest N.P.V.'s principal advantages are:

- (i) The net present value (N.P.V.) method will always give correct results whilst in some situations the

rate of return and cost ratio methods can give ambiguous answers.

- (ii) Following from (i) above, if the alternatives considered have different service lives or terminal dates, the N.P.V. method gives correct answers, whereas the rate of return method may not. In order to handle this problem the rate of return method requires that all alternatives be considered for the same analysis time period and reinvestment of earnings generated in the analysis period must be specifically accounted for. Therefore, computationally the N.P.V. method is much simpler and does not present problems with reinvestment decisions.
- (iii) Another computational advantage of the N.P.V. method as compared with the other methods, is that the net present value of increments of investment between successively higher investments can be determined simply by inspecting the difference of the N.P.V. Of the investments themselves. Using the rate of return method one cannot be sure that the rate of return to be obtained from an incremental analysis of investment will be equal to or greater than the cost of capital, without actually carrying out additional calculations. Again greater computational difficulties will be encountered in using the rate of return method as compared to the net present worth method.
- (iv) All costs and benefits are stated in present terms and thus are "uninflated" by interest costs which occur in the future.
- (v) The N.P.V. method produces answers that are readily understandable as comparative measures. Conversely the benefit-cost ratio method produces ratios of say 1,05 or 1,08 for two different alternatives. Information in this form makes it difficult to assess the relative viability or difference between the projects.

In summary, it can be stated that the net present value method is computationally the simplest and most reliable of the above methods. It produces information that can be easily understood by the decision maker and is least likely to cause problems arising from implied assumptions.

#### (d) Traditional Cost-Benefit Method of Evaluation.

In the opening paragraphs of this section it was mentioned that cost-benefit analysis (COBA) is often referred to as the traditional method of highway analysis. Although the exact categorisation and structure of costs and benefits may vary from project to project, Figure 5-1 below, shows a typical example of the cost-benefit model that is used for the economic appraisal of highways.

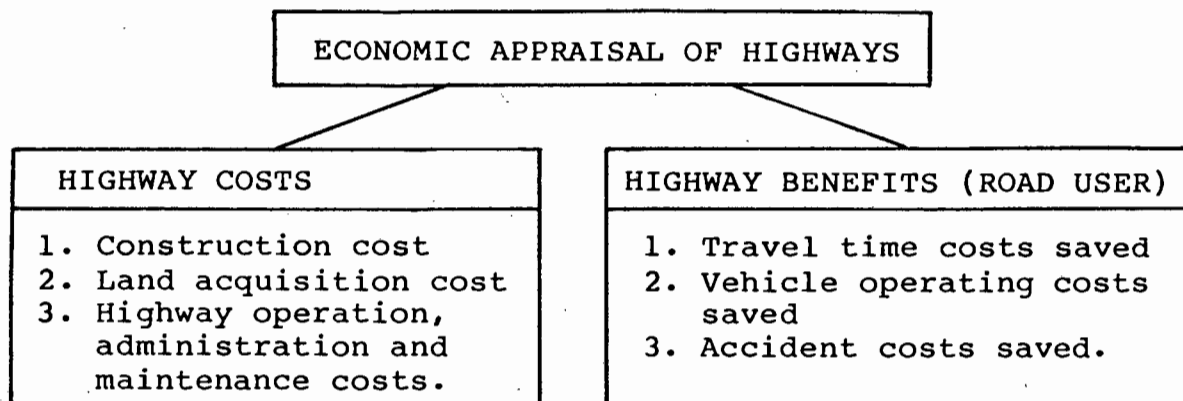


FIGURE 5-1 EVALUATION CRITERIA FOR THE ECONOMIC APPRAISAL OF HIGHWAYS.

(Source : American Association of State Highway Officials : (1973, pp. 232-237)

It is well known that the flow of costs and benefits as categorised in Figure 5-1 vary with time over the design life of the facility (see Figure 5-2 overleaf). Section 5.3.1 (b) highlighted the fact that COBA has the ability to take into account the time value of money. However, it will be seen in Figure 5-2 that the majority of costs occur (naturally) at the beginning of the design life, whilst the benefits grow at an assumed rate as the traffic increases with time, reaching their maxima at the end of the design horizon.

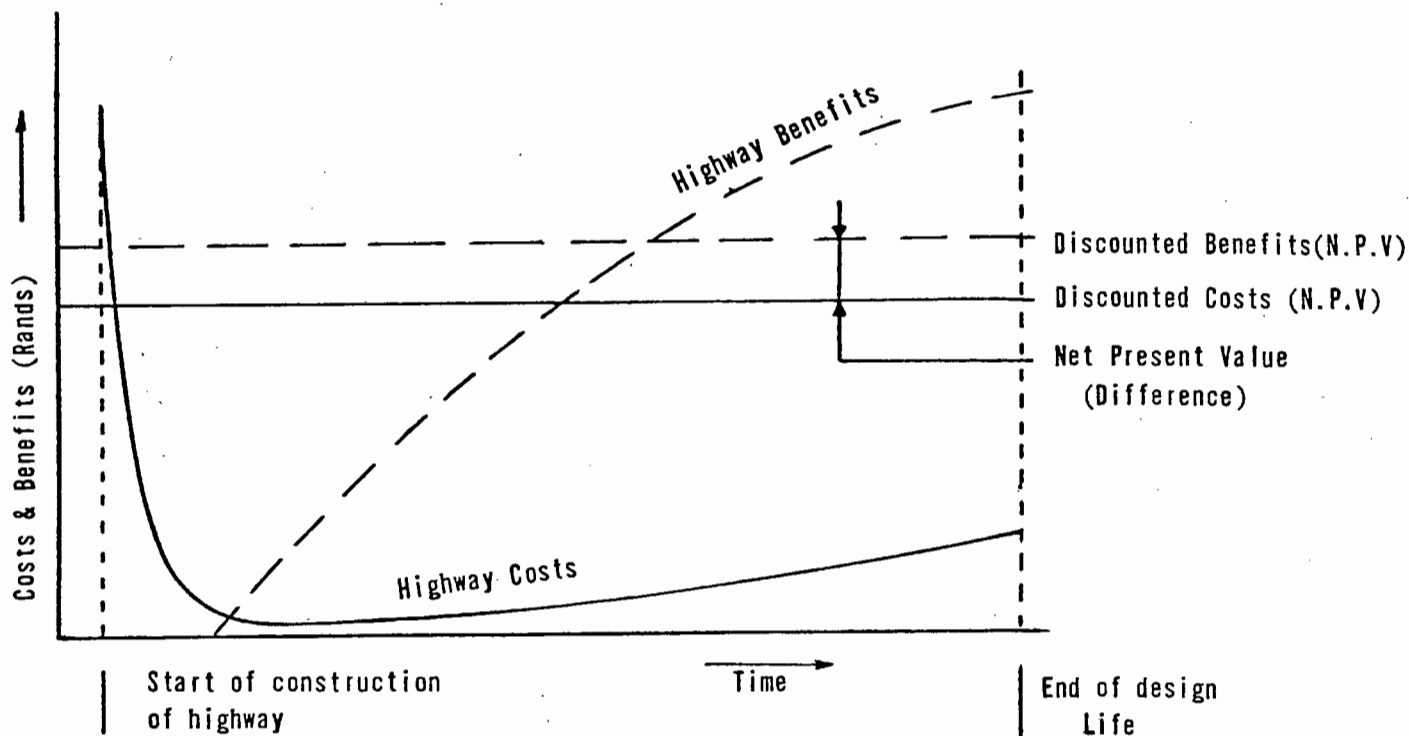


FIGURE 5-2 HYPOTHESIZED RELATIONSHIP BETWEEN COSTS AND BENEFITS OVER TIME.  
(Based on Dickey, 1975, p. 306)

On account of the uncertainty and risk that is always attached to forecasts, the cost-benefit technique has developed a formalised approach for the determination of

highway benefits. The monetarisation of highway benefits and their influence on the COBA evaluation methodology has been widely criticised and it is therefore important to discuss in more detail the component items of highway costs and benefits as set out in Figure 5-1. In an endeavour not to interrupt the comparative appraisal of the different evaluation methodologies, this discussion has been summarised in Appendix A.

However, based on the categorisation of costs and benefits shown in Figure 5-1 and using the net present value method, a typical COBA summary to be presented to the decision-maker would be as shown in Table 5-1.

		Alt.1	Alt.2	Alt.3	Alt.n
Construction Cost	(N.P.V. in Rm.)	6,214	4,982	4,104	---
Land Cost	( " )	1,219	0,890	1,076	---
Maintenance Cost	( " )	0,028	0,031	0,043	---
Total Capital Cost	( " )	7,461	5,883	5,223	---
Total Road-User Benefits	( " )	7,193	5,945	6,834	---
Net Present Value	( " )	-0,268	+0,062	+1,611	---

TABLE 5-1  
TYPICAL CATEGORIZATION OF COSTS & BENEFITS.

By comparing the total capital cost against the cost-savings to the road-users (ie the benefits) for each alternative plan, it can be seen that alternative 3 in this example has the greatest net present value and is therefore the one with greatest economy.

### 5.3.2. Capabilities And Limitations.

Dealing first with the method's good characteristics:

- (i) One of the main objectives for highway agencies is to determine the financial implications of alternative investments. Since COBA techniques were specifically developed to evaluate the economic and financial consequences, 'cost-benefit analysis' has an advantage over other evaluation methods as this is it's principal strength.

In addition, the use of money as a common measuring rod has certain advantages. Firstly, money is currently the most well developed high order

transformation measurement scale that exists and many different types of impacts and effects are amenable to either direct or indirect market evaluation. Secondly, the monetary compensation principle is now well established in the transportation planning process where people who are adversely affected are compensated financially, although, as was noted in Section 5.3.1 (A), monetary compensation for adverse effects are usually confined to those directly effected. Adverse transmitted or transferred effects are not normally taken into account in the traditional cost-benefit appraisal.

- (ii) In the author's experience it is the most widely used of all the evaluation methodologies and therefore, the analyst and the decision-maker have developed a certain amount of expertise and confidence both in its use and its presentation of results. Related to its wide use, the drawbacks of the method and the potential pitfalls have been well documented; eg the treatment of intangibles, double counting, discount rate etc. Thus a set of defined procedures have been developed to minimise the limitations of the cost-benefit analysis.
- (iii) Many sophisticated computer program packages have been developed which can accommodate a comprehensive array of design parameters and variables. (Bellomo, 1980). The use of "Standard Programs" can lead to certain data and manpower resource advantages, for example, various sensitivity tests can be undertaken which can enlighten the evaluation with little extra effort or cost. The computer modeling aspect means that there is no analyst bias in the evaluation, although the applicability and validity of the prescriptive aspects in the program must be carefully examined prior to the ensuing evaluation. In Britain there has been much public criticism of the role computer programmes like COBA have played in the overall evaluation of projects. Adams(1978) likens COBA, the computer road programmes used by the Department of Transport in England, to a "Solomon Machine".
- (iv) Cost-benefit analysis is the preferred technique when evaluating mutually exclusive alternatives with different time horizons, or with high initial cost-low recurring cost-low initial cost-high recurring cost options.
- (v) The methodology is flexible enough to operate at the different planning and time horizons that were mentioned in Section 4.2. At the systemwide level of planning, broad cost estimates would be used, ie construction costs per kilometre, lump sum structure costs, expropriation costs etc. At the project level of planning, more detailed cost comparisons would be determined. Due to its wide use, one major advantage of the COBA approach, is that there exists a good data

base of economic costs that can be used to prepare an economic comparison, regardless of the level of planning. Major public organisations, like the Department of Transport and the Provincial Administrations have continually updated standard cost schedules which aids consistent evaluation and minimises analytical bias.

Now the poorer aspects of the method are considered.

Although the criterion of plan efficiency is very important, it has been shown that it is not possible to measure and value all consequences of alternative plans on a common monetary scale. The economic efficiency criterion should therefore not be the sole basis for a decision; the evaluation process should embrace other relevant criteria - social, ecological, physical, cultural, aesthetic - into the appraisal of alternative courses of action.

- (i) The current need to evaluate social and environmental consequences of highway plans, presents major problems for the cost-benefit analysis methods. Many of these factors are qualitative in nature and cannot be market priced and as a result cannot be incorporated directly into the COBA method.

Thus, the results of the evaluation must be presented in two parts to the decision-maker; the tangibles reduced to a single figure (usually net present value) to be compared to the intangible factors. This is an unsatisfactory method of presentation, since in the final evaluation there is a definite tendency to give greater weight to the discounted factors than the undiscounted intangibles. As Barrell and Hills (1972a) state, in COBA there is an inherent bias towards schemes which are characterised by highly monetarised net present values, against schemes which may have lower net present monetary values but considerable intangible advantages. Furthermore, if there are numerous incommensurable and intangible factors, Figure 4-9 showed that as their number increases so their individual importance to the decision decreases.

- (ii) The COBA method encourages the analyst to render all consequences in money terms for eventual aggregation and evaluation. Thus, techniques have been developed to permit the analyst to make some monetary allowance for items that are not subject to market transactions. One such technique is to create "shadow prices" that are outside normal market pricing.

Shadow prices are indirect costs that are considered appropriate measures of the real value society places on them. In a highway evaluation context the cost-benefit approach has developed a sophisticated set of indirect market values for road-user benefits. The Leitch Report (Leitch, 1978a) has shown that the procedures used to value road-user benefits have been

widely and severely criticised (see Appendix A).

In addition, shadow prices have been used to value the aspects of environmental amenity, such as a fine landscape or a beautiful old building. This category of shadow pricing has created many imponderables for the COBA method. Firstly, the monetary valuation of an old building or beautiful landscape implies that the removal of any building or landscape is (economically) justified, provided the aggregate economics of the evaluation are positive. Countering this statement it is argued that it is ethically wrong to use a monetary measurement scale to appraise the qualitative values of beauty and heritage, which for many people are by definition values that are unpriceable.

Finally, the pricing of non-market items, by definition, must be subjective and introduces into the COBA value judgements which may not be explicitly apparent to the decision-maker, on account of the method's single aggregate metric.

(iii) The COBA method evaluates alternatives using the principle of economic efficiency as the prime measure of plan performance. The value of equity is not considered in the COBA framework and this clearly is a major deficiency in the method. The reason for the deficiency is primarily because COBA operates with unitary values, emphasis being placed on total aggregated benefits rather than the distribution of the benefits at a disaggregate or sectorial level. The insensitivity of COBA to distributional effects of costs and benefits can be clearly seen in the example Figure 5-3.

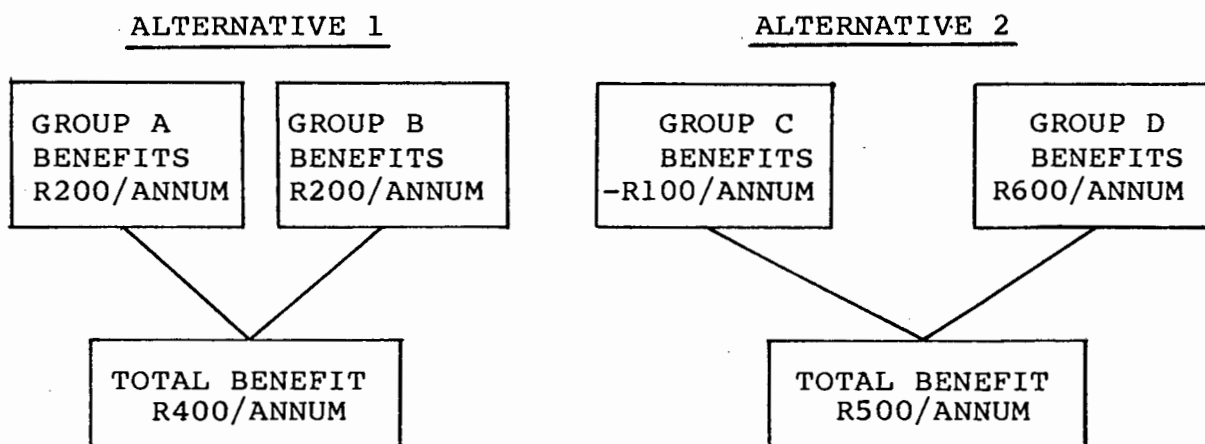


FIGURE 5-3 EXAMPLE ILLUSTRATING THE INSENSITIVITY OF COBA TO DISTRIBUTION OF BENEFITS.

Figure 5-3 demonstrates that COBA, if applied in a strictly unitary way, will always select case 2, (ie maximum net benefit), even if there are gross inequities of benefit. From a criterion of equity, case 1 would be considered a better "economic" choice, for although the total benefit is slightly smaller the benefits are apportioned more fairly.

In addition it has been suggested that the COBA as it is applied to highway / transportation evaluations, introduces further inequities, in that it favours the richer sectors over the poorer sectors of society (Mishan, 1970). The evaluation of travel times, accident costs relative to income level, increased car ownership with increasing income level, higher residential property values associated with the wealthy are all factors that critics use to suggest that COBA is nothing more than an economic arrangement that makes the rich richer and the poor poorer. Dickey (1975) considers COBA's lack of equity considerations as its principal short coming.

### 5.3.3. Closure.

It has been stated that of all the evaluation techniques reviewed, the cost-benefit methodology is the most widely used. Its widespread use results from the fact that for the evaluation of most major transportation projects in the developed and developing countries of the world, COBA is an evaluation requirement. Such diverse organisations from the World Bank to our own Department of Transport stipulate it's use, (though not always its exclusive use in project evaluation.) This favoured status is on account of its ability to appraise alternative plans against the important value of economic efficiency.

Cost-benefit analysis has the unique distinction of being the only evaluation methodology for which computer programs have been developed to aid and routinise evaluation. This attribute is because it is a totally quantified technique using a monetary system of measurement. The development of sophisticated programmes has undoubtedly enabled the method to analyse a far broader range of alternatives than would be possible with many of the other evaluation techniques. In the evaluation of metropolitan transportation alternatives where vast amounts of information must be analysed and evaluated, the computerised COBA approach has significant resource advantages compared with other methods. This is particularly so with respect to the resources of manpower and time.

As regards the review criterion information transfer, the COBA methodology's aggregate metric presents information to the decision maker in a form that facilitates decision making. In addition and depending on the categorisations of costs and benefits, the common monetary metric allows the analyst to demonstrate the various trade-offs that may occur. The comparative evaluation is however limited to costable items, the intangible items requiring a separate appraisal. Thus, one of the major criticisms of cost-benefit analysis is

its inherent economic bias and its inability to incorporate non-economic criterion into its evaluation framework.

Another major weakness of this methodology is that it is unable to embrace a comprehensive value framework to ensure that the evaluation is holistic in scope. It is particularly weak in effectively evaluating projects that have environmental or equity considerations. As is well known, many environmental factors are qualitative, ie non-economic in nature and cannot be incorporated directly into the evaluation framework. Similarly, cost benefit analysis as traditionally practised in the evaluation of transportation plans is unitary value orientated and does not appraise the distributional effects of alternatives at the group or sectorial level of analysis. Thus on account of its weakness with respect to the fundamental values of environmental amenity and equity, it has been criticised as a partial method of evaluation. In order for projects to be holistically evaluated, it is not enough to show that an alternative has the largest net benefit - it must also incorporate evaluation criteria that measure relevant environmental and equity considerations.

Further, it has been noted that to accommodate the relevant non-economic component in the evaluation, a fundamental problem of incommensurability occurs. When there is no common metric, an overall weighting system cannot be applied. A system of weights can be applied to the cost-benefit part of the evaluation but in practice this usually is not necessary, since the individual economic values should reflect their relative importance either through the market or the shadow pricing mechanism.

In closing, the principal strength of the cost-benefit method is then its ability, through the process of discounting, to compress all costs and consequences of alternatives into a single dimension - net present value. Paradoxically, the major weakness of the technique is its inherent "economic narrowness" and its inability to evaluate within its framework the incommensurable and intangible items. However, the fact that all items cannot be reduced to common monetary units, does not invalidate the method but merely reduces its effectiveness as a comprehensive evaluation technique.

#### 5.3.4. Broaden Scope Of COBA.

The following sections of this chapter (Sections 5.4; 5.5; 5.6; 5.7 & 5.8) will review some of the different evaluation procedures that have been developed to "overcome" some of the weaknesses of the cost-benefit approach. It will be noted that the "raison d'être" of all the subsequent evaluation techniques is to develop an evaluation framework that is broader in scope than the traditional cost-benefit approach as discussed in this section of the thesis. It is therefore considered prudent that a few comments be made to demonstrate why the need to broaden the scope of the cost-benefit approach has only been fairly recently recognised.

It will be noted from Figure 5-1 that the costs and benefits considered are confined to the facility provider and the facility user. Thus the analysis was evaluated as a closed system and costs and benefits external to the system (externalities) were usually not considered. There were primarily three reasons for ignoring externalities:

- (i) In the 1950's and 1960's there was a general lack of awareness of the significance of non-user costs and benefits to the evaluation, particularly with respect to the environmental and social effects of highways. Only the primary facility related effects were normally considered relevant to the evaluation. The secondary consequences of highway construction, changes in accessibility, concomitant changes in land usage - both residential and commercial and the qualitative aspects, were usually considered external to the evaluation. At best, these secondary consequences were appraised separately to the COBA evaluation or at worst were considered to be beyond the scope of evaluation and thus ignored.
- (ii) Coupled with the above neglect of non-user effects, it was recognised that to incorporate these effects into the COBA evaluation would be problematic. First there was the problem of identification of non-user effects and the functional linking of them into the COBA method of evaluation, both spatially and temporally. For example, often the costs and benefits did not accrue equally to the various community groups and thus the evaluation values expanded from one of system economic efficiency to aspects of equity and income redistribution. Secondly, the social and environmental nature of these non-user effects were not easy to measure and moreover most difficult to monetarise.
- (iii) The current need to broaden the scope of the traditional COBA approach must be seen against the vast increase in development that has occurred since the 1950's and 1960's. In many major transportation projects it is now not unusual for the external effects to have greater significance on the overall evaluation than the internal or direct effects. The public opposition to the "Garden route freeway" and "Johannesburg's M6 motorway" projects are local manifestations of the need to broaden the scope of the traditional method of evaluating highways. As Lichfield (1972) comments, for these categories of project the disbenefits to the environment are now ranking in the public's eye at the same level at least as the transportation benefits.
- (iv) The last reason for ignoring the external effects was that the non-users were often adversely affected by the facility, which meant they entered the cost-benefit equation on the cost side, which sometimes did not suit the promoting authority!

The need to broaden COBA method of evaluation to include

non-user impacts and externalities is now widely recognised (Bridle, 1978). However, it is apparent from the discussion of the traditional approach that the inclusion of external effects makes the COBA a far more complex method of evaluation. The complexities that are introduced have led to a schism of evaluation methodologies. The aim to broaden the scope of cost-benefit analysis as it is traditionally practised, has therefore become a point of departure, since this aim has given rise to the development of many different methods of evaluation.

In this review of the different evaluation methodologies, the following "schools of thought" are apparent:

- \* The American Association of State Highway Officials (AASHO, 1973) has suggested transportation plans be evaluated in two parts : (a) cost-benefit analysis that would include all the items that can be reduced to money terms, (b) an analysis of all the social and environmental items that cannot be stated in money terms but that are relevant to the evaluation. This approach to evaluation has been widely adopted in the USA, Canada and Australia. A review of the various techniques for environmental impact assessment will not however be undertaken in this thesis.
- \* In an attempt to overcome the obvious disadvantage of presenting two incommensurable parts to be carefully weighed by the decision-maker, another school of thought has attempted to develop evaluation methodologies that are more holistic and comprehensive in intent than the traditional cost-benefit approach. At the same time these methodologies are not presented in two separate parts as in the AASHO approach above. It is this category of method that will be reviewed in this thesis. They are namely, the cost-effectiveness technique (Section 5.4), the ranking/rating matrices (Section 5.5), the utility method (Section 5.6) and the goals achievement matrix (Section 5.7).
- \* Another school of thought argues that monetary measurement is the best and highest order commensurable scale developed to date. For this reason, economists have taken the traditional cost-benefit analysis further and endeavoured to incorporate many of the "externalities" into the evaluation. Such an approach is termed social cost-benefit analysis and has been used for appraising the social worth of public sector projects, such as transportation. Social cost-benefit analysis (SCBA) is based on the complex theory of welfare economics and attempts to evaluate systems from the public's point of view - ie projects are assessed in terms of an overall concept of general welfare. The SCBA method of evaluation is beyond the scope of this thesis but is mentioned to show the full range of evaluation techniques that are currently used to evaluate alternative transportation plans.

#### 5.4. Cost Effectiveness Technique.

As Skinner and Deen (1978) comment, cost-effectiveness is a broad and elusive term meaning different things to different people. Heuston and Ogawa (1966) define cost-effectiveness analysis as an analytical technique for evaluating the broad management of economic implications of alternative choices of action, with the objective of assisting in the identification of the preferred choice.

The cost-effectiveness technique in the form discussed in this thesis was developed in the 1950's and 1960's for the evaluation of military and aerospace investments, a field where it was particularly difficult to assign monetary values to system benefits or worth. Thus, with this military space origin, it is not surprising that the cost-effectiveness method of evaluation is an interdisciplinary subject. Its interdisciplinary approach stems from its synthesis of techniques developed in the associated disciplines of systems analysis, engineering, economics and mathematics. The cost-effectiveness technique was first suggested as an appropriate method for evaluating alternative transportation plans by Thomas and Schofer (1970). However, a stimulus to its wider use, particularly in the United States, was the U.S. Government requirement in September 1975 that the principles of cost-effectiveness be used to evaluate transportation alternatives that required federal funds. Similarly the Report of the Urban Motorways Committee to the British Department of the Environment (Burns et al, 1972), concluded that the cost-effectiveness technique was a promising new method of evaluation.

In the cost-effectiveness method of analysis alternative plans are evaluated using two related but separate frames of reference. The first frame of reference is the traditional monetary efficiency criterion. The second frame of reference is that each plan should be considered in terms of the degree to which it attains the objective specified. The extent to which a plan achieves its objectives is defined as its criterion of effectiveness. Thus the cost-effectiveness technique is a general framework that permits the relevant consequences of the alternative plans, to be separated into two categories of performance, costs and indicators or measures of effectiveness. Thus, the choice between alternatives is made on the basis of these two separate but related classes of information. The need to reduce all the consequences of the alternative plans into a single scalar dimension is therefore avoided. Thomas and Schofer suggest this attribute to be one of the most important properties of the cost-effectiveness method, since the other techniques of evaluation suffer from an inability to realistically collapse the multiple characteristics of alternative plans into a single number.

#### 5.4.1. Characteristics Of The Method.

##### A) Plan Costs.

The method begins with determining the cost aspect of the alternative plans. Costs are defined as the total monetary outlay necessary for the design, construction, operation and maintenance of the facility or system being evaluated. The technique can accommodate either actual costs or discounted costs. If the latter costs are used the approach would be similar to the cost-benefit method of analysis. However, the economic efficiency criterion in the cost-effectiveness technique differs principally in two ways from the cost-benefit method. Firstly; the pricing of non-market consequences is not necessary as they can be left in their original and natural units of measure. For example, it is not necessary to determine a value of time so that the benefits of reduced travel time can be converted into monetary units. Travel time can be left in its original units of hours and minutes. Secondly; the economic efficiency criterion is not the sole criterion of assessing plan performances. The emphasis placed on "costs" changes and they are considered in relation to what each plan achieves when compared with the objectives of the study.

##### B) Plan Effectiveness.

The next step in the method is to determine and select a set of measures of effectiveness (criteria) that will characterise the alternative plans. Thomas and Schofer emphasise that an important and critical aspect of the cost-effectiveness method is that it is necessary to develop a comprehensive and meaningful set of goals and objectives. As Section 3.5.2 showed, for objectives to be meaningful in the context of plan generation and evaluation, they must be carefully structured both vertically and laterally in their hierarchical inter-relationships.

To ensure that objectives are specifically developed so that they provide an appropriate means of measuring plan effectiveness, two criteria are used. The criteria of relevancy and feasibility. The concepts of relevancy and feasibility are used to aid the establishment of boundaries to the system under study and hence the consequences or impacts to be considered. Ideally a decision about an alternative plan should only be taken when all the relevant variables that are feasibly included in the evaluation have been carefully considered. It will be noted that the criteria of relevancy and feasibility are in conflict. Relevancy has connotations of breadth and comprehensiveness, whilst feasibility paradoxically suggests limits and constraints. The following procedure is suggested to find a balance between these two fundamental criteria.

##### C) Criterion of Feasibility.

Feasibility refers to the level of detail of the information supplied about various consequences and the number of consequences to be considered. In practice it is rarely

feasible for the analyst to include all the factors or consequences that can be tentatively identified. Constraints such as cost, time, measurement capabilities, etc, naturally tend to establish boundaries to the system under study. Even if no resource constraints were present, the criterion of feasibility demands that the number of consequences considered must be bounded at the selection and decision-making stage of the evaluation. Figures 4-9 and 4-10 showed that as the number of consequences considered, or level of detail increases, there comes a point where the quality of the decision is no longer increased. Thus there is a point of diminishing returns beyond which the decision making process becomes overloaded and inefficient.

In summary, the criterion of feasibility can be considered to act as a constraint in the selection of factors to be considered and can be classified in a similar manner as a planning constraint (see Section 3.4.1).

- \* Feasibility is related to the resources that are available to collect and process data.
- \* Feasibility is related to the ability to use the processed data within the decision making process.

#### D) Criterion of Relevancy.

The criteria for relevancy are primarily dependent upon the values, goals and objectives of the planning process. Once the study objectives have been formulated, a consequence or impact that has no relevance to the specified objectives is clearly irrelevant to the decision making process. Similarly, if a consequence is identical for all alternatives considered, then it will not be a relevant consequence in appraising the differences between alternatives. For reasons of efficiency, the criterion of feasibility requires that only relevant factors be considered in the decision making process.

Another important step in determining the relevance of various consequences, is to understand the relationship between the transportation system and its environment. The development of a conceptual systems model may be useful to ensure that the consequences of the alternatives are correctly and fully described.

Consequences may be classified as relevant to the evaluation of alternative plans if they give rise to adverse or favourable impacts that specific social / economic / environmental groups either cannot accept those impacts or will benefit greatly from them.

Setting guidelines for criteria of relevancy by which particular factors can be included or excluded from the planning process is particularly difficult. Although the above guidelines will aid the selection process, the measures of effectiveness that are finally chosen will by necessity depend on the subjective judgement and experience of the analyst.

## e) Framework for evaluation.

The framework for the cost-effectiveness technique is particularly flexible with respect to the different ways plan effectiveness is presented to the decision maker. At a higher level of measurement, plan effectiveness can be represented directly in physical units, eg reduction in peak hour travel time in vehicle minutes, change in noise levels in decibels etc. However, a complete quantitative model of effectiveness in most planning situations is not possible. Fortunately, lower levels of measurement can also be accommodated in the framework, eg comprehensive verbal or pictorial presentations. Thus many kinds of information, regardless of the degree of sophistication of description are admissible in the cost-effectiveness framework. Figure 5-4 is a conceptual model showing the informational linkages in the cost-effectiveness framework.

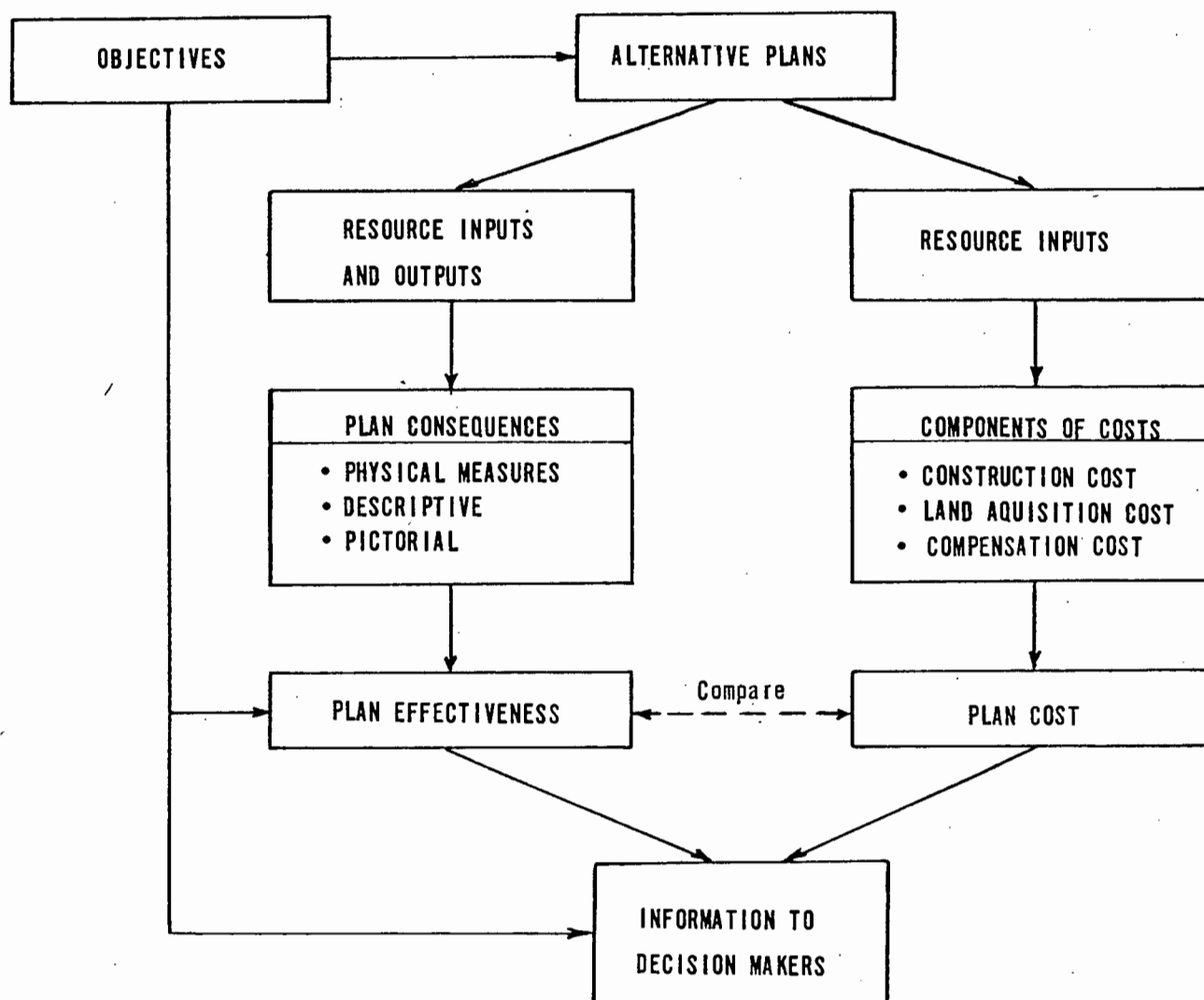


FIGURE 5-4 CONCEPTUAL MODEL OF THE COST-EFFECTIVENESS FRAMEWORK FOR EVALUATION.

f) Presentation Format.

The most common form of presentation used in this technique is the tabular matrix, as shown in Table 5-2. The attributes of the alternative plans are represented by the appropriate column in the table and are typically grouped into three categories of information; economic efficiency criteria, direct performance consequences and concomitant consequences. The difference or trade-off between plans for a particular attribute may be assessed by reading across a row.

It will be observed from Table 5-2 that each attribute is presented to the decision maker in its original and natural units of performance. The different categories of information are presented to help characterise the effectiveness of the alternative plans. On account of the variety of dimensions, there is no attempt to aggregate the information into an overall plan performance on effectiveness. Rather, the emphasis in this method is to show to the decision maker the comparative trade-offs or compromises of selecting one alternative over another. To explore the relative trade-offs and different levels of effectiveness between alternatives, extensive use can be made the multi-dimensional cost-effectiveness diagrams, eg Figures 5-5 and 5-6 and pictorial information, eg photomontages as shown in Figure 5-7.

Figure 5-5(a), for example, demonstrates to the decision maker the performance of the four alternatives with respect to the frames of reference of construction cost and travel time saved. The decision-maker may go through the following steps of evaluation. First, he may decide to eliminate alternative 4, since he may consider alternative 1 to be more cost-effective. In comparing alternative 1 with alternative 2, it can be seen that alternative 2 produces, for a relatively large increase in cost, only a small increase in travel time saved. Then, finally he must decide when comparing alternatives 1 and 3 whether it is worth spending the additional money in order to gain the extra travel time saved. Therefore, regardless of which alternative is selected the final choice is a subjective matter. If alternative 1 is chosen, this alternative can be termed cost-effective, since it provides the decision maker with a satisfactory level of effectiveness at what he considers to be a fair price.

In addition, the graphical presentation identifies alternatives that are dominated by others; eg Figure 5-5(b) shows that alternative 1 dominates alternative 2 with respect to its effectiveness in reducing accidents. In certain instances it may aid the decision making process if value lines are placed on a diagram. Figure 5-5(c) demonstrates the value in terms of construction cost per house of choosing one alternative over another.

In this manner, the cost-effectiveness diagrams illustrate clearly and objectively the relationships between alternatives and the trade-off that must be made to choose one alternative over another.

ATTRIBUTE	ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE 3	ALTERNATIVE 4
<u>Economic Efficiency Criteria</u>				
1. Project construction cost in millions of rands	18,6	20,2	21,0	16,8
2. Funding Share*				
(a) Government	14,9	14,1	14,7	13,4
(b) Provincial	3,7	6,1	6,3	3,4
3.	:	:	:	:
<u>Direct Performance Consequences</u>				
1. Total time saved in 1980 in hours compared to Alternative n	2 560	2 840	3 210	1 250
2. Reduction in fatal and serious accidents in 1980 compared to Alternate (n)	200	180	280	501
3. Attractiveness of view from road (ranked)	1	3	2	4
:	:	:	:	:
:	:	:	:	:
<u>Concomitant Consequences</u>				
1. Number of houses to be demolished	112	72	20	140
2. Noise impact				
(a) Number of properties subject to increase 5 - 10 d.B (A) L10	180	40	12	240
3. Aesthetic Impact on local community**	Severe	Moderate/ severe	Moderate	Slight
4. Ecological Impact**	Slight	Slight	Moderate	Slight
:	:	:	:	:
:	:	:	:	:
:	:	:	:	:

\*Assumes funding share for Alternative 1 and 4 will be 80% central government and alternative 2 and 3 will be 70% central government.

\*\*Summaries from supplementary, social and ecological assessments.

TABLE 5 - 2

SUMMARY OF CONSEQUENCES OF ALTERNATIVE PLANS

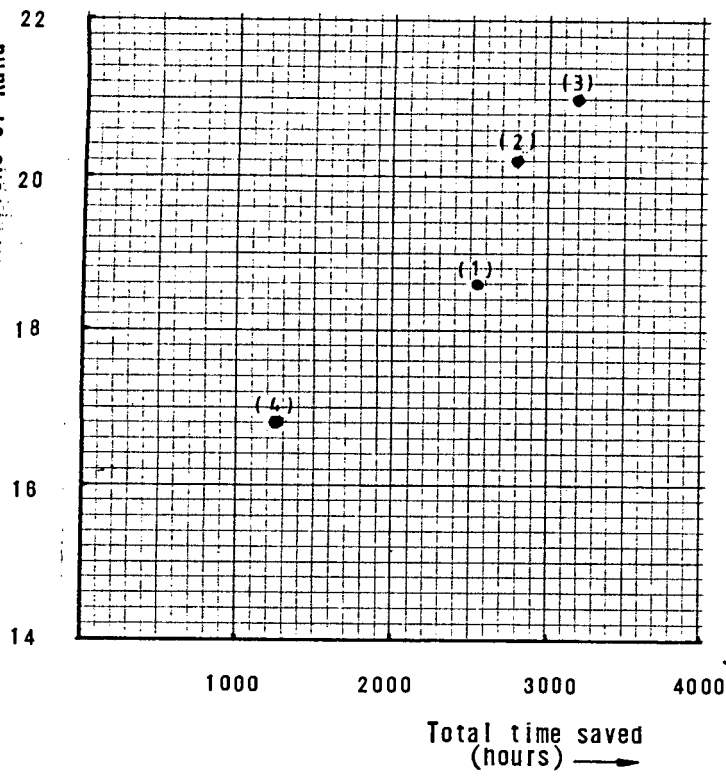


Figure 5 - 5 (a)

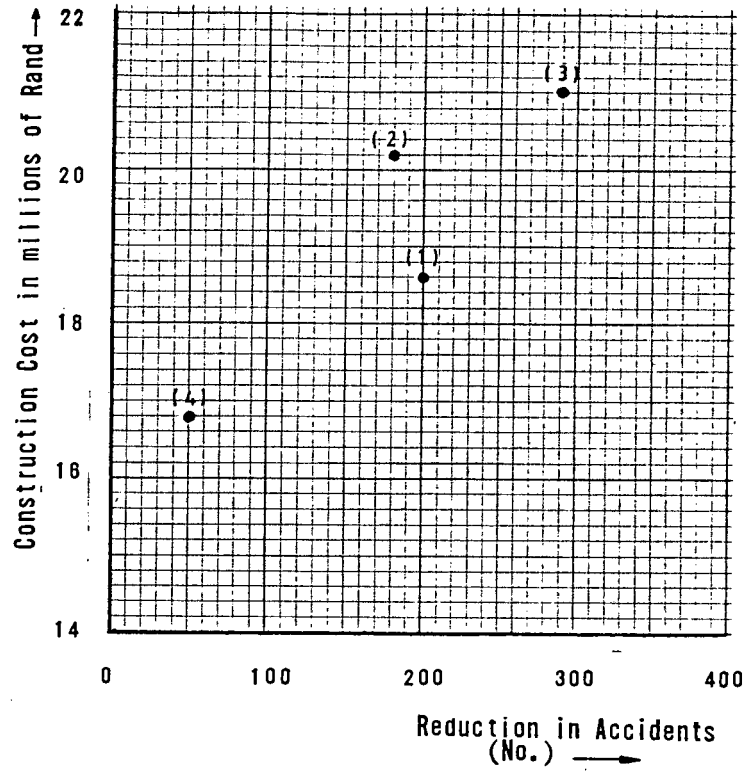


Figure 5 - 5 (b)

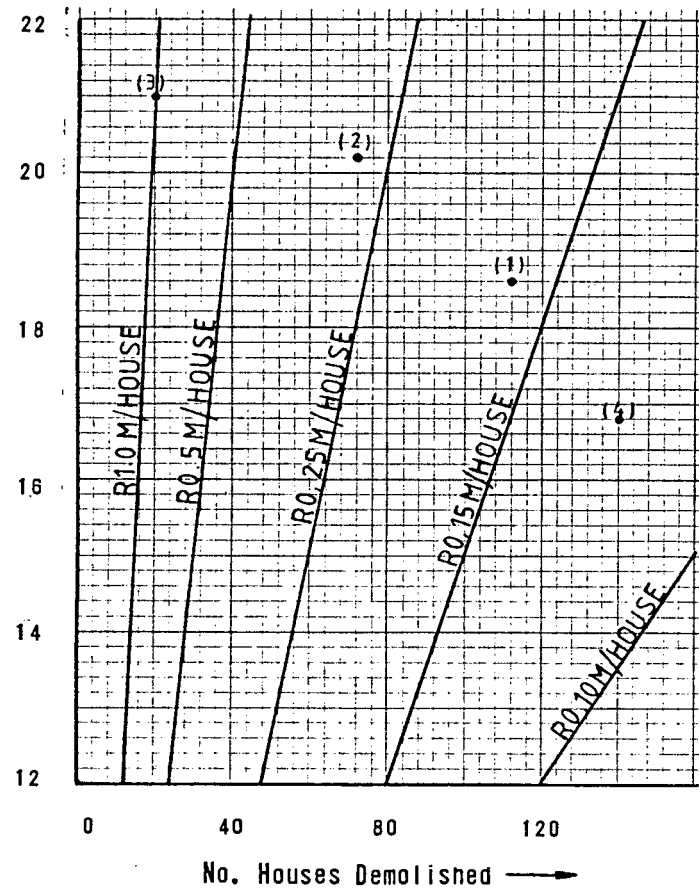


Figure 5 - 5 (c)

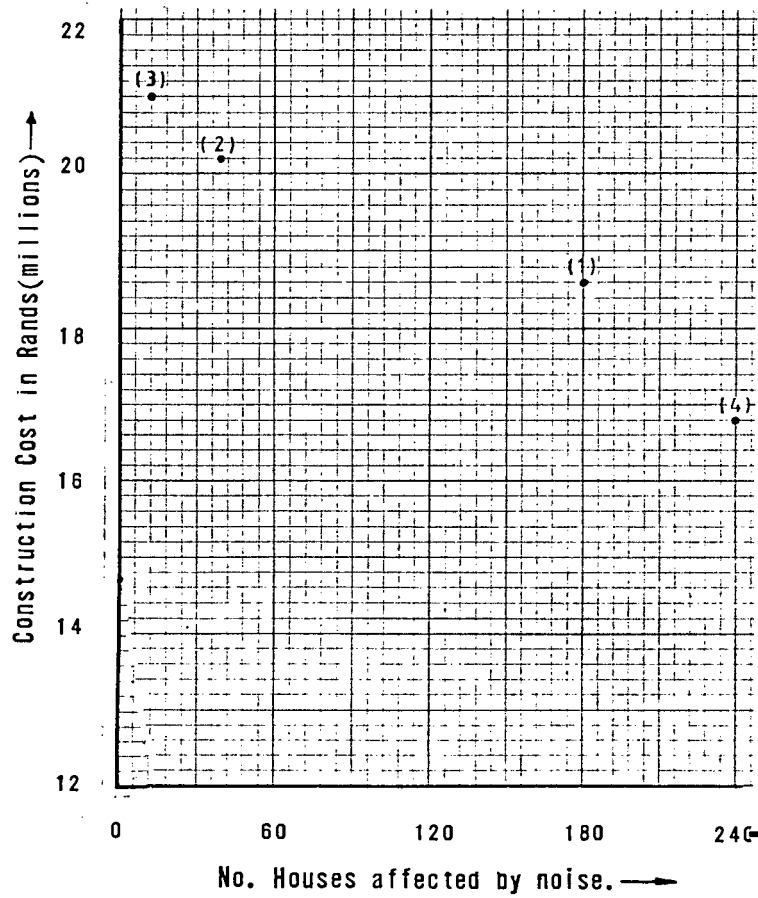


Figure 5 - 5 (d)

FIGURE 5 - 5 TYPICAL COST - EFFECTIVENESS DIAGRAMS

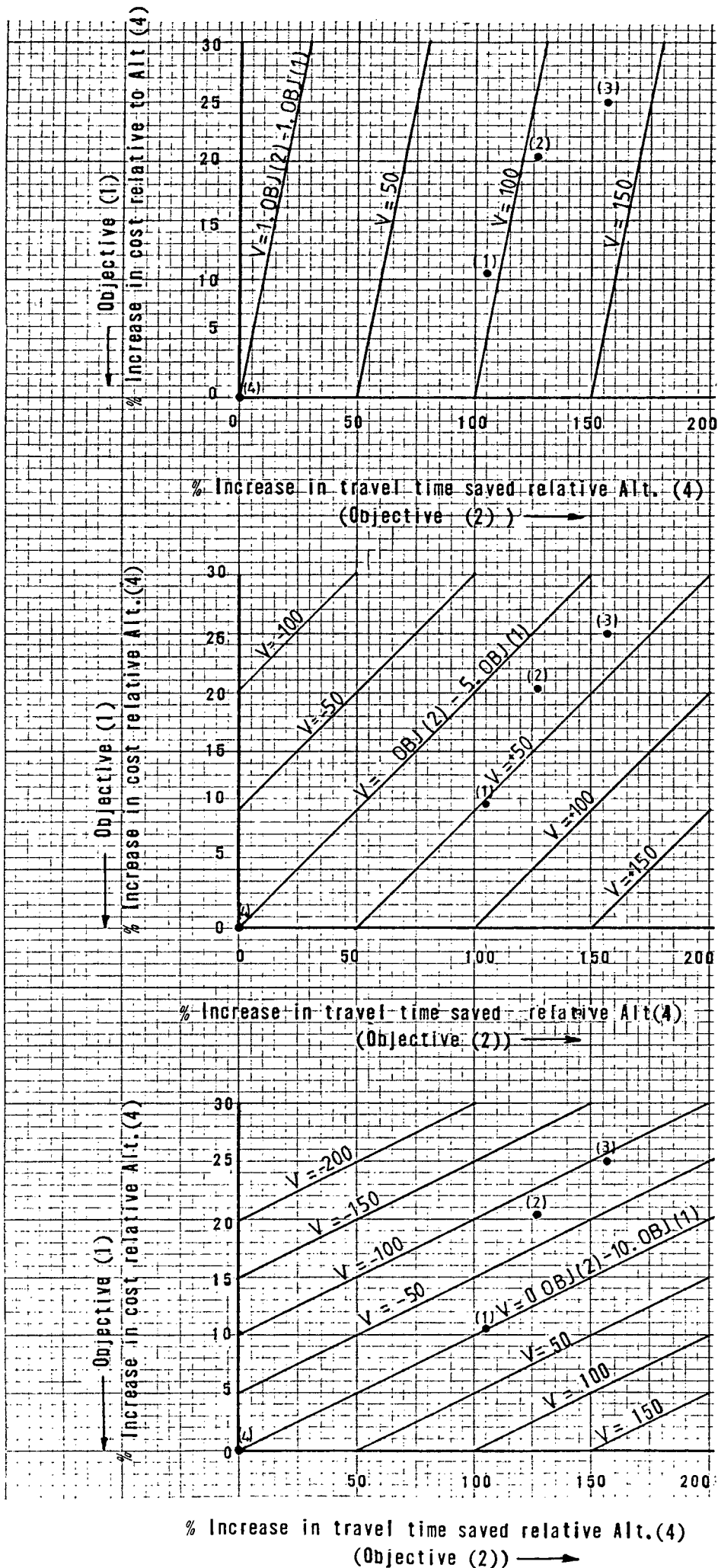
FIGURE 5 - 6

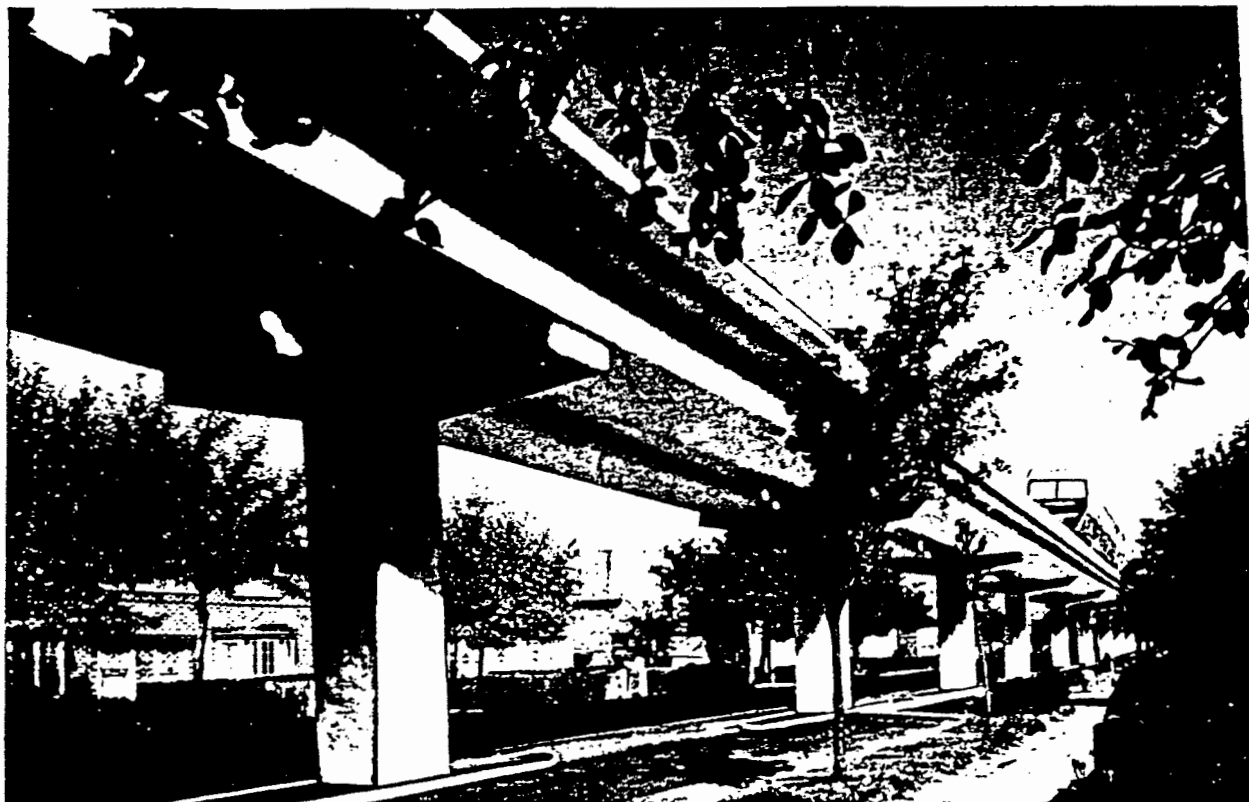
DIFFERENT VALUE TRADE-OFF LINES

Figure 5 - 6 (a)  
Value lines when  
Objective (1)&(2)  
Have equal weight

Figure 5 - 6 (b)  
Value lines when  
Objective (1) is weighted  
5 X Objective (2)

Figure 5 - 6 (c)  
Value lines when  
Objective (1) is weighted  
10 X Objective (2)





Duorail



Monorail

20TH CENTURY HOUSING, OBLIQUE

---

Figure 5-7 : THE EVALUATION OF VISUAL INTRUSION BY USING PHOTOMONTAGES

(Source : Freedman, 1973, p. 1, 9, 13)

## g) Weighting Effectiveness.

The cost-effectiveness diagram can also be used to evaluate the effect of different objectives having different weights. This is done by developing a set of trade-off lines, known in economics as indifference curves. These indifference curves represent combinations of the two objectives with the same combined value. The value of the trade-off lines is controlled by the general equation:

$$V = W_1 (\text{Objective 1}) + W_2 (\text{Objective 2}) \dots W_n (\text{Objective } n)$$

where  $V$  = combined value.  
 $W$  = numerical weight of specific objective

by applying the above equation a set of numerical weights can be applied describing the marginal rates of the trade-offs between the objectives. An example of different value trade-off lines are shown in Figures 5-6 (a) (b) and (c).

First it should be noted that to determine the trade-off lines or rates of exchange the two axes of criteria must be reduced to a common scale. In the examples shown a relative percentage scale referenced to alternative 4 has been used. Secondly, because two objectives are in conflict, ie the purpose of objective 1 is to minimise the percentage increase in cost whilst the aim of objective 2 is to maximise the percentage increase in travel time saved, the resultant composite value of the two objectives is given by:

$$V = W_2 (\text{Objective 2}) - W_1 (\text{Objective 1})$$

Figure 5-6(a) shows the set of indifference curves for when objectives 1 and 2 have equal weight. Each indifference line represents a combination of the two objectives that gives the same combined value. Thus if two alternatives fall on the same indifference line they can be termed to be of equal value or effectiveness. In Figure 5-6(a) when the two objectives have equal weight, alternative 3 is the best alternative since it lies nearest the highest combined value line. Figure 5-6(b) shows the set of lines for when objective 1 is weighted five times more important than objective 2. It is clear from the value lines that with this weighting alternative 1 is now the best alternative. Finally Figure 5-6(c) shows the trade-off lines for when objective 1 is weighted 10 times more important than objective 2. Here it can be seen that alternative 4 and alternative 1 are now of equal value.

By applying different weights to objectives and developing different sets of trade-off lines, it is possible for the decision maker to explore the effectiveness of the alternative plans in a very comprehensive and clear manner. However, it must be remembered that since the trade-off lines permit a decision to be made, it must be explicitly recognised that the relative scale and trade-off lines are subjective in nature.

#### 5.4.2. Capabilities And Limitations.

Discussing first the technique's good characteristics.

- i) The cost-effectiveness method has the desirable properties that it is founded on a systems-analysis framework and is orientated towards a system of values, goals and objectives. In the evaluation process the effectiveness criteria are an outgrowth of the study objectives. Therefore, the capability of the method is conditioned on a meaningful and complete specification of goals and objectives.
- ii) The method has a broad and flexible framework which has been designed to present objective information to aid the decision making process. There is an emphasis on providing information to support the decision, rather than providing a set of decision rules.
- iii) The multidimensional characteristics of evaluation criteria are recognised and the method does therefore not require the development of a common dimension or relative scale that is required for the other evaluation techniques. The attributes of the alternatives are, wherever possible, presented in their natural units of measurement, free from any subjective measurements. Where direct quantitative measurement is not possible, then subjective scales can be explicitly used. The method does however attempt to present only objective information, leaving the subjective aspect of the evaluation to the decision-maker.
- iv) Socio-environmental and equity considerations are evaluated under the category of concomitant consequences. In Table 5-2 the incidence of the plan consequences have been shown only at an aggregate level, ie the total number of houses affected etc. However, the information format is flexible enough for the incidence of plan consequences to have been presented in the form of (say) high income, middle income, low income groups or any other appropriate grouping. The only drawback of a more detailed equity/incidence breakdown is that the volume of disaggregate information increases significantly. It is hence the opinion of the author that a detailed equity/incidence evaluation is perhaps better achieved in the form of a separate supplementary evaluation.
- v) The information format is disaggregate in nature. Many analysts feel this is a good characteristic (Sorensen and Moss, 1973). It is often felt that an evaluation matrix that collapses total plan performance into an aggregate index can mask the individual inter-relationships. An aggregate score tends to obscure some of the information about alternative plans. In addition, it is suggested that an evaluation on a disaggregate basis permits a more realistic final selection than the aggregate

approach which offers the decision-maker a "yes" or "no" choice.

- vi) The method recognises the complex and divergent nature of transportation decisions and specifically allows the decision-maker to examine the different trade-offs or compromises that may be associated with selecting one alternative over another. The trade-off lines are a particularly useful procedure to evaluate two objectives when they are to some extent in conflict and when objectives have a different weighting. (Hawkins, Hawkins and Osborn, 1979)
- vii) The cost-effective diagram (Figure 5-5) is an excellent method of presenting information for evaluation and selection. In general, the criteria are measured on the interval scale and therefore reflect accurately in absolute terms the plan performance. The graphical presentation also permits the decision-maker to assess the the marginal difference between alternatives. Therefore, the graphical presentation permits an assessment of both absolute and marginal plan performance.
- viii) The cost-effectiveness technique is a comparatively cost efficient method of evaluation as compared with the cost benefit and utility methods of evaluation (Burns et al, 1972). For both the cost benefit and utility methods can require considerable resources (particularly the latter) to translate the different impact measurements into a common monetary or utility scale.

Considering now the poorer aspects of the method.

- i) The most obvious limitation (paradoxically) of the method is its disaggregate presentation of information to the decision maker. Decisions made with this type of information support cannot be other than difficult (refer to Section 4.7 vii). Stopher and Meyburg (1976) consider the disaggregate presentation to be a major shortcoming of the method. When the number of criteria considered in the evaluation is large, there is a danger that the decision-making process can become overloaded with information and the judgemental capability of the decision-maker may be exceeded. Wilson and Schofer (1979) have reported that decision makers when confronted with the disaggregate cost-effective format have requested the analysts to collapse the data into fewer dimensions to facilitate understanding and choice.
- ii) Since a numerical weighting system is a procedure that permits automatic selection (refer to Section 4.3.2) the cost-effectiveness techniques is not amenable to a general weighting system as is used in the rating and utility methods of evaluation. In some respects this is a major limitation. However, it should be remembered

that the purpose of cost-effectiveness techniques is to present information that is relatively free of value judgements and any weighting procedure is by definition highly subjective. Nevertheless, Figure 5-6 demonstrated for most quantitative criteria a system of weights can be applied on a pair wise basis once a common relative scale has been developed. The assigning of explicit numerical weights to qualitative criteria cannot be applied, the weighting of these criteria can therefore, only be subjectively weighed by the decision maker.

- iii) In the evaluation matrix presented to the decision maker, (Table 5-2) it will be noted that the measures of effectiveness are in different units. There is a danger that the large unit measures, such as travel time saved might dominate small unit measures such as the number of houses demolished. Therefore, the foregoing aspect requires the decision maker to be sensitive to not only the absolute measures of impacts but also their relative magnitude compared with the other impacts or consequences.

#### 5.4.3. Closure.

Thomas and Schofer (1970a) summarise succinctly the principal characteristics of the method. The strategy of the cost-effectiveness technique is that it presents information in a decision orientated framework stating what each plan is expected to achieve in relation to the objectives of the system (effectiveness), in relation to the cost of the alternative (efficiency) and in relation to the other alternatives. (trade-offs).

Compared with the other evaluation techniques reviewed in this thesis the cost-effectiveness technique is conceptually different. The difference lies in it's treatment of incommensurable criteria. It does not develop a common scale or unit of measurement but compares costs with effects on an individual basis. The disaggregate nature of the methodology means that different kinds of information; quantitative, verbal and pictorial, can all be included in the information matrix. The disaggregate nature of the information can make decisions difficult, although the proponents of the method argue that this difficulty of selection reflects in a real way the complexity of consequences associated with transportation plans. Further, it is suggested that if the choice process is oversimplified through the restriction of information, then although the decision may be made easier the quality of the decision may be compromised.

A further desirable attribute of the cost-effectiveness technique is that it can accommodate divergent goals and objectives. The cost-effectiveness diagrams (Figures 5-5 and 5-6) are a particularly useful technique to examine the trade-offs or compromises that will result in selecting one alternative over another.

From the critical appraisal in Section 5.4.2 it appears that the cost-effectiveness technique compares well with the other review criteria. The criteria are; the value framework represented, resource requirements, information presentation and replicability. The methods replicability attribute is very good, since the analyst is encouraged to present information that is primarily free of value judgements, the majority of the subjective weightings and selections being left to the decision maker.

The method has the following two major limiting features with respect to the review criteria; weighting of criteria and information format. Firstly, the direct application of a general weighting system for both quantitative and qualitative criteria is not possible. Wilson and Schofer (1979) have shown that if a general weighting system is to be applied then the disaggregate information must be "rescaled" using either a rating or utility procedure. Secondly, although the cost-effectiveness information format is very comprehensive and objective, if the number of criteria to be assessed is large then the decision-maker can struggle to synthesise and weigh the large volume of disaggregate information.

On account of its flexible framework and ability to handle different kinds of information, the cost-effectiveness method is eminently suitable to evaluating plans at either the systemwide or the localised level of planning (Stuart, 1974).

## 5.5. Ranking And Rating Matrices.

Plan ranking and rating schemes have been widely used by engineers and planners, often as a supplementary evaluation technique to an economic appraisal. This is due to their ability to reconcile and compare alternative project costs with other relevant, incommensurable and intangible criteria.

Section 4.4.3 showed that all ranking - rating methods are to a greater or lesser extent subjective in rationale. Nevertheless, their principle advantage is that they can accommodate many important objectives and criteria that are left outside the cost-benefit framework of evaluation. The subjective nature of this approach implies that the measurement of plan performance will not be as precise as the economic efficiency criterion of measurement but will be broader in scope.

In its simplest form, this method of appraisal ranks alternative proposals by an ordinal or cardinal score against a relevant set of design criteria. Tables 4-2 and 4-3 show typical ranking and rating matrices.

### 5.5.1. Rank-based Expected Value Method.

This particular method was originally developed in the business discipline to evaluate alternative long-term marketing/corporate strategies. It was first adapted for evaluating alternative regional land-use/transportation plans by Schlager (1968). The method is both simple in concept and application and principally involves the following steps:

- \* Rank ordering of study objectives.
- \* Rank ordering of plans under specific objective.
- \* The estimation and assignment of a probability of implementation for each plan alternative.

The rank ordering of study objectives is to reflect their relative importance to one another in a multi-dimensional value system. The rank ordering of the plans under each specific criteria reflects the incommensurability of units. The probability of implementation concept reflects the aspect of uncertainty into plan evaluation.

The matrix table (Table 5-3) demonstrates the approach for evaluating three alternative plans, 1, 2 and 3 against three study objectives. In the example shown, plan 3 would be selected as the best alternative having the highest rank-based expected value.

Plan	Specified Development Objective	Balanced Allocation of land	Natural Resource Conservation	Facility Costs	Expected Total Value $V = P \sum n_1 m_1 + n_2 m_2 + n_3 m_3$
		Rank Order Value of Objectives $n = 2$	Rank Order Value of Objectives $n = 3$	Rank Order Value of Objectives $n = 1$	
		Rank Order Value of Plan m	Rank Order Value of Plan m	Rank Order Value of Plan m	
1	Probability of Implementation $P = 0,6$	3	1	3	$0,6[(2 \times 3) + (3 \times 1) + (1 \times 3)] = 7,2$
2	Probability of Implementation $P = 0,5$	2	2	1	$0,5[(2 \times 2) + (3 \times 2) + (1 \times 1)] = 5,5$
3	Probability of Implementation $P = 0,9$	1	3	2	$0,9[(2 \times 1) + (3 \times 3) + (1 \times 2)] = 11,7$

TABLE 5-3 EXAMPLE OF RANK-BASED EXPECTED VALUE METHOD.  
(Source: Schlager, 1968, p. 154)

#### 5.5.2. Capabilities And Limitations.

The principal advantage of this method is that it is simple and quick to use. It will be appreciated however, that at best it is a very coarse method of evaluation and is appropriate to the systemwide level of planning rather than the localised level.

Unfortunately, the method has two fundamental limitations. Firstly, Section 4.4.3 demonstrated that ordinal ranking methods are not amenable to any arithmetic manipulation, if the basic principles of measurements are to be obeyed. Therefore, the multiplication of probability factors, objectives and plan rankings to give an aggregated value is not a legitimate mathematical operation. Secondly Section 4.4.2 showed that any ordinal ranking procedure suffers from the major drawback that the relative difference in plan score between actual plan performance and ranked performance is not reflected. If only ranking information is presented to the decision-taker, it is thus impossible to select the preferred alternative with any confidence, except in the simple and trivial case where dominance exists.

#### 5.5.3. Relative Rating Matrix Method.

To overcome the shortcomings of ordinal ranking, the rating method can be used for plan evaluation. In Section 4.4.3, three types of rating procedures were examined; cardinal,

normalised and relative rating. Jessiman et al (1967) have developed an approach to evaluation that uses the relative rating transformation function to appraise plan performance. The method is characterised by its ability to incorporate in a formalised framework both objective and subjective plan measurements. It involves the following steps.

- \* Weighting of study objectives.
- \* Rating the way each plan meets each specific objective.
- \* Aggregation of plan scores into single numerical values which represents plan worth.

Expanding on the above steps and using Jessiman's transit agency example, the planner must first assign weights of importance to the relevant set of objectives:

OBJECTIVE	ASSIGNED WEIGHTING OF POINTS
1. To maximise annual return on investment	8
2. To increase transit patronage	4
3. To maximise percentage of seated patrons	3
4. To increase miles of extension into corridor	3
5. To divert peak-hour auto-users to transit	2
	----- 20 points -----

Table 5-4 shows a typical alternative scheme versus measurement criteria array.

Criteria Schemes	1 % Annual return on investment	2 Daily number passengers (x 1 000)	3 Average % passengers seated in peak - hour	4 Miles of extension into corridor	5 Peak-hour auto- users diverted to transit (x 1 000)
A	13,0	25,0	25,0	8	3,5
B	14,0	23,0	35,0	7	3,0
C	11,0	20,0	40,0	6	2,0
D	13,5	18,0	50,0	5	1,5
E	15,0	17,0	50,0	5	1,5

TABLE 5-4 EXAMPLE OF ALTERNATIVE SCHEMES VERSUS CRITERIA.  
(Source: Jessiman, 1967, p. 75)

The next step is to rate the way each plan achieves the specific objective or design criterion. This is done by developing transformation functions similar to Figures 4-5 and 4-6 for each measurement criterion. When the alternative schemes have been rated for each objective, the scores can be summed. The alternative with the highest number of points can then be selected as the alternative that best meets the combined objectives of the transit agency. Table 5-5 demonstrates the presentation of the relative rating method of evaluation. Clearly Scheme B would be selected as the best alternative.

Criteria Weight Schemes	1 (8 points)	2 (4 points)	3 (3 points)	4 (3 points)	5 (2 points)	Total Score
A	4,0 $(\frac{13-11}{15-11} \times 8=4)$	4,0 $(\frac{25-17}{25-17} \times 4=4)$	0,0 $(\frac{25-25}{50-25} \times 3=0)$	3,0 $(\frac{8-5}{8-5} \times 3=3)$	2,0 $(\frac{3\frac{1}{2}-1\frac{1}{2}}{3\frac{1}{2}-1\frac{1}{2}} \times 2=2)$	13,0
B	6,0	3,0	1,2	2,0	1,5	13,7
C	0,0	1,5	1,8	1,0	0,5	4,8
D	5,0	0,5	3,0	0,0	0,0	8,5
E	8,0	0,0	3,0	0,0	0,0	11,0

TABLE 5-5 : RELATIVE RATING MATRIX  
(Source : Jessiman, 1967, p. 75)

#### 5.5.4. Capabilities And Limitations.

Dealing first with the methods' good characteristics:

- (i) The method can evaluate objectives and design criteria than can be described as multi-dimensional. Thus, the evaluation can be comprehensive in that it can include social, environmental, aesthetic and economic objectives.
- (ii) The method has the desirable attribute in that it considers plan effectiveness by attempting to measure the extent to which each alternative plan achieves the formulated set of objectives and design criteria.
- (iii) Another desirable characteristic is that objectives and design criteria can be assigned different weights to reflect their relative importance.
- (iv) The technique is particularly adaptable and can be applied to alternative evaluation problems at any

level of planning and also different aspects of transportation planning.

- (v) The derivation of the transformation scoring function is simple to develop and the technique therefore, does not require excessive data or manpower requirements.

Now, considering the poorer aspects of the method:

- (i) One shortcoming of this technique is that the transformation scale is based on a relative scale. The disadvantage of this scale was noted in Section 4.4.3. This limitation can however, be minimised in most cases by using the null alternative as a comparative base for the relative scaling function.
- (ii) If it is accepted that the purpose of evaluation is to present information rather than to make the selection of a specific alternative, then the format of the procedure has certain subtle dangers. Firstly, the single aggregated index of plan performance requires the engineer or planner to take on the dual role of evaluator and decision-maker. Therefore, the temptation and danger of analytical bias entering the evaluation must be guarded against.

Secondly, the relative rating array is aggregate in concept and the prescriptive and descriptive disaggregate elements are therefore, not obviously apparent unless highlighted by the analyst. The transformation functions should also be presented to the decision-maker to show how the subjective judgements have been incorporated into the evaluation matrix.

Thirdly, the aggregated index format is not conducive to illustrating the relative trade-offs between alternatives. For example, a primary consideration for any decision-maker is project cost, an aggregation of which with all the other consequences may be a limitation in many cases. For the above reasons, the format of the technique may be considered more a decision document than an information document.

- (iii) Although the relative rating method is fairly comprehensive in scope and incorporates both the values of both economic efficiency and social-environmental amenity to measure plan performance, it does not specifically take account of equity considerations. Thus, if equity/incidence effects are considered relevant to the total evaluation, they must be examined in a supplementary evaluation, separate to the relative rating matrix method.

#### 5.5.5. Closure.

From the foregoing overview it can be concluded that all ranking methods of evaluation, by definition, convey very limited information to the decision-maker as compared with methods which use ratio and interval scales. The coarse measurement scale that is used, the subjective rationale of the scoring function and the fact that the ranking scores cannot be unified into a single numerical value of plan performance, seriously limit the validity of using the rank-based methods in the evaluation process. If these methods have a niche in the evaluation process, they should be confined to limited information situations. In this instance, they would be used as a preliminary decision-making model for screening a large number of alternatives that consistently rank poorly, from further in-depth analysis and evaluation. This thesis does therefore not consider the rank-based techniques to be effective or appropriate methods of evaluation in the general transportation planning process.

In contrast, the rating methods and in particular the relative-rating matrix methodology appears to possess the ability to handle a comprehensive array of both quantitative and qualitative criteria in a systematic and rational framework. Further, it has good characteristics with respect to the review criteria of flexibility, value framework represented and resource requirements. Even poorer aspects such as; the relative scaling function, possibility of analyst bias and information transfer need not be serious limitations if recognised in the evaluation process. In certain instances, the "poor" characteristic that the technique is more a decision document rather than an information document can be used to advantage. For example, if the evaluation and decision-taking elements are carried out in an open evaluation system (refer to Section 3.8) with the eventual choice being made on the basis of co-determination, then the relative-rating matrix method is a very suitable technique.

The characteristics of the relative-rating method therefore suggest that it should be used in highway and transportation studies where the intangibles form a significant facet to be evaluated and weighed against the economic factors.

In an effort to obtain the best of both the ranking and rating approaches in evaluation, Jarvis et al (1976) has misguidedly, in the opinion of the author, combined the ranking and rating values to produce averaged normalised values. The main emphasis in recent research appears however, to have been in the direction of developing a more formalised rating methodology and in particular a scoring function that is based on the highest measurement scale, the ratio scale. The outgrowth of this recent research is the utility method of appraisal, which will be studied in the next section of this thesis.

## 5.6. Utility Method Of Appraisal.

The utility method is very similar in structure to the previous relative rating method, the principle difference is the former's use of a utility scoring function based on a ratio scale. This methodology has been used to a limited extent in North America (Schimpler and Grecco, 1968 and Kay, 1970), but has been widely used in Germany, where it has been adopted as one of the standard methods of evaluating federal highway transportation alternatives (Zangemeister, 1973 and Leitch, 1978b).

However, the particular utility method of evaluation described here has been developed by the National Institute of Transport and Road Research (NITRR) and has been reported by Baxa (1978).

### 5.6.1. Characteristics Of The Method.

A conceptual model of the utility evaluation process is shown in Figure 5-8. It will be noted that this particular method uses both the fundamental criteria of economic efficiency and effectiveness as the basis for eventual choice. The right hand side of the figure (blocks 2, 5, 12 and 13), illustrates in an abridged form the economic efficiency aspect which was discussed in greater detail in Section 5.3. In this portion of the thesis, our attention will focus on the effectiveness element (blocks 1 to 11) which forms the kernel of the utility method.

The effectiveness element can be broken down into principally three sub-sections:

- \* Weighting of study objectives and criteria
- \* Scoring the way each plan meets performance criteria
- \* Aggregate plan scores into a single numerical value which represents overall plan utility or worth.

#### A) Weighting of Study Objectives and Criteria.

The hierarchical relationship between goals, objectives and criteria (refer to Section 3.5), is specifically accounted for. The relative importance (and therefore the weighting) of each set of goals and objectives is now determined by a weight allocation procedure described in Section 4.3.2.

In order to evaluate the performance of each plan, certain measurement criteria are developed for each objective. For objectives that are described by two or more criteria, these too must be assigned a number of points to reflect their relative importance to the specific objective. The allocation of points between the selected goals, objectives and criteria is illustrated in Table 5-6.

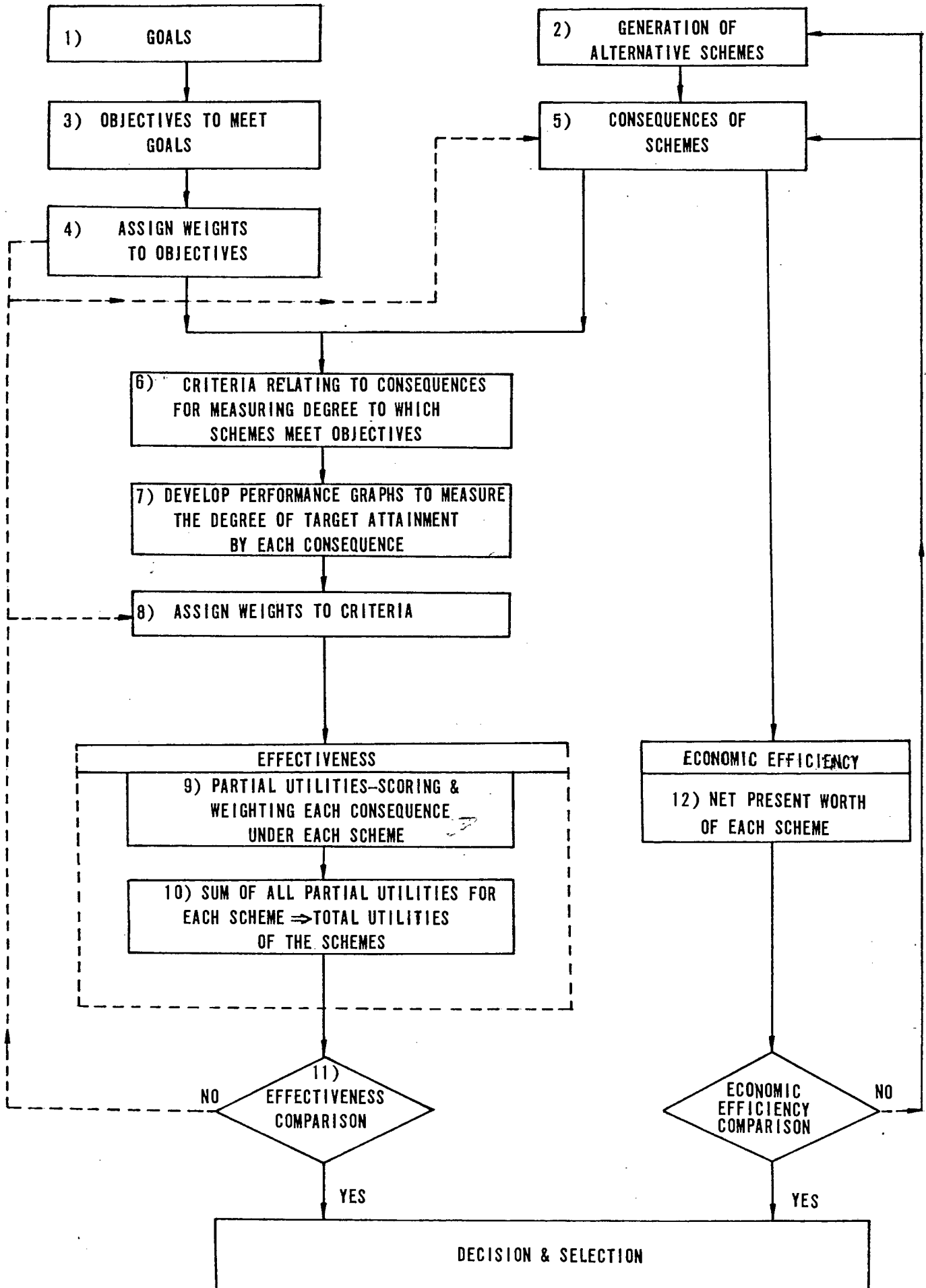


FIGURE 5 - 8: CONCEPTUAL MODEL OF THE UTILITY EVALUATION PROCESS (Source : BAXA (1978 p.13))

B) Rating the way each plan meets each performance criteria.

This step in the utility method differs from the rating method in that a performance graph (Figure 5-9) must be developed which describes the effectiveness or utility of each plan in meeting the relevant criterion (using a ratio scale). The concept of performance graphs have been used in certain environmental impact analyses, particularly the Battelle technique (Dee et al, 1972), which systematically transforms all the relevant parameters into commensurate units.

The purpose of using performance graphs is primarily two fold:

- (i) By using predetermined absolute scales for each criterion the shortcomings of using relative scales are avoided. Thus, the analyst should establish, where possible, the maximum and minimum range of performance by which each criterion can vary. For example, the nuisance of noise could be intuitively evaluated by adopting a noise performance graph as shown in Figure 5-9.

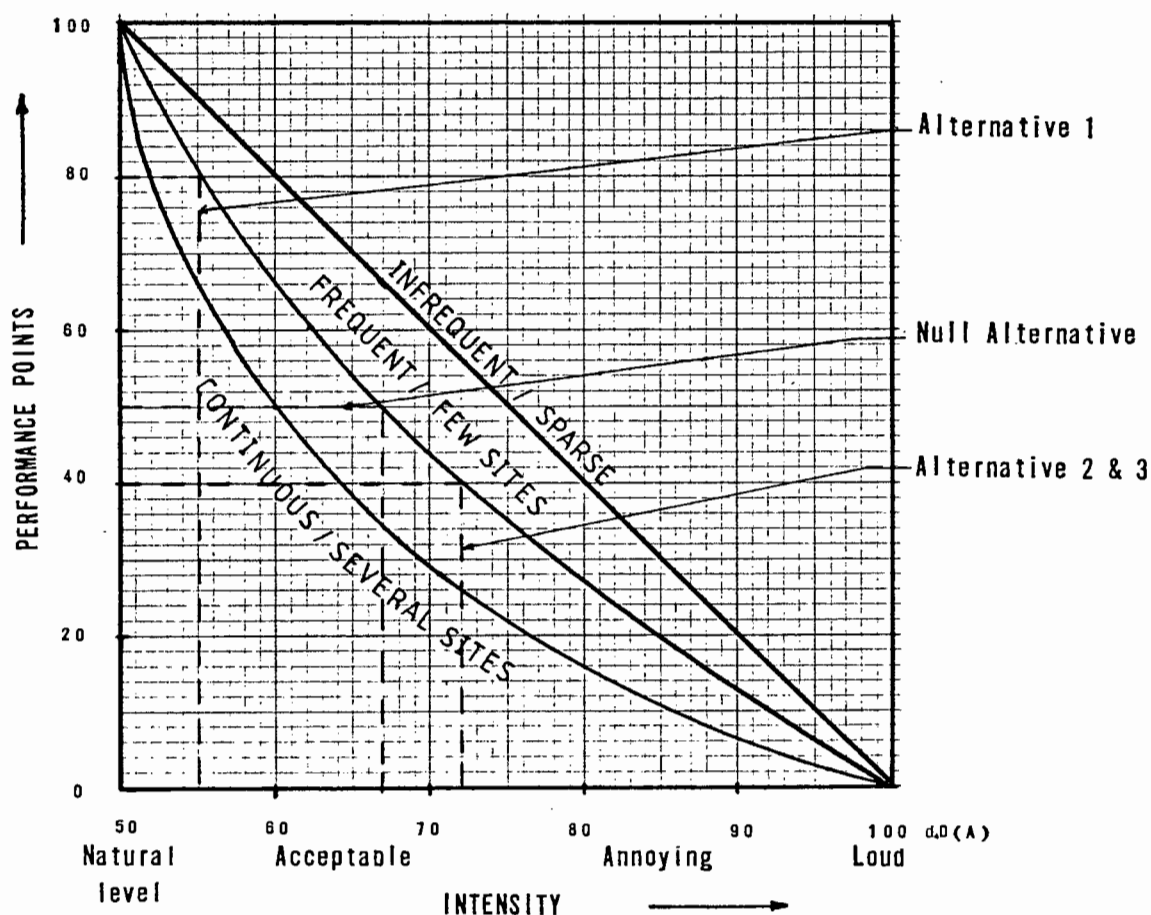


FIGURE 5-9 : NOISE PERFORMANCE GRAPH

Here the criterion of noise pollution is described in terms of the measurable parameters 'intensity of noise' and 'frequency of occurrence'. It should be noted that the performance function can be linear or non-linear.

The absolute performance scale therefore overcomes the relative rating scale drawback of the best alternative receiving a full score even though it may be far from ideal. Conversely, the worst alternative getting zero score, even when it is not much worse than the best alternative is overcome.

- (ii) Defining the performance relationship is an attempt to formalise the analyst's subjective judgement ensuring that it is based on the latest relevant information and where possible, measurable parameters. Baxa (1978a) suggests that performance graphs should be developed by experts from the disciplines to which the criteria of the graphs relate.

Once the performance graphs have been developed for each criterion, the analyst would then score the performance or effectiveness of each alternative.

- C) Aggregate the plan scores into a single numerical value which represents plan utility.

The final step in the technique is to determine the partial utilities of each alternative for each criterion. Referring to Table 5-6, the partial utility of any alternative is the product of criterion weight (Column B) and the performance score (columns C, E, G & J). The summation of these partial utilities produces the total utility or worth of each alternative. From Table 5-6 it can be seen that Alternative 3 has the highest total utility or worth.

#### 5.6.2. Capabilities And Limitations.

Dealing first with the method's good characteristics. Since the utility method is similar in structure to the relative rating method, it has in common certain good attributes that were noted in Section 5.5.4. These are the following; the utility method can accommodate multi-dimensional design criteria, it appraises the effectiveness of alternative plans and it caters for the fact that certain objectives and criterion can be given different weights to reflect their importance. In addition to these important attributes the following can be stated:

- (i) Like the relative rating technique, this method has been specifically developed to meet the problem of incommensurable criteria. The use of the ratio scale in the performance graph ensures that the axioms of measurement are obeyed and hence the measurement limitations of the ranking and rating techniques are avoided.

Average objective weight	CRITERION A	Average criterion weight B	Null Alternative		Alternative 1		Alternative 2		Alternative 3	
			Points C	D	Points E	F	Points G	H	Points J	K
25	Change in vehicle operating costs	14	50	700	100	1400	60	840	55	770
	Change in travel time	11	50	<u>550</u>	100	<u>1100</u>	70	<u>770</u>	60	<u>660</u>
	Partial utility =			1250		2500		1810		1430
17	Construction cost	6	50	300	1	6	30	180	45	270
	Maintenance cost	6	50	300	40	240	35	210	60	360
	Resident relocation cost	5	50	<u>250</u>	1	<u>5</u>	100	<u>500</u>	100	<u>500</u>
Partial utility =			850		251		890		1130	
17	Change in fatal accidents	8	50	400	100	800	75	600	90	720
	Change in injury accidents	5	50	250	100	500	75	375	95	475
	Change in damage accidents	4	50	<u>200</u>	100	<u>400</u>	75	<u>300</u>	90	<u>360</u>
Partial utility =			850		1700		1275		1555	
16	Air pollution	5	50	250	80	400	60	300	70	350
	Noise	5	50*	250	80*	400	40*	200	40*	200
	Visual intrusion	6	50	<u>300</u>	10	<u>60</u>	80	<u>480</u>	60	<u>360</u>
Partial utility =			800		860		980		910	
13	Fuel consumption	13	50	<u>650</u>	75	<u>975</u>	60	<u>780</u>	55	<u>715</u>
12	Dislocation	12	50	<u>600</u>	1	<u>12</u>	50	<u>600</u>	50	<u>600</u>
100	TOTAL =	100		5000		6298		6135		6340

Note : D = B X C  
F = B X E  
H = B X G  
K = B X J

\* See Figure 5-9 for derivation

TABLE 5-6 UTILITY MATRIX

(Source : Baxa 1978, p 19)

- (ii) The concept of performance graphs for non-quantitative criteria formalises subjective value judgements in the whole evaluation process. This is a very important aspect that can enhance the attribute of replicability.
- (iii) The method is aggregate in concept and therefore endeavours to demonstrate to the decision-maker the overall effectiveness of plan alternatives. Table 5-6 shows that the format of presentation also permits the decision-maker to inspect the partial utility trade-offs between alternatives for any of the study criteria.
- (iv) The two fundamental frames of reference for evaluating alternative sets of plans, namely economic efficiency and effectiveness, are formalised in the methodology. This is also an important and desirable attribute.

The limiting aspects of the method centre on three issues. These are the derivation of the performance graphs, the requirement that decision-makers participate in the evaluation methodology and the high resources than can be required:

- (i) The determination of the maximum and minimum values of the utility scale on the performance graphs is problematic. The utility scale for qualitative criteria can only be determined subjectively. Similarly, the relationship between the utility scale and the performance variable is also open to subjective judgement. Although it is recognised that in any evaluation process there will be the subjective judgement component, it is felt that the performance graphs with their annotated ratio scales, linear or non-linear functions can give an aura of output accuracy beyond the quality of information input. Perhaps, in fairness, this is more a danger to be avoided than a limitation. Nevertheless, the analyst must always be aware of the prescriptive elements of the method used. In some cases it may therefore be prudent to undertake a sensitivity analysis using different maximum and minimum limits, changing linear to nonlinear functions and vice versa, in order to determine their effect on the evaluation. However, to do this will be both time-consuming and laborious.
- (ii) The prescriptive and aggregate nature of this method requires effectively that the decision-makers be part of the "evaluation team". This can be an advantage if the evaluation takes place in an open system. Section 3.8 showed that an evaluation dilemma can occur if the decision-maker elects to remain independent of the weighting and scoring aspects of the method. If this were the case, then the format and presentation of the technique would become more a decision document than an information document, limiting the effectiveness of the decision-makers

ultimate selection. Thus, to avoid this limitation it is almost a prerequisite of this method that the decision-makers co-determine the relative weight and performance graph functions.

- (iii) The derivation of the utility functions would require a higher commitment of manpower and data resources than the simpler relative rating functions. For instance, it can be foreseen that a large portion of the data requirements for the non-quantitative performance graphs would be difficult to obtain. In addition, specialist skills may have to be imported into the study to derive the relationship of the utility function. The analyst should therefore ensure that the additional requirements of data, manpower, cost and time to derive the utility scoring functions would produce a cost effective increase in the quality of information for evaluation.
- (iv) The utility method, like the previous technique, does not take full account of equity considerations. This aspect must be undertaken in a separate but supplementary evaluation.

### 5.6.3. Closure.

The foregoing overview demonstrates that the utility method is one of the more sophisticated techniques of evaluation studied in this thesis. Like the cost-effectiveness methodology, it is soundly structured around the two inter-related fundamentals of plan effectiveness and economic efficiency. The method has particularly good attributes with respect to the review criteria of comprehensiveness, weighting procedure, transformation measurement scales and replicability. The transfer of information on account of its matrix-aggregate format tends to be decision rather than information orientated. However, in mitigation, the disaggregate values of the individual criteria are also presented and the procedure for aggregation is clearly shown.

The limitations of the method tend to be use-specific rather than general evaluation limitations. On account of the transformation scaling procedure using the ratio scale, it would be inappropriate to use the utility technique at the systemwide level of planning where the quality of information is often low. Similarly, the method loses some of its effectiveness as a method of evaluation in situations where decision-taking is carried out in a closed system.

The structured approach to formalising subjective judgement performance graphs is an important and promising attribute of the methodology. However, the scoring of the so called "intangibles" will be difficult and complex. The manpower effort in time and money must also always be carefully weighed with the quality of information that these subjective functions produce.

Thus, the attributes of the utility method suggest it should be used in high information situations, where social and environmental considerations are an important aspect to be weighted against economic criteria. It seems an appropriate technique to use at the localised level of planning for large public-capital projects such as urban freeways, airports, etc.

## 5.7. Goals Achievement Matrix.

One of the major drawbacks of most the evaluation methods discussed so far, is that the value of equity is usually not considered directly in the evaluation methodology. If it is considered, it is appraised in the form of a separate, supplementary evaluation. However, because equity considerations are an important aspect in transportation planning decisions, evaluation techniques have been developed which specifically take account of equity considerations. The two best known and most widely used procedures are the Goals-Achievement matrix and the Planning Balance Sheet method. In spite of the differences between the two methods, they are fundamentally similar in concept and use. Since the Goals-Achievement Matrix is the more widely used procedure, and for reasons of brevity, only this methodology will be discussed in the thesis.

### 5.7.1. Characteristics Of The Method.

The Goals-Achievement Matrix (GAM) was developed by Professor Hill in the late 1960's (Hill 1967) and is very much an outgrowth of Professor Lichfield's Planning Balance Sheet method, developed in the early 1960's. (Lichfield, 1964 & Lichfield & Chapman, 1968).

The GAM method of evaluation is an adapted form of cost-benefit analysis, where the evaluation has been broadened to include non-monetary, qualitative and intangible items. It will be recalled that one of the major criticisms of the cost-benefit analysis was its unitary and economic efficiency emphasis in evaluation. As a reaction against the emphasis of unitary values in the last 10-15 years, there has been a marked shift in transportation planning (in the United States and Britain) away from a unitary concept of society and the notion of a single public with one set of goals and objectives. This has moved towards the identification and categorisation of community or group objectives. Associated with this shift from unitary to community or sectorial values, has been the public participation in the planning process.

The GAM therefore, reflects the above changes in transportation planning and attempts to provide an evaluation framework that will appraise plan alternatives according to the weighted objectives of affected groups, such as public agencies, community groups and major interest groups. As Hall comments, the methodology specifically recognises that different groups of the public may have different value-systems and may place quite different weights on different objectives. (Hall, 1974). The GAM methodology allows for this by disaggregating (initially) it's analysis.

The incidence of the favourable (benefits) and unfavourable (costs) consequences on each sector of the community are traced and identified. The benefits represent plan consequences that fulfil one of the agreed objectives while

costs represent plan consequences that are contrary to the objectives. A set of weights are applied to both the objectives and the interest groups in such a manner that the aggregated set of incidence weights applied to the objectives can be considered as representing the communities conception of equity (Hill, 1968).

A conceptual model of the Goals-Achievement Matrix is shown in Figure 5-10 and it's presentation format is shown in Table 5-7.

FIGURE 5-10 CONCEPTUAL MODEL OF GOALS-ACHIEVEMENT MATRIX  
(Source : Schermer, 1975, p. 34)

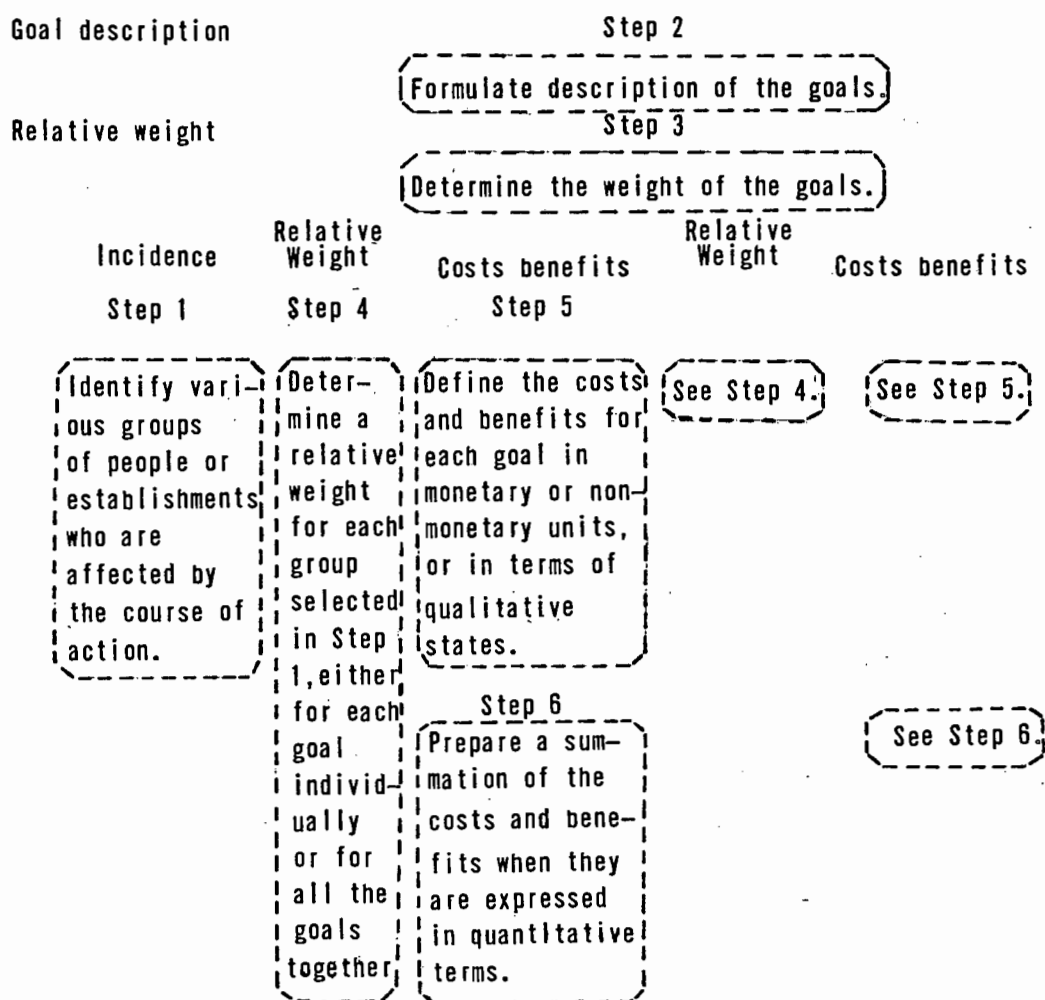


TABLE 5-7 THE GOALS-ACHIEVEMENT MATRIX  
(Source : Hill, 1968, p. 23)

Goal description Relative weight	$\alpha$ 2			$\beta$ 3			$\gamma$ 5			$\delta$ 4		
Incidence	Relative weight	Costs	Benefit	Relative weight	Costs	Benefit	Relative weight	Costs	Benefit	Relative weight	Costs	Benefit
Group a	1	A	D	5	E	-	1		N	1	Q	R
Group b	3	H	J	4	-	R	2		-	2	S	T
Group c	1	L		3	-	S	3	M	-	1	V	W
Group d	2	-		2		-	4		-	2	-	-
Group e	1	-	K	1	T	U	5		P	1	-	-
		$\Sigma$	$\Sigma$					$\Sigma$	$\Sigma$			

The following points should be noted with respect to the above matrix:

- (i) Although the method is called the "Goals" Achievement Matrix, the goals used in the matrix are really objectives, since if the evaluation is to be meaningful, the goals must be defined in measurable terms (ie like objectives) rather than as abstract terms (ie like goals). The Greek letters  $\alpha$ ,  $\beta$  and  $\gamma$  represent the study objectives and their relative importance to the study is shown by their relative weights. In a similar manner, the relative importance of the affected groups or communities can also be indicated.
- (ii) The letters A, B ..... represent the incidence of costs and benefits that will occur on the affected groups. A dash (-) indicates that for a particular group/objectives interaction there is no cost or benefit.
- (iii) The costs and benefits may be defined in either monetary or quantitative units or qualitative states. However, for the same objective the costs and benefits must always be defined in the same units, ie either both money or both quantitative.

- (iv) The brackets show that the cost-benefit associated with these groups can be combined where there is no differentiation of group impact.
- (v) For certain goals (eg  $\alpha$  and  $\gamma$ ) where it is possible to express plan performance in monetary units, the cost benefit accounts can be aggregated to give a grand total. However, for all other goals where costs and benefits are represented by different units, the overall goal achievement cannot be aggregated.
- (vi) Table 5-7 is the evaluation matrix that would be produced for each alternative plan that is to be appraised. The decision-maker would then have to compare the different matrices to determine the preferred alternative.

In its original form, Hill's Goal-Achievement Matrix was presented to the decision-maker in the disaggregate format shown in Table 5-7 (Hill, 1967a). This format of presentation facilitated the evaluation phase but made the selection and decision-making phase most demanding. Although Hill appears to have recognised that his original matrix format presented the decision-maker with a "task of undoubted complexity", his later paper (Hill, 1968a) suggested the use of transformation scoring functions to overcome the problem of disaggregation.

The Goal-Achievement Matrix has therefore generally been applied in two stages in practice. The first stage is shown conceptually in Figure 5-10 and the presentation format in Table 5-7. The emphasis in this phase is that group incidence/objective achievement is identified and measured using the highest order measurement scales practicable. Thus the initial evaluation presentation is disaggregate in nature resulting in difficult decision-making. The second stage of evaluation usually utilises some form of ranking or rating indices to allow the analyst to arithmetically apply the system of weights so that aggregation of the Goals-Achievement account can be carried out. The introduction of transformation functions and a numerical set of weights, as was shown in Section 4.3.2, ensures that a unique plan score can be determined which greatly simplifies the selection process. The "Newark Planning Balance Sheet" is a typical example of the second and final stage of the Goals-Achievement method as used in practice (see Table 5-8).

In this particular example which involved the evaluation of eight alternative program packages and a "no project" option against 13 distinct interest groups, the simplification of the evaluation by the introduction of a common numerical rating scale was most desirable. The group weight was determined by the financing authority which reflected their view of the relative importance of each affected group in relation to the project. The allocation of the group score was undertaken by each interest group, once they had determined their sectorial objectives.

In the first stage of the evaluation, the relative degree of objective fulfilment was determined using the most precise measurement scales possible. Table 5-8 illustrates the second stage of the evaluation matrix where the disaggregate presentation is transformed to a common rating scale of 1 to 10. The total value scores represent the community group preferences, with the highest score representing the most desirable alternatives. Table 5-8 illustrates the planning balance sheet for only three interest groups against three alternative program packages. It can be seen that in this example, alternative 1 is preferred for each of the interest groups shown.

#### 5.7.2. Capabilities And Limitations.

It will be noted that the Goals Achievement Matrix is similar in character to the rating and utility method of appraisal. The main characteristic difference is the emphasis on equity/incidence considerations and community involvement in the evaluation process. The principal advantages associated with this method are summarised below.

- (i) Conceptually, the goals achievement matrix provides a comprehensive and systematic framework for evaluation and as its name implies it is a goal orientated method. Unlike the other methods reviewed in this thesis however, the goals and objectives selected in GAM reflect individualistic or sectorial values rather than unitary values. It follows that for projects which have a high localised impact, compared with their systemwide consequences, it can be foreseen that this method will be a highly effective method of evaluation.
- (ii) The method's approach to evaluation, from the perspective of community interests, ensures that the fundamental value of equity is adequately considered. Affected community groups are identified and the inter-relationship between project consequences and group objectives are examined and appraised. Thus the incidence and relative impact of the project consequences with respect to the various groups will be made apparent to the decision-maker.
- (iii) The treatment of incommensurable criteria are handled in two stages in the evaluation process. In the first stage, each objective or criteria is measured on the highest order measurement scale. This has the advantages that the evaluation is relatively free of any subjective judgements and the information format is disaggregate in nature. The second stage, the introduction of a common transformation scale, has the advantage that the information format can now be aggregated and the system of group/objective weights can be applied.

TABLE 5-8 EXCERPT FROM NEWARK PLANNING BALANCE SHEET

(Source : Schermer, 1975, p.42-43 )

INTEREST GROUPS AND OBJECTIVES	Weight	Program Package I (Light rail underground with considerable redevelopment)		Program Package II (Buses in exclusive lanes partly in a tunnel with limited redevelopment)		Program Package III (No transit extension limited redevelopment)	
		RANK	VALUE	RANK	VALUE	RANK	VALUE
<b>HOUSING DEVELOPMENT AND REHABILITATION CORPORATION</b>							
A. Upgrade corridor through redevelopment	3	6	18	4	12	4	12
B. Obtain minimum community disruption	3	8	24	3	9	10	30
C. Insure satisfactory com- pensation and relocation	2	10	20	10	20	10	20
D. Reduce traffic congestion	1	9	9	7	7	0	0
E. Integrate transit facility with proposed developments	1	9	9	6	6	2	2
Group total	10		80		54		64
<b>TRANSPORT OF NEW JERSEY</b>							
A. Improve accessibility	5	6	30	7	35	3	15
B. Improve travel convenience	3	5	15	7	21	8	24
C. Reduce congestion	2	9	18	7	14	8	16
D. Increase travel safety	2	9	18	5	10	0	0
E. Improve passenger comfort	1	6	6	5	5	4	4
F. Implement transit program in context of a total regional transportation im- provement program	1	8	8	8	8	8	8
G. Implement program in a speedy co-ordinated fashion	1	7	7	6	6	5	5
Group total	15		102		99		72
<b>SPRINGFIELD AVENUE MERCHANT'S ASSOCIATION</b>							
A. Improve travel convenience	4	5	20	7	28	8	32
B. Strengthen corridor business	4	6	24	5	20	5	20
C. Upgrade corridor through redevelopment	3	6	18	4	12	4	12
D. Improve accessibility	3	6	18	7	21	3	9
E. Provide adequate com- pensation and relocation	2	10	20	10	20	10	20
F. Improve employment situation in Newark	2	8	16	6	12	6	12
G. Strengthen public economy of Newark	1	6	6	5	5	0	0
H. Insure political commitment to project	1	7	7	7	7	0	0
Group total	20		129		125		105

- (iv) The evaluation methodology operates at the localised level of planning and has been structured to allow a meaningful level of community participation in the planning process. At a time when it is generally held that there should be some form of community involvement in the transportation process, this property of GAM is advantageous.

Now the limiting aspects of the method are considered:

- (i) The principal limitation of the GAM is that it is both complex, expensive and time consuming. First, each evaluation matrix will require inputs from a minimum of five or six community groups which will require many meetings with the planners. Further, the fulfilment of each community objective will have to be analysed and measured by the planning team for each alternative considered.
- (ii) Following from the above limitations is the poor attribute that in practice the method has to be evaluated in two stages. The first evaluation stage is carried out in natural units and the evaluation matrix would in most cases be disaggregate in nature. This format of presentation makes the decision-making stage very difficult causing the system of goals and community weights to be ineffectively applied. Thus, for an effective decision, some form of transformation scaling procedure has to be used. The type of scoring function that is normally used is either a simple ranking or a cardinal rating scale. (Lichfield and Chapman, 1968 and Schermer, 1974). Section 4.4.3 demonstrated that both these measurement scales have definite evaluation shortcomings.
- (iii) Barrell and Hills (1972b) have criticised the method's characteristic of double counting benefits or losses. Double counting is difficult to avoid in the GAM method on account of two related problems. Firstly, in practice, the classification of groups within the affected community may not always neatly coincide with the incidence of gains or losses upon those groups. Some individuals, for example, may be represented in more than one group. Secondly, group objectives often overlap, eg objectives A and C under the group "Transport of New Jersey" in Table 5-8 appears to be a typical example.
- (iv) The method's community participation linkage does require a high level of community involvement which can be problematic. Schermer reports that some community representatives have become confused and intimidated when attempting to distinguish between tangible benefits, intangible benefits, tangible costs, intangible costs, ratings, values, objective weights, etc. (Schermer, 1975a). In addition when evaluating projects that are controversial or unpopular, it may be difficult to obtain the co-operation of the affected groups in the

evaluation process. Therefore, in cases where community judgement is going to be very biased the GAM method may be an inappropriate method of evaluation.

- (v) The South African approach to decision-making in planning is generally strongly authoritarian and reasons for decisions are not normally given. (Fuggle, 1980). Decision-taking is consequently taken in a closed system with little opportunity for debate between the planning team, the general public and the decision-makers. In a national context, this method assumes a higher level of public participation than is normally practised. From the public's standpoint, this can give rise to the shortcomings mentioned in (iv) above. From the decision-makers standpoint, the method requires a commitment to a more open system of evaluation and decision-taking.
- (vi) Although not strictly a limitation of the methodology, there is the problem of the allocation of community group weights. If the procedure is perceived primarily as an "equitable" decisionmaking tool, then the financing authority would probably assume the responsibility for the assignment of weights. However, if the procedure is considered as a process of involving the affected communities in the evaluation process then the responsibility for assigning weights should be undertaken by the groups themselves. Schermer (1975b) suggests two methods of obtaining priority weights, both using the Delphi technique. The first option is for the affected groups to select an inter-group committee for allocating group weights. The second is for each group to allocate all the group weights and then to determine an average composite group weight which would then be used in the evaluation. Lichfield et al (1975) and Hill (1968b) take the view that determining group weights is an ethical judgement and in a democratic system of government, this responsibility should rest with the appropriate elected representatives. Regardless of who determines the group weights, their relative values must be determined before evaluation. This aspect of "a priori" weighting can present evaluation problems and in practice equity weights may need to be revised in the light of the subsequent evaluation. It will be appreciated that to determine equity weights by any of the above approaches will be a complex and time consuming task, doubly so if equity weights must be formulated before and after evaluation.
- (vii) The last point, like the one above, is again not strictly a limitation of the actual procedure but rather a problem that is a product of the divergent value system in which transportation planning operates. Most transportation evaluation in the Republic currently tends to be unitary value

orientated. The GAM method is sectorial value orientated leading to criticism of this technique as not giving enough emphasis (weight) to the actual construction and operating costs of alternative plans in the evaluation. In Britain and the United States where GAM has been widely used in transportation decisions, the financial appraisal has been presented as a separate or supplementary evaluation to GAM. The decision-maker then has the problem of assigning a relative weight to the financial appraisal as compared with the community weightings.

### 5.7.3. Closure.

In Section 4.3.1 the notion was put forward that to evaluate plans effectively a comprehensive value framework is required. In most of the evaluation methods reviewed so far, the value of equity has received only secondary consideration. The principal merit of the Goals-Achievement Matrix method is therefore that it identifies and evaluates the advantages and disadvantages of alternative plans for the different groups in the population. As a result, the principal values, efficiency, equity and amenity can all be represented in the methodology, giving it good characteristics of comprehensiveness. In addition the methodology emphasises goal identification and goal achievement for the community as a whole and for the groups within it.

Considerable attention has been given to the structuring of value judgements into the methodology. It has the good attribute in that the decision maker has to make explicit judgements about the importance or worth of different community groups while the community groups can make value judgements about the importance or worth of the study objectives. Therefore, the potential for analytical bias from the professional evaluators (the planning team) is very small, since all of the major value-assumptions are not their responsibility.

It can be seen from the disaggregate format (Table 5-7) presented to the decision-maker that the method is information rather than decision orientated. The method unfortunately does not appear to have resolved the paradoxical problems that exist between complexity of decisions with a disaggregate format and a system of weights that cannot be effectively applied unless the evaluation format is aggregated via a common metric. On account of this conflict, in practice the methodology is carried out in two phases which means the method demands high resource requirements, particularly in manpower, time and money.

The method's community participation linkages have been formulated to enable the consideration of fairness and justice to enter into the evaluation. However, guiding and determining community objectives and their relative weight for each interest group is a complex and challenging task. Although the aim of each evaluation process is ideally to

achieve consensus, this approach in practice may in some instances, expose group polarisation which in turn can lead to an evaluation stalemate. It can be argued that the method has only exposed disparities that would (and should) have become evident in any event. The method does however, require a high level of community co-operation and if this is not evident then this procedure would be unsuitable and should not be used.

The method has been specifically designed for localised planning situations where sectorial objectives are perceived to have greater weight than systemwide or unitary objectives. In practice, it has been used more widely in urban and regional planning situations than transportation planning, (Hall, 1974a) since the unitary approach to transportation planning tends to be prevalent.

In summary, the relative strengths with respect to the review of the criterion method are; its comprehensiveness, value framework, treatment of incommensurable criteria and little or no analyst bias. The relative weaknesses are; the complexity of the method, high resource requirements and the low order of transformation scales used prior to the application of the relative weights.

## 5.8. Supplementary Evaluation Procedures.

It will be noted from the foregoing review that each evaluation methodology has some major limitation which inhibits an holistic evaluation. For instance, with the exception of the goals-achievement matrix, all the other evaluation techniques did not take into full account equity considerations. This section therefore describes certain "supplementary evaluation" procedures that may be incorporated into the total evaluation process to make-up for the deficiency in any particular evaluation technique. These procedures can further be used to interpret, test and refine the tentative choice(s) from the general evaluation stage. Their purpose is to demonstrate to the decision-maker (and the analyst) the robustness (or weakness) of the tentative choice and thus help establish a level of confidence in the plan ultimately chosen.

The supplementary evaluation procedures are thus really a form of iteration with the purpose of improving the quality of the evaluation phase and consequently the final decision. Beimborn (1976) suggests that it is important that a distinction be made between the tentative choice and the final choice, so that the supplementary evaluation phase allows the analyst the real option of changing the tentative choice.

It is suggested that the interpretive phase should include the following supplementary evaluation activities, though not necessarily in the sequence listed:

- \* Marginal Analysis
- \* Contingency Analysis
- \* Equity Analysis

### 5.8.1. Marginal Analysis.

In the general evaluation of alternative plans, most criteria of plan performance are absolute measures, ie total construction cost, total capacity etc. Absolute measures are especially useful in the early stages of evaluation when comparing a large number of alternatives but marginal measures become increasingly valuable as the number of alternatives are reduced.

It is imperative for an evaluation to be comprehensive and that both absolute and marginal measures be used.

Marginal analysis is used to examine the differences in scale between the tentative choice and the second or third best alternatives. Beimborn suggests that marginal analysis can demonstrate to the decision-maker that the differences between the best and second-best alternatives are significantly large enough that they are not within the range of differences that might be expected from the data and procedures used.

Thus in the analysis, the marginal gain of the best plan over the second-best plan is examined. The following hypothetical example (Skinner and Deen, 1978a) illustrates the analysis.

TABLE 5-9 : MARGINAL ANALYSIS-COMPARISONS OF COSTS PER PASSENGER-MILE.

Measure	Alternative 1	Alternative 2	Null Alternative
Annual total cost, in thousands of dollars	102	49,5	30
Daily passenger-miles in thousands of dollars	600	300	200
Absolute cost per passenger-mile	0,170	0,165	0,150
Marginal cost per marginal passenger-mile (compared to null)	0,180	0,195	Base
Marginal cost per marginal passenger-mile (Compared to Alt.2)	0,175	Base	-

In terms of the absolute measure, cost per passenger-mile, the null alternative is the best alternative with alternative 2 the next best and alternative 1 the worst. When the analyst compares the marginal costs of alternatives 1 and 2 over the null alternative (ie the best plan), the following is apparent. Alternative 1 now appears better than alternative 2; this reversal in order is because of difference in scale between alternatives 1 and 2. This does not mean that alternative No 1 is preferred over alternative 2 but it does provide additional information on the differences between alternatives to the analyst.

#### 5.8.2. Contingency Analysis.

In the evaluation of most transportation plans, many assumptions with regard to traffic forecasts, regional characteristics etc, have to be made. One of the major lessons transportation planners should have learnt is that one must demonstrate that the recommended alternative will still be right, even if one is not sure of the precise forecasted values - ie it must be demonstrated that the chosen alternative has performance attributes of robustness and flexibility.

In order to take proper account in the planning process of the uncertainty of the future, there has been a move away from evaluating a set of alternative plans against a unique future, by applying a contingency analysis (Schofer and Stopher, 1979).

Beimborn (1976a) defines a contingency as an event whose occurrence is possible but not probable. Thus in a contingency analysis, the assumptions that were initially made are modified and different values of the variables are then assumed. The consequences of the variations on the resultant evaluation are then examined. If the results of the analysis show the tentative choice to be very sensitive to certain assumptions, then either the assumptions must be soundly motivated or the sensitivity of the evaluation to the assumed values must be indicated and emphasised. A contingency analysis ensures that the decision-maker is explicitly aware of the uncertainty associated with certain parameters. A diagram to illustrate the sensitivity of the evaluation to change in certain parameters is often worth a thousand words of explanation. A typical presentation of contingency analysis is Figure 5-11.

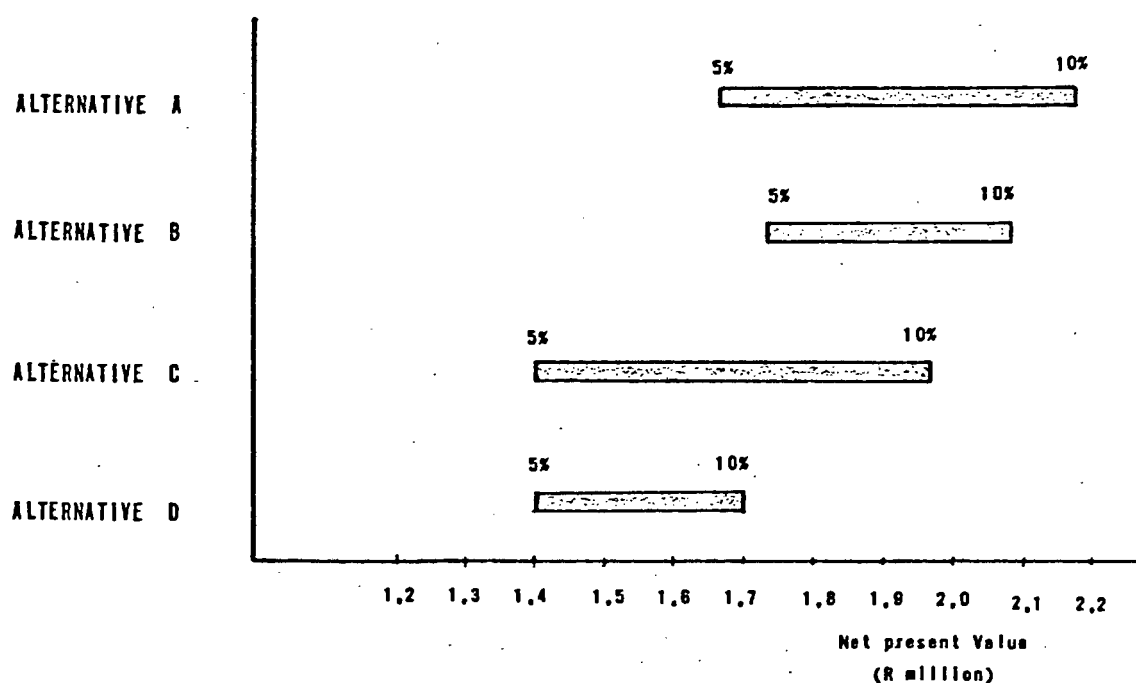


FIGURE 5-11 : DIAGRAM SHOWING THE VARIATION OF NET PRESENT VALUE FOR DIFFERENT TRAFFIC GROWTH FACTORS - 5% AND 10%

The scope and scale of contingency analysis in the evaluation phase can vary significantly, depending primarily on the design horizon and the hierarchy of planning that is under study. At the systemwide or regional level of planning where the design horizon is long, the contingency analysis may take the form of generating scenarios thereby, forming a major part of the evaluation phase. Royce (1978) suggests certain guidelines for the scenario approach to long term transportation planning. The following general factors, which may be appropriate for the generation of alternative

scenarios, show the magnitude and scope a contingency analysis can acquire.

- \* Changes in population in an urban area
- \* Changes in employment in an urban area
- \* Variation in the quantity of goods to be moved
- \* General level of prosperity
- \* Price and availability of fuel for personal transport
- \* Money available for investment in transport
- \* Government policy, re: transport, energy, land-use
- \* Technology changes
- \* Economic structure of a region.

At the project or localised planning level where the design horizon is not so distant, the contingency analysis may take the form of a sensitivity analysis which tests the better alternatives for robustness and flexibility under a limited number of different contingent situations. Typically, the analyst would examine the implications on the final selection of parameters that are normally difficult to forecast with accuracy or certainty eg traffic growth, modal share, etc.

Although the scope and form of the contingency analysis may vary, depending on the level of planning and the nature of the project, its purpose is always to demonstrate the effect of uncertainty to the decision-maker so that a rational and informed decision may be made. In the final analysis, this requires those rare qualities of mature judgement and experience on the part of both the analyst and the decision-maker.

### 5.8.3. Equity Analysis.

Barrell and Hills (1972c) have stated that equity, as well as economic efficiency, must be regarded as an essential criterion of evaluating alternative transportation plans otherwise incorrect decisions with undesirable social consequences will be made.

The concept of equity relates to the notion of fairness or equal treatment. It is concerned with identifying and measuring the impact and incidence of costs and benefits resulting from the alternative proposals on the various sectors of the public. Equity considerations are particularly relevant in transportation planning, since the consequences of most proposals are not uniformly distributed amongst all sections of the public. There are usually the beneficiaries and the losers. Often in a highway planning context the losers may be geographically concentrated, whilst the beneficiaries may be dispersed and receive a relatively large number of small gains.

In the traditional highway cost-benefit evaluation, equity/incidence problems were not explicitly appraised. This was primarily because the study boundaries were too narrowly drawn examining only the incidence of the road-user orientated costs and benefits (ie the gainers). The impact and incidence of consequences on the non road-user (ie often

the losers) were considered external to the evaluation and were not considered. Equity considerations nevertheless became very important when the external effects of a project compared significantly with the internal effects. Barrell and Hills (1972a) suggest the following categories of projects

- \* Government capital projects, eg urban freeways, town bypasses, new airport.
- \* Where group wants are catered for, eg the provision of bikeways through private properties, central city pedestrianisation schemes.
- \* Projects that have a re-distributional effects as built-in objectives, eg to reduce rural unemployment by adopting labour intensive construction techniques.

In order to analyse the incidence of the favourable and unfavourable consequences, it is first necessary to establish the criterion or basis for grouping the different sectors of the affected public (Allen, 1976). Common groupings are; income group, race, location, facility user, property owner etc. Having established the affected groups, the next task is to estimate the gains and losses to the various groups. This is often a difficult task, regardless of the evaluation procedure used, since the social and environmental aspects are often qualitative in nature. For instance, how does one quantify or compensate a loss of amenity (increased traffic noise) or a change in accessibility (major road relocation)?

Although equity considerations are usually analysed by grouping individuals into common activity groups, this very group classification can sometimes cause difficulties in evaluation. For example, there is often the complication of certain individuals being represented in more than one activity group, eg the property owner who lives adjacent to a new road and experiences a loss of amenity - a beautiful view but at the same time will use the new road and benefit from the increased accessibility. Thus, in certain cases, the group classification may not demonstrate the extent of the people's net losses or gains.

From the foregoing comments it can be seen that the emphasis and form the equity analysis can take in the evaluation phase can vary enormously. The analyst must therefore exercise considerable judgement as to which form the equity analysis should take. This assessment should be done in the early part of the planning process (ie stages 1 and 2 in Figures 3-2 and 3-3), when the analyst judges the likely importance of the equity/incidence problem for the particular project under study. Thus having assessed its importance relative to the economic and effectiveness aspects, the appropriate evaluation technique can be selected.

## REFERENCES FOR CHAPTER 5

- ADAMS, J.G.U. (1978) "PAVING WITH NUMBERS". Paper delivered at the P.T.R.C. Summer Annual Meeting at University of Warwick, England. 10th - 13th July 1978.
- ALLEN, G.R. (1976) "Incorporating Economic Considerations in the Preparation of Environmental Impact Statements". Transportation Research Record, No. 583.
- AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS (AASHO), (1973) "A Policy on the Design of Urban Highways and Arterial Streets", p. 260
- BARRELL, D.W.F. and HILLS, P.J. (1972) "the Application of Cost-Benefit Analysis to Transport Investment Projects in Britain". Transportation. Elsevier : Amsterdam Volume 1.
- BARRELL, D.W.F. and HILLS, P.J. (1972a) Ibid., p. 48
- BARRELL, D.W.F. and HILLS, P.J. (1972b) Ibid., p. 49
- BARRELL, D.W.F. and HILLS, P.J. (1972c) Ibid., p. 52
- BARRELL, D.W.F. and HILLS, P.J. (1972d) Ibid., pp. 30-31
- BAXA, J.V. (1978) "An Evaluation Procedure for Short-term Planning". National Institute for Transport and Road Research. CSIR. Report TPRR 9
- BAXA, J.V. (1978a) Ibid., p. 33.
- BEIMBORN, E.A. (1976) "Structured Approach to the Evaluation and Comparison of Alternative Transportation Plans". Transportation Research Record, No. 619, pp. 22-26.
- BEIMBORN, E.A. (1976a) Ibid., p. 25
- BELLOMO, S.J. (1980) "The Effectiveness of Priority Setting". Transportation Research Board Meeting : January 1980, Washington, U.S.A.
- BRIDLE, R.J. (1978) "A General Framework for Trunk Road Appraisal". Paper delivered at the P.T.R.C. Summer Annual Meeting at University of Warwick, England. 10th-13th July, 1978.
- BURNS, W. (1972) Chairman for the "Report of the Urban Motorways Committee". Her Majesty's Stationery Office p. 37
- BURNS, W. (1972a) Ibid., p. 36
- DEE, N., BAKER, J.K., DROBNY, N.L., DUKE, K.M. and FRAHRINGER, D.C. (1972) "Environmental Evaluation

System for Water Resource Planning". Report to the U.S. Bureau of Reclamation. Battelle Columbus Laboratories.

DICKEY, J.W. (1975) "Metropolitan Transportation Planning". McGraw-Hill. pp. 330-331

FREEDMAN, A.J. (1973) "Environmental Acceptability of New Urban Transportation Systems". Paper delivered at the 5th Quinquennial Convention : Transportation and the Environment. Johannesburg.

FUGGLE, R.F. (1980) "Regulating Environmental Change in South Africa". The Civil Engineer in South Africa. Volume 22. No. 4. p. 81

HALL, P. (1974) "Urban and Regional Planning". Pelican Book, p. 286

HALL, P. (1974a) Ibid., p. 285

HAWKINS, HAWKINS and OSBORN, (1979) "A Report on the Cost Effectiveness of Climbing lanes as compared to Climbing Embayments on Rural Two Lane Roads". March 1979.

HEUSTON, A.C. and OGAWA, G. (1966) "Observations on the Theoretical Basis of Cost Effectiveness". Journal of Operations Research Society of America. Volume 14, No. 2.

HILL, M. (1967) "A Method for the Evaluation of Transportation Plans". Highway Research Report, No. 180.

HILL, M. (1967a) Ibid., p. 25

HILL, M. (1968) "A Goals-Achievement Matrix for Evaluating Alternative Plans". American Institute of Planners Journal. Volume 34. No. 1. p. 22

HILL, M. (1968a) Ibid., pp. 25-28

HILL, M. (1968b) Ibid., p. 27

JAIN, R.K., URBAN, L.V. and STACEY, G.S. (1977) "Environmental Impact Analysis - A New Dimension in Decision Making". Van Nostrand Reinhold Company. pp. 74-78

JARVIS, J.L., UNGER, V.E., SCHIMPELER, C.C. and CORRADINO, J.C. (1976) "Multiple Criteria Theory and Airport Site Evaluation". Journal of Urban Planning and Development, Division of A.S.C.E. Volume U.P.2

JESSIMAN, W., BRAND, D., TUMMINIA, A. and BRUSSEE, C.R. (1967). "A Rational Decision-Making Technique for Transportation Planning". Highway Research Record No. 180.

KAY, J.L. (1970) "Signal System Studies - A New

Approach". Institute of Traffic Engineers Journal Volume 39. No. 1.

LEITCH, G. (1978) Chairman for the "Report of the Advisory Committee on Trunk Road Assessment". Her Majesty's Stationery Office. pp. 39-45

LEITCH, G. (1978a). Ibid., pp. 54-56

LEITCH, G. (1978b). Ibid., pp. 46-47

LICHFIELD, N. (1964) "Cost-Benefit Analysis in Plan Evaluation". The Town Planning Review. Volume 35. July 1964.

LICHFIELD, N. and CHAPMAN, H. (1968) "Cost-Benefit Analysis and Road Proposals for a Shopping Centre". Journal of Transport Economics Policy, September 1968.

LICHFIELD, N. (1972) "Evaluation of Amenity in Relation to Transport Costs and Benefits". Proceedings of the conference : Transportation Engineering, 1972. Institution of Civil Engineers, London. April 1972. p. 157

LICHFIELD, N. KETTLE, P. and WHITBREAD, M. (1975) "Evaluation in the Planning Process". Pergamon Press Ltd., p. 84

\* MISHAN, E.J. (1970) "What is Wrong with Roskill". Journal of Transport Economic Policy. Volume 4. p.222.

MORLEY-ENGLISH, J. (1968) "Cost Effectiveness - the Economic Evaluation of Engineered Systems". Wiley, p. 8.

ROYCE, N.D. (1978) "Scenarios and Long-Term Planning". National Institute for Transport and Road Research. CSIR. Report TPRR 6.

SCHERMER, J.H. (1975) "Interest Group Impact Assessment in Transportation Planning". Traffic Quarterly. January 1975. pp. 29-49.

SCHERMER, J.H. (1975a) Ibid., p. 39

SCHERMER, J.H. (1975b) Ibid., pp. 47-48

SCHIMPLER, C.C. and GRECCO, W.L. (1968) "Systems Evaluation : An Approach Based on Community Structure and Values". Highway Research Record No. 238.

SCHLAGER, K. (1968) "The Rank-Based Expected Value Method of Plan Evaluation". Highway Research Record, No. 238.

SCHOEMAN, H. (1980) Opening Address Given by the Minister of Transport Affairs, at the Annual General Meeting of the Southern African Road Federation, on 17th November 1980.

SCHOFER, J.L. and STOPHER, P.R. (1979) "Specifications for a New Long - Range Urban Transportation Planning Process". Transportation. Volume 8. No. 3.

SKINNER, R.E. and DEEN, T.B. (1978) "Cost-Effectiveness Guidelines for Transit Planning". Transportation Engineering Journal, Division of A.S.C.E. Volume T.E.3.

SKINNER, R.E. and DEEN, T.B. (1978a) Ibid., p. 342.

\* SORENSEN, J.C. and MOSS, M.L. (1973) "Procedures and Programs to assist in the environmental impact statement process. Institute of Urban and Regional Development. University of California, Berkeley.

STOPHER, P.R. and MEYBURG, A.H. (1976). "Transportation Systems Evaluation". Lexington Books, p. 5

STOPHER, P.R. and MEYBURG, A.H. (1976a) Ibid., pp 92-95

STOPHER, P.R. and MEYBURG, A.H. (1976b) Ibid., p. 155.

STUART, D.G. (1974) "Interactive Sensitivity Analysis in Transportation Plan Evaluation". Transportation, Volume 3, No. 3.

THOMSON, J.M. (1974) "Modern Transport Economics". Penguin Books, pp. 126-128

THOMAS, E.N. and SCHOFER, J.L. (1970) "Strategies for the Evaluation of Alternative Transportation Plans". National Co-operative Highway Research Program (NCHRP) Report 96. Highway Research Board.

THOMAS, E.N. and SCHOFER, J.L. (1970a) Ibid., p. 76.

WILSON, D.I. and SCHOFER, J.L. (1979) "Decision-maker defined Cost-Effectiveness Framework for Highway Programming". Transport Research Report No. 677.

WILSON, D.I. and SCHOFER, J.L. (1979a) Ibid., pp. 2-5.

WINFREY, R. (1969) "Economic Analysis for Highways". International Textbook Company pp. 144-146.

WOHL, M. and MARTIN, B. WOHL, M. and MARTIN, Analysis for Engineers and Planners". McGraw-Hill pp. 226-243.

WOHL, M. and MARTIN, B.V. (1967a) Ibid., pp. 234-241.

\* ZANGEMEISTER, C. (1973) "User-Value Analysis in Systems Analysis". Wittemannsche Buchhandlung, Munich.

\* Publication not available to the author.

CHAPTER 6 SUMMARY AND CONCLUSIONS

6.1 A SYNOPTIC ASSESSMENT .. .. .	6-1
6.2 SOME PARADOXES OF EVALUATION .. .. .	6-1
6.2.1 Systems Analysis in Evaluation . . . . .	6-5
6.2.2 Evaluation Linkages in the Planning Process	6-6
6.2.3 Value Framework in Evaluation .. .. .	6-7
6.2.4 Hierarchical Levels of Evaluation . . . . .	6-8
6.2.5 Measurement in Evaluation .. .. .	6-9
6.2.6 Presentation and Evaluation . . . . .	6-10
6.3 SOME FINAL THOUGHTS .. .. .	6-12
REFERENCES FOR CHAPTER 6 .. .. .	6-13

## 6. SUMMARY AND CONCLUSIONS.

---

### 6.1. A Synoptic Assessment

The most fundamental (and perhaps obvious) conclusion from the foregoing review of the different methodologies of evaluation, is that no technique can do everything. The review criteria demonstrate without exception that each method has its relative strengths and weaknesses.

In studying the different evaluation techniques it was interesting to note that the rationale behind the development of each technique was to overcome certain weaknesses of the other techniques. The "designer" of each evaluation technique would expound the virtues of his technique, endeavouring to demonstrate it's ability to handle the many diverse factors. Hudson (1979) makes the incisive comments that many of the subtle differences between techniques are a matter of labelling and packaging. The differences are often over emphasised to achieve what the retail market calls "product differentiation", something that will help sell the particular technique each "designer" is trying to offer. Perhaps this is only to be expected since the emphasis of no method is strictly neutral, each having a characteristic bias towards one or other of the review criteria. It is therefore difficult to maintain a sense of balance and perspective when undertaking a thesis of this nature, for so many of the fundamental parameters in transportation planning are in conflict, causing many evaluation dilemmas.

In spite of the foregoing comments Table 6-1 attempts to summarise the performance of the six evaluation methodologies against the review criteria drawn up in Section 5.1. Table 6-2 summarises the overall pattern of emphasis and neglect of each method found in the comparative review. In the opinion of the author it will be noted that not one method has obviously superior overall characteristics compared with the others - perhaps with the exception of the ranking matrix which has poor overall characteristics of evaluation in general.

In the planning of transportation infrastructure with their high capital investment, the cost-benefit method of evaluation has tended to dominate the "evaluation scene". Further, it is interesting to note that it is the cost-benefit methodology that is the point of departure for most of the other evaluation techniques which either represent a modification of COBA or a reaction against it. In the opinion of the the author, it is the methodologies that have modified the cost-benefit approach, particularly the cost-effectiveness and utility techniques that are the more robust techniques. This is opposed to those that have rejected this approach, namely the ranking and rating matrices. Robustness, in this context, refers to the scope of problems they can address and the diversity of evaluative criteria they can effectively accommodate.

However, each methodology has serious blind spots which, in the opinion of the author, can only be eliminated by parallel or supplementary evaluation. This thesis therefore advocates that for an evaluation to be comprehensive, complex transportation problems should be evaluated in two stages. The primary evaluation is to be undertaken with the "best overall" methodology, followed with a supplementary evaluation augmenting any deficiency in the former.

TABLE 6 - 1 A RELATIVE APPRAISAL OF THE DIFFERENT EVALUATION METHODOLOGIES AGAINST THE REVIEW CRITERIA

REVIEW CRITERIA	COST - BENEFIT	COST-EFFECTIVENESS	RANKING MATRIX	RATING MATRIX	UTILITY ANALYSIS	GOALS-ACHIEVEMENT MATRIX
Accommodation of different planning and time horizons	●	●	○	●	○	○
Value framework : 1. Economic efficiency	●	●	○	○	●	●
2. Environmental	○	○	○	○	○	○
3. Equity	○	○	○	○	○	●
Weighting of Criteria	○	○	●	●	●	●
Transformation Scales used : High or low	○	●	○	○	●	○
Resource requirements : Low or high	●	●	●	●	○	○
Replicability	●	●	○	○	●	●
Information transfer Aggregate (A) or Disaggregate (D)	A	D	A	A	A & D	A & D

Legend :  
 ● Indicates a major strength  
 ○ Indicates partial or one sided treatment  
 ○ Indicates a major weakness

TABLE 6-2: A SUMMARY OF THE PRINCIPLE CHARACTERISTICS OF THE SIX EVALUATION TECHNIQUES

EVALUATION TECHNIQUE	MAJOR STRENGTH	MAJOR WEAKNESS
<b>COST - BENEFIT METHOD</b>	<ul style="list-style-type: none"> <li>• Measures plans against the important value of economic efficiency</li> <li>• Computer programmes aid evaluation in high information situations.</li> <li>• Resource efficient</li> <li>• Widely used and well known</li> <li>• Can be applied to any hierarchy of planning</li> </ul>	<ul style="list-style-type: none"> <li>• Inherent economic bias</li> <li>• Socio - environmental and equity factors considered in a separate supplementary evaluation</li> <li>• Aggregate presentation masks trade - offs and subjective elements</li> <li>• Not amenable to evaluating conflicting goals and trade - offs</li> </ul>
<b>COST - EFFECTIVENESS METHOD</b>	<ul style="list-style-type: none"> <li>• Goal - orientated methodology</li> <li>• Measures plans against the criteria of economic efficiency and effectiveness</li> <li>• Can accommodate divergent value system</li> <li>• Flexible information format</li> <li>• Resource efficient</li> <li>• Analyst's subjective value judgements well controlled</li> <li>• Can be applied to any hierarchy of planning</li> </ul>	<ul style="list-style-type: none"> <li>• Disaggregate presentations in high information situations makes decision very difficult</li> <li>• Not amenable to a general weighting system</li> </ul>
<b>RANKING MATRIX</b>	<ul style="list-style-type: none"> <li>• Can accommodate multi-dimensional criteria</li> <li>• Simple and quick to use</li> <li>• Can accommodate a general weighting system (but breaks rules of numbers)</li> </ul>	<ul style="list-style-type: none"> <li>• Very coarse method of evaluation</li> <li>• Low ordinal scale used to measure plan performance</li> <li>• If principles of measurement are to be obeyed, not amenable to any arithmetic manipulation</li> </ul>
<b>RELATIVE RATING MATRIX</b>	<ul style="list-style-type: none"> <li>• Goal - orientated methodology</li> <li>• Can accommodate a general weighting system</li> <li>• Simple technique to use and resource efficient</li> <li>• Can be applied to any hierarchy of planning</li> </ul>	<ul style="list-style-type: none"> <li>• Plan performance based on the relative rating scale</li> <li>• Aggregate presentation masks trade-offs and subjective elements</li> <li>• Equity factors considered in a separate supplementary evaluation</li> <li>• More decision document than information document</li> </ul>
<b>UTILITY METHOD</b>	<ul style="list-style-type: none"> <li>• Goal - orientated methodology</li> <li>• Measures plans against the criteria of economic efficiency and effectiveness</li> <li>• Can accommodate a general weighting system</li> <li>• Plan performance based on the highest measurement scale</li> <li>• Analyst's subjective value judgements well controlled</li> </ul>	<ul style="list-style-type: none"> <li>• Requires large resources of manpower and time, particularly to develop performance graphs</li> <li>• More decision document than information document</li> <li>• Only suitable at the localised level of planning</li> <li>• Equity factors considered in a separate supplementary evaluation</li> </ul>
<b>GOALS ACHIEVEMENT MATRIX</b>	<ul style="list-style-type: none"> <li>• Goal - orientated methodology</li> <li>• Measures plans from the perspective of community interests</li> <li>• Strong community participation linkages</li> <li>• Two stage evaluation, first disaggregate format, second aggregate format</li> <li>• Can accommodate a general weighting system</li> <li>• Analyst's subjective judgements well controlled</li> </ul>	<ul style="list-style-type: none"> <li>• Method is complex and requires high resources of manpower and time</li> <li>• Low rating scale used to measure plan performance, prior to weighting</li> <li>• May require a separate supplementary economic evaluation</li> <li>• Only suitable at the localised level of planning</li> <li>• Danger of double counting costs and benefits</li> </ul>

## 6.2. Some Paradoxes Of Evaluation.

The foregoing section has shown that each method has its strengths and weaknesses. Why is it that no method has been designed to evaluate transportation problems comprehensively and holistically? The primary reason, in the opinion of the author, lies in the divergent nature of planning where there are fundamental paradoxical requirements that run through the whole planning process. These conflicts which interface on the evaluation phase, effectively neutralise any one method from being totally effective. This section will thus draw together some of these contradictory requirements.

### 6.2.1. Systems Analysis In Evaluation.

The basic principles of analysis and synthesis were demonstrated and the virtues of using a systems analysis approach to the evaluation element were summarised in Section 2.7. However, certain paradoxical requirements were apparent.

- \* The complementary and yet conflicting requirements of analysis and synthesis. Analysis, the break-down of the problem by the technique of classification or categorization into its component functions. Synthesis, the re-arrangement and building-up of the component parts to create alternative plans for evaluation.
- \* Figure 2-1 demonstrated that associated with the processes of analysis and synthesis is the process of iteration. The purpose of iteration is to improve the quality of information put forward to the decision-maker (Figure 1-2). It is important that each iteration uses better quality input information, models, designs and evaluation criteria. At the same time a balance should be kept between the quality of information and the hierarchical level of evaluation.
- \* One of the central activities of systems analysis was the development of a model of the system under study. Each evaluation technique that has been studied is in fact a model. Each designer has developed his evaluation model to depict the reality of evaluation as he sees it. It can be seen that the cost effectiveness and to some extent goals-achievement methods of evaluation could be categorised as descriptive models - since they attempt to present information free of the analyst's value judgements. The other methods; cost-benefit, rating and utility matrices are more prescriptive in nature since they are given a value of worth or utility for each alternative.
- \* The categorisation of the evaluation into descriptive and prescriptive natures (although not exact) does demonstrate another evaluation dilemma; objective and subjective judgements. The descriptive evaluation models attempt to present only objective information

leaving subjective judgement of weightings and relative worth to the decision-maker. On the other hand, prescriptive models incorporate objective and subjective sub-models into their evaluation matrix. This may simplify the decision-making process but means the evaluation will contain the analyst's subjective judgements which may or may not be explicitly apparent. Chapter 5 showed that both approaches have their merit and therein lies the dilemma.

### 6.2.2. Evaluation Linkages In The Planning Process.

Chapter 3 attempted to trace some of these pivotal evaluation linkages with the other activities in the planning process. It was shown that if these linkages were ignored, dialectical tensions can unnecessarily restrict the efficiency of plan evaluation and thus reduce the effectiveness of evaluation as an aid to decision taking.

The following general evaluation dilemmas were apparent and are reflected in each particular evaluation methodology reviewed:

- \* The need to utilise the linkage between the data collection and analysis phase, in order to avoid internal evaluation inconsistencies.
- \* The fundamental dilemma between constraints and objectives. The purpose of the study constraints is to bound the problem and to imbibe a measure of resource effectiveness into the analysis and evaluation elements. Whilst the purpose of the study objectives is to guide the synthesis of alternative designs and to lead to criteria for evaluating those designs. The criteria of feasibility and relevancy are contradictory concepts that should be used to ensure that the study constraints and objectives are in reciprocal balance.
- \* The reciprocal balance of constraints and objectives are used to check the alternative plans for internal and external consistency. External consistency is checked by applying the criteria of feasibility to ensure that all the alternatives generated comply with study constraints prior to evaluation. Internal consistency is checked by applying the criteria of relevancy to ensure the alternative plans meet the study objectives prior to evaluation. These inter-relationships are shown in conceptual form in Figure 6-1.

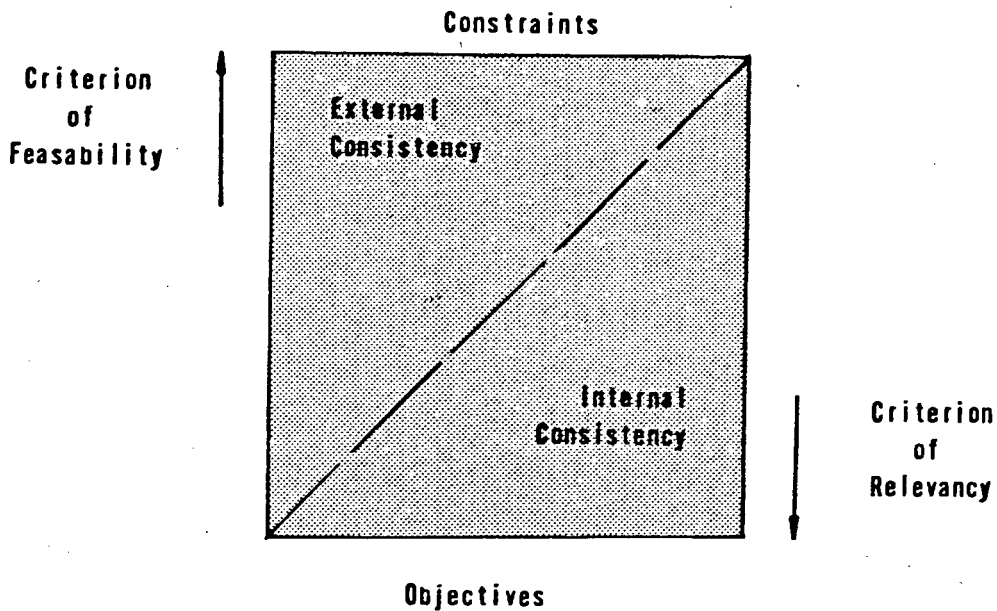


FIGURE 6-1 CONCEPTUAL MODEL SHOWING THE RELATIONSHIP BETWEEN CONSTRAINTS AND OBJECTIVES.

- \* An evaluation dilemma can exist when evaluation and decision-taking elements are carried out in a closed system. In this situation there is the hazard that the evaluation criteria and decision criteria may reflect in emphasis two different value frameworks resulting in the planning team recommending one alternative and the decision-makers selecting an entirely different alternative plan.

### 6.2.3. Value Framework In Evaluation.

A comprehensive value framework is a fundamental requirement before any effective evaluation can be undertaken. Section 4.3.1 put forward three fundamental values that should be accommodated in any evaluation methodology. These values were the values of economic efficiency, equity and environmental amenity. It was suggested that around these three values, the goals, objectives, evaluation criteria should be structured. (However, it should be added that because of the broad nature of transportation problems, these three values will not always be exclusively relevant).

Chapter 5 has demonstrated that not one of the evaluation techniques can effectively incorporate such a broad value framework into its rationale. This is due to the divergent and intertwined nature of transportation planning and relates to, inter alia : complementary and conflicting requirements of the values themselves, hierarchical levels of planning, spatial and temporal considerations and the

incommensurability of evaluation criteria. Table 6-1 shows in a simplistic graphical display the individual value emphasis or neglect that is apparent in each evaluation methodology.

Table 6-1 shows that the cost-benefit, cost-effectiveness and utility analysis models have an emphasis or bias towards the unitary value of economic efficiency. Conversely, the goals-achievement matrix, being disaggregate value in concept, focuses on equity considerations.

#### 6.2.4. Hierarchical Levels Of Evaluation.

On account of the diverse nature and the different time horizons that are present in transportation planning, the evaluation of alternatives is undertaken at two different levels of analysis. The purpose of a multi-level approach to evaluation is that it is an efficient method of searching out (from a broad base) good alternatives and corresponds to first doing a preliminary or exploratory design and then a detailed final design.

Section 4.2 showed that the scope of evaluation varied from the high-level systemwide or network planning down to the localised or project planning levels. The former's information being characterised by approximate or gross parameters and higher level of uncertainty, whilst the latter's information was more precise and associated with a lower level of uncertainty. The relationship between these two levels of evaluation is shown in Figure 6-2. It is obviously important that accuracy and quality of information presented for evaluation is in balance with the level of planning.

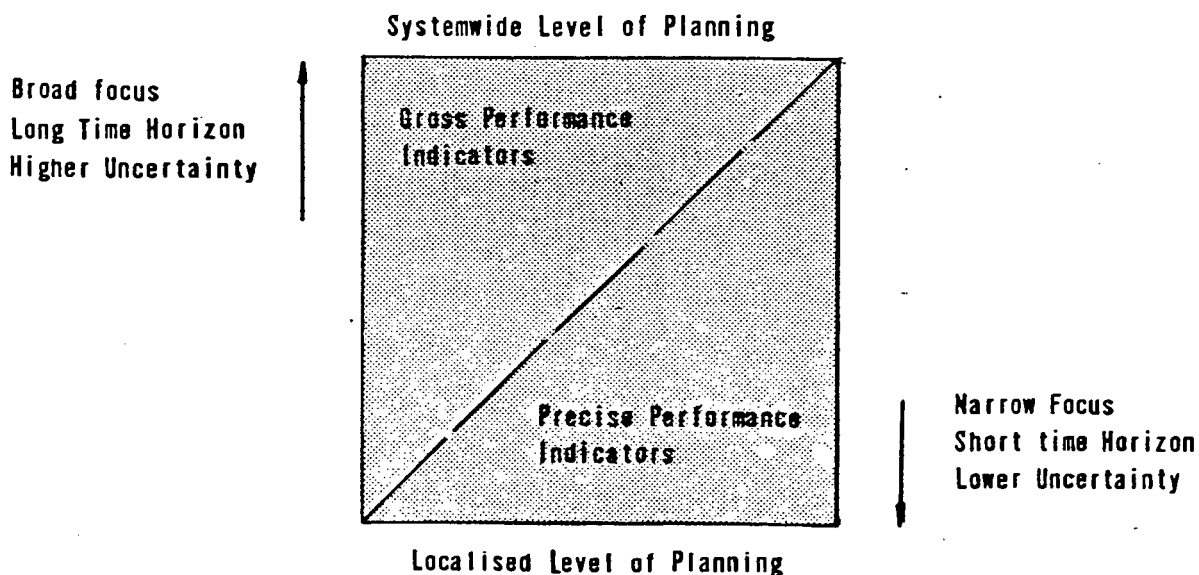


FIGURE 6-2 CONCEPTUAL MODEL SHOWING THE RELATIONSHIP BETWEEN THE DIFFERENT LEVELS OF TRANSPORTATION PLANNING.

### 6.2.5. Measurement In Evaluation.

Section 4.4 discussed the various dilemmas associated with the measurement of plan performance for eventual evaluation. The central evaluation dilemma that was identified was the incommensurability of measurement units and scales. Associated with this dilemma it was found that there were the following disparate categories of measurement:

- \* Objective vs. subjective measurement.
- \* Qualitative vs. quantitative measurement.
- \* Money vs. non-money measurement.
- \* Low vs. high order transformation scales.

The dialectical relationship between these categories of measurement is shown diagrammatically below in Figure 6-3.

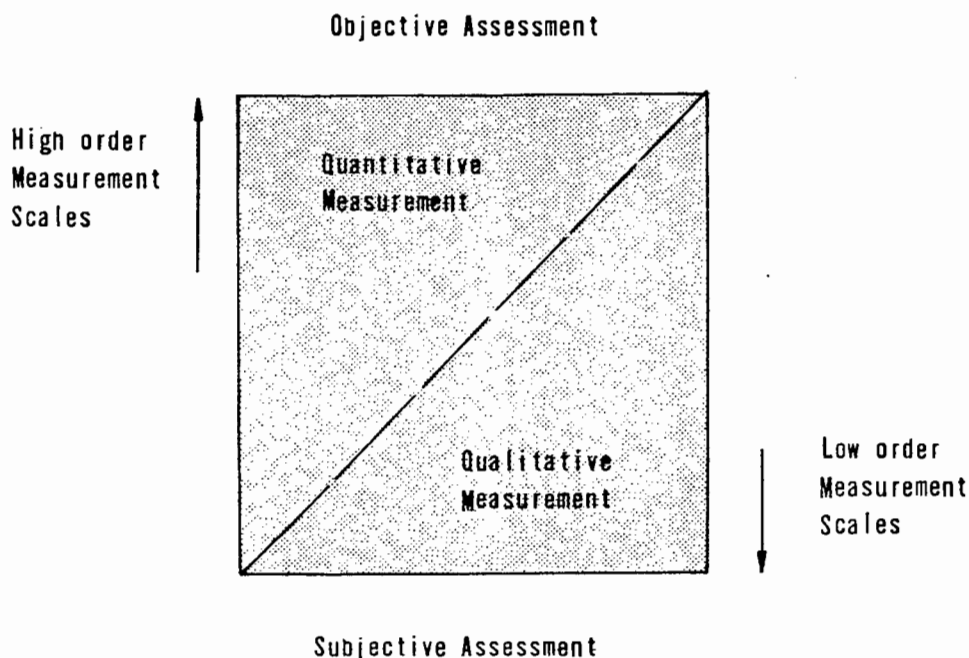


FIGURE 6-3 DILEMMA OF PLAN MEASUREMENT.

The main rationale behind the measurement of plan consequences and inputs is to increase the quality of information presented for evaluation. Since the quality of information is related to the four different kinds of measurement scales, each evaluation technique endeavours to use the "appropriate" highest order of scale. Thus, wherever possible, objective-quantified indicators of plan performance are preferred to subjective-qualitative indicators. For to quote Lord Kelvin; "when you can measure what you are speaking about and can express it in numbers, you know something about it, but when you cannot express it in numbers, your knowledge is of meagre and unsatisfactory .....". However, objectivity and quantification are

themselves not absolute frames of measurement, since they exclude, by definition, those subjective and qualitative aspects that are usually present and relevant to transportation evaluations.

Since there is no absolute frame of measurement, certain of the evaluation techniques have used transformation functions to translate the diverse quantitative and qualitative scales into a common scale. The desirability of evaluation techniques having a common scale were two-fold; firstly, to enable a comparative evaluation to be undertaken on the basis of alternative differences. Secondly, only with a common scale can a system of weights reflecting the value framework of the study be effectively applied.

However, it was seen that the approach of each evaluation technique to this dilemma was different. The cost-benefit approach uses the high order and versatile measurement scale of money, which gives the evaluation its characteristic asymmetric weight towards monetary tangibles as against non-monetary intangibles.

The cost-effectiveness approach uses the highest order scale appropriate for each indicator of plan performance, making no attempt to force indicators into commensurable scales. This approach to measurement gives this technique the characteristics of high objectivity, by leaving the subjective weighting of the many incommensurable factors to the decision-makers.

Conversely, the rating, ranking and utility matrices emphasise the need to aid the decision-makers task of choice, by giving major emphasis to ensure all indicators of plan performance are in commensurable units. The rating, ranking and utility matrices are characterised by their respective progressive use of a higher order transformation scales and their non differentiation between objective and subjective measurement in the evaluation matrix.

The goals achievement matrix uses a two-step evaluation approach. The first phase of evaluation is similar to the cost-effectiveness approach, ie it is disaggregate in nature using the highest order measurement scales wherever possible. The second phase usually uses either a simple ranking or a rating transformation function to ensure the system of community weights can be applied thus aiding the decision-makers task of plan selection.

#### 6.2.6. Presentation And Evaluation.

The primary purpose of evaluation is to provide the best information and to present that information concisely and clearly to the decision-maker. Again an evaluation dilemma is apparent and centres on whether the presentation should be aggregate or disaggregate in format. Table 6-1 demonstrated that with the exception of the cost-effectiveness technique, the other evaluation techniques were aggregate in nature. The advantage of an aggregate format is that the consequences of

each plan can be summed into a total performance index which permits easy comparison with the other alternatives presented. Thus an aggregate presentation simplifies the decision-makers task of plan selection.

The disadvantages of this approach is that the emphasis given to the disaggregate, conflicting or contentious consequences in the evaluation format rests with the analyst. In addition, the aggregate approach is more decision orientated than information orientated. The analyst's subjective judgements are built into the presentation because of this characteristic. The magnitude of this disadvantage will depend on how much exposure the subjective assessments in the evaluation have been exposed to the triangular debate between the planning team, the affected community and the decision-takers. Thus, in an aggregate format of presentation, there is a subtle shift of responsibility of decision-taking away from the decision-maker to the evaluation team.

The strength of an aggregate format is that it gives a good indication of overall plan performance. Conversely, the strength of a disaggregate format is that it gives a good indication of the trade-offs and conflicts that exist in the performance of different plans.

Further, there is a natural paradox between aggregate - disaggregate format and depth of explanation - ease of interpretation. This dilemma is illustrated in Figure 6-4.

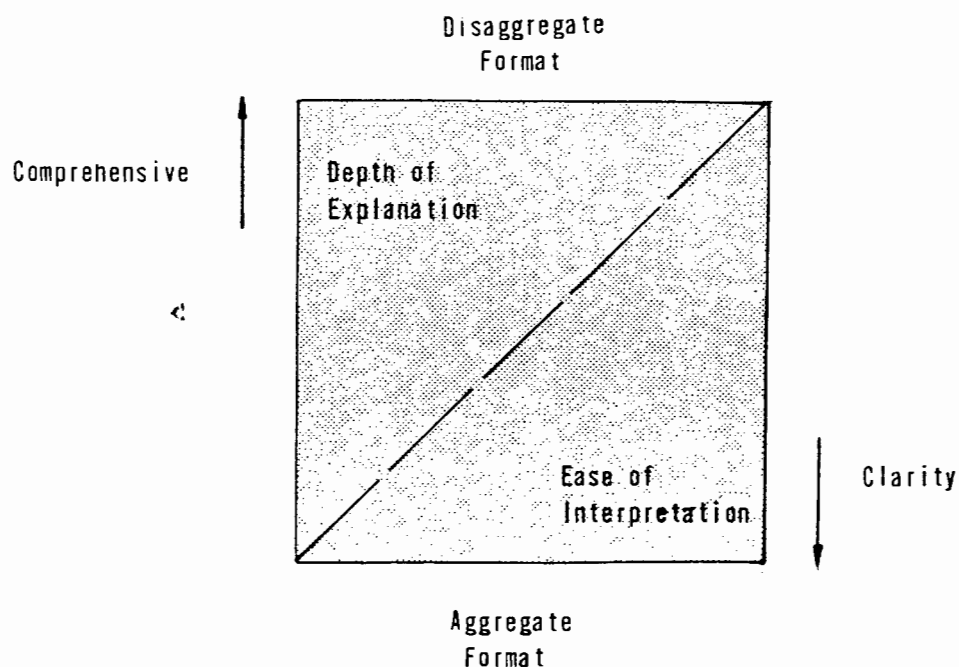


FIGURE 6-4 DILEMMA BETWEEN DEPTH OF EXPLANATION AND EASE OF INTERPRETATION.

The above paradox is seen most accutely in metropolitan transportation studies where the large volumes of computer generated information and the large number of variables

inevitably makes the balance between comprehensiveness and clarity difficult to achieve. It is the opinion of the writer that this conflict can only be resolved by evaluating proposals selectively at both the disaggregate and aggregate levels.

### 6.3. Some Final Thoughts

Gilbert and Jessop (1978) and Beimborn (1976) have suggested that for too long the transportation planning process has been unbalanced, in that an excessive amount of resources have been spent on the development of complex models to analyse and forecast future travel demand, at the expense of the crucial evaluation element. However, as Stuart (1974) states, this asymmetry of effort is now being rectified and increasing attention is being focused on the evaluation element as perhaps the pivotal point in the transportation planning process. It is the author's hope that in a small way, this overview of the different methods of evaluation will bring the evaluation element into even sharper focus.

Therefore, which is the best method of evaluation?

This thesis has shown that there are no simple answers to this question, for such a question is divergent in nature. Thus, the author finds it disturbing when such eminent researchers as Stopher and Meyburg (1976) state, "There seems to be little question that the cost-effectiveness procedure is the ideal evaluation scheme, provided that its current shortcomings can be surmounted". Its current shortcomings as we have seen in Table 6-2 are; it is not amenable to a general weighting system and decision taking is very difficult on account of its disaggregate presentation. This thesis has tried to demonstrate that the shortcomings of the cost-effectiveness technique (as indeed the shortcomings of all the other evaluation techniques), merely reflects the fundamental paradoxes that are an inseparable part of the transportation evaluation fabric. In consequence no amount of additional research is, therefore, likely to fundamentally change these shortcomings.

The initial hope when this study was conceived that with the help of systems analysis it could be shown that one method was better than the others. However, as Schumacher (1977) points out with divergent problems such as transportation planning, systems analysis logic is not sufficient to solve the problem, it can only illuminate the inherent conflicts. Therefore, as long as transportation planning is concerned with optimally and equitably dividing scarce resources amongst competing needs, evaluation of alternative courses of action will be a challenging and demanding task - regardless of the evaluation methodology used.

## REFERENCES FOR CHAPTER 6

BEIMBORN, E.A. (1976) "Structured Approach to the Evaluation and Comparison of Alternative Transportation Plans". Transportation Research Record, No. 619, p. 22.

GILBERT, D and JESSOP, A. (1978) "Taxonometric Evaluation". Transportation. Elsevier : Amsterdam. Volume 7, p. 147.

HUDSON, B.M. (1979) "Comparison of Current Planning Theories : Counterparts and Contradictions". Journal of American Institute of Planners. Volume 45, No. 10, p. 388.

SCHUMACHER, E.F. (1977) "A Guide for the Perplexed". Sphere Books Ltd., p. 142.

STOPHER, P.R. and MEYBURG, A.H. (1976) "Transportation Systems Evaluation". Lexington Books. p. 156.

STUART, D.G. (1974) "Interactive Sensitivity Analysis in Transportation Plan Evaluation". p. 289.

APPENDIX A  
THE COST-BENEFIT APPROACH TO DETERMINING  
HIGHWAY COSTS AND BENEFITS

7.1 INTRODUCTION .. .. .	7-1
7.2 HIGHWAY COSTS .. .. .	7-1
7.3 ROAD USER BENEFITS .. .. .	7-2
7.3.1 Travel Time Reduction Benefits . . . . .	7-2
7.3.2 Criticism of the Valuation of Time .. .. .	7-5
7.3.3 Vehicle Running Costs . . . . .	7-7
7.3.4 Accident Reduction Benefit .. .. .	7-8
7.4 CLOSURE .. .. .	7-9
REFERENCES FOR CHAPTER 7 .. .. .	7-10

---

 THE COST BENEFIT APPROACH TO DETERMINING HIGHWAY COSTS & BENEFITS
 

---

## 7.1. Introduction

Appendix A will briefly review the traditional cost-benefit approach to the evaluation of highway investments. In addition, some of the difficulties and criticisms associated with this approach will be discussed.

It will be recalled that in cost-benefit analysis, plan performance is measured in terms of the criteria costs and benefits. Figure 5-1 illustrates the categories of costs and benefits that are traditionally considered as the principal elements of the highway cost system.

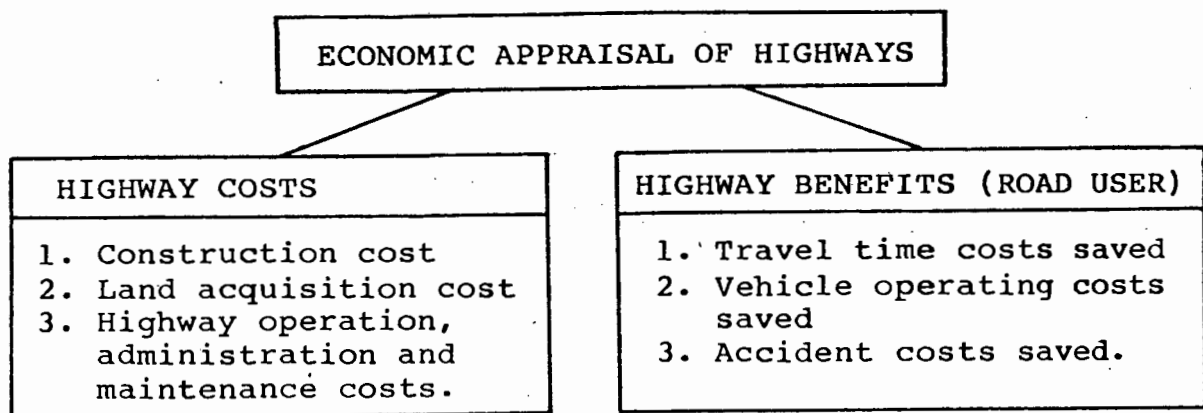


FIGURE 5-1 EVALUATION CRITERIA FOR THE ECONOMIC APPRAISAL OF HIGHWAYS.

## 7.2. Highway Costs

The different cost categories will be discussed in turn.

## \* Construction Cost

The construction cost is usually estimated by the engineer taking due account of the physical design, method of construction and current market prices.

## \* Land Acquisition Cost

This category of cost covers compensation monies paid to the affected landowners for the land, buildings, homes, improvements, etc. required for the highway corridor. Market valuation is usually determined by an independent land-property valuator.

\* Highway Operation, Administration and Maintenance Costs

This category of cost covers the annual cost of operating and maintaining the facility. This will include such items as; general maintenance, road surface repairs, signing, road markings and their associated administrative costs.

In Section 5.3.1(a) the above costs were categorised as direct effects, with the transmitted and transferred effects being considered external to the evaluation. Similarly, when the highway benefits are considered, only the direct effects are accounted for, ie the road-user benefits.

### 7.3. Road User Benefits

Road travel, for whatever purpose, involves the road-user in certain costs namely; the cost of time spent travelling, the cost arising from road accidents and the associated vehicle operating costs. In the evaluation process the major benefit from the construction of a new highway is therefore the reduction of the foregoing costs.

Whilst the reduction in vehicle operating and accident costs are an important stream of benefits when considered over the life of the project, the most significant of the above benefits is the reduction in road-user travel time. Searle (1978), reports that in Britain 80%-96% of the quantified benefits from a typical trunk road scheme evaluation are derived from time savings. Similarly, Stopher and Meyburg (1976) report that in the evaluation of the United States interstate highway system, between 72%-81% of the benefits are derived from travel time savings. From the author's experience, similar percentage time benefits are found in the Republic's urban and peri-urban areas. In view of the extreme importance of the valuation of time in the evaluation process, the procedures that have been developed to value travel time savings will be considered in some detail.

#### 7.3.1. Travel Time Reduction Benefits

The concept of travel-time saved is problematic. Firstly, time itself has no inherent value and secondly, time cannot be intrinsically saved. As Winfrey (1969) states, the value of time is a substitute expression for the value of the products produced or services gained during the passage of time.

The value of time should therefore be considered as the value, or the net utility, of spending time in a chosen way. In transportation economics, travel time is treated as a disutility (ie a "dis-benefit"), on the basis that the traveller would prefer to do something else during the trip. Clearly, the valuation of time in a highway context is multi-factorial in nature, it's value being primarily dependent on certain trip characteristics.

- \* trip purpose - business, commuter, leisure
- \* persons travelling - number, occupation, wage earnings
- \* time of trip - hour of day, day of week
- \* location of trip - type of highway, rural, urban
- \* volume of trips - composition of traffic, car, bus, truck

From inspection of the above inter-related factors and because of the importance of time values to the evaluation process, it is hardly surprising that there is a wealth of research and literature on this subject. Predictably, there are also a myriad of different theories and techniques for determining the value of time with a concomitant range of values for the engineer or planner to choose from. It is beyond the scope of this thesis to undertake a comprehensive "state of the art" review on this complex subject. The following comments are however based primarily on the recent and very comprehensive "state of the art" report on Trunk Road assessment in Britain carried out under the chairmanship of Sir George Leitch and published in January 1978.

Leitch (1978) points out that there are principally four assumptions in the current approaches to valuing work time savings.

- (a) The employer is assumed to be sensitive to time savings made by his employees and on average is able to use them.
- (b) It is assumed that all travel is carried out in working time and that during the trip no productive work is possible.
- (c) The assumption is made that employees in travelling, always act in their employer's interest.
- (d) The assumption that all time savings, whatever their length, are of value and can indeed be valued at the same rate, irrespective of their length.

The above assumptions, particularly (a) and (d) often give rise to criticism and disagreement. It is often questioned whether it is right to value working time by reference to average wage rates because such a procedure assumes that all time savings, no matter how small or under what circumstances they occur, are capable of being translated into productive output. Leitch (1978a) concludes in his review of work time values that the principle of valuing working time at the gross cost of employing labour is currently the most reasonable and practical method to incorporate this important component into the evaluation framework. It was however considered that the use of a single "equity" value of time for all the time savings, regardless of trip characteristics, is too simplistic an approach and a source of potential error and confusion.

Leitch has therefore recommended that time savings be broken

down into three "activity categories" with each category being given appropriate values of time.

The three categories of trip identification are:

- \* work trip
- \* commuter trip (ie journey to and from work)
- \* leisure trip (ie includes personal business trips)

The above categorisation is sound, since De Donnea (1971) in his research on the valuation of time, has concluded that the value of travel-time saved is dependent upon the activity that replaces travel. Freeman (1978), in considering the valuation of travel time for South African conditions has also used the above categorisation.

The categorisation by trip characteristic is prudent, since there is clearly considerable variation from one highway location to another as regards the proportion of annual average daily traffic (AADT) which are work trips. It would therefore be realistic to recognise that the proportions of the three types of trips would vary with the location.

#### (i) Work Time Values

The benefit that arises from working time being saved is the assumed opportunity for extra productive activity which is of value to either the individual, firm or nation. Working time is normally valued at its cost to the employer plus certain overheads. This category of time saving equates the employer's cost with the value of the extra output he gains from the employment of the individual traveller concerned.

#### (ii) Commuter Time Values

Jackson and Burrell (1977), amongst others, have shown that the journey to and from work in urban transportation studies is generally the most dominant category of trip in shaping urban travel patterns. Another characteristic of this category of trip making is that commuters perceive a change in the time taken in their journey to work akin to a change in their length of day or hours of work. The importance of this category of trip to the evaluation process is obvious but the benefit that arises from commuter time being saved is less so than the previous category of work time savings.

Due to the absence of a market for non-working time, the values usually adopted are based on observations of peoples' behaviour, usually in transport choice situations. Many modal choice decisions have an implicit value of time. As an example; if a commuter selects a fast, expensive mode in preference to a slow, cheap mode, he shows he is willing to pay X Rand to save Y minutes. He is revealing an implicit valuation of his time of at least  $X/Y$  Rands per minute. De Donnea

(1971) has shown that individuals do value travel time in non-work activity situations (ie in commuting or in leisure time) and that it is not correct to assume that time only has value when it can be used for productive activities.

### (iii) Leisure Time Values

This category of trip encompasses a wide range of activities from personal business ie shopping trips, school trips, to pure leisure travel. This category of trip would have important implications for the evaluation of schemes where a high proportion of leisure trips are made, such as in holiday areas.

As with commuter time values, no direct market values exist for leisure time and it's valuation has to be deduced from observing peoples' behaviour.

The National Institute for Transport and Road Research (NITRR) currently recommends the following national average values for travel time, 1980 base. (Freeman, 1981)

- \* Working Time Value - R2,50 per hour
- \* Commuting Time Value - R0,75 per hour (30% of working time)
- \* Leisure Time Value - R0,63 per hour (25% of working time)

### 7.3.2. Criticism of the Valuation of Time

In the foregoing approach to the value of time savings, there are several issues which often attract criticism:

- \* Stopher and Meyburg (1976a) in their review of the valuation of travel time conclude that most derived values of time should be more accurately termed average or marginal prices of time, as they are derived from specific choice situations. The value of time depends upon personal, specific cost-time trade-off situations. The average price of time and concomitantly the behavioural response of the individuals would alter should any of the parameters change. Purists would argue that a list of standard (national) values of travel time is not theoretically appropriate.
- \* The second criticism relates to the equity of decisions based upon the proposed categories of time values. Maximum benefits are likely to accrue from alternatives that save time for the higher income groups since it is proposed to value the benefits to travellers on the basis of their income. In South Africa where the differences in wage rates are often synonymous with race, such a "bias" is clearly not desirable from a social welfare or public investment viewpoint. Again, Stopher and Meyburg (1976b) report that this fundamental problem in economic evaluation has not yet been resolved and in fact must be

considered outside the evaluation process.

- \* The third criticism relates to the above points, is that the value of time is linked to specific choice locations as the value of time varies substantially with the level of economic and social development of a country or region (Adler, 1971). As an example, in the underdeveloped regions of Transkei or Zululand where the size of the active population is much greater than the number of job opportunities and income per capita is low, the value of time is relatively cheap. The value of time savings used must therefore always reflect the local or regional situation to avoid any bias in the economic analysis.
- \* A further criticism often levelled at the foregoing approach to travel-time valuation is that the values of small time savings are aggregated in the cost benefit analysis at a uniform unit value. It is thus assumed that the value of time saved is a direct function of the amount of time saved, whatever its length. Thus, in a cost-benefit analysis, the benefits that accrue when one person saves 1 hour or 60 people save 1 minute or 3,600 people save 1 second are the same.

Many critics state that the above assumption is contrary to common sense, suggesting that small time savings have no value and should be disregarded in the evaluation. This is based on the view that small time savings either cannot be put to productive use or are not able to be perceived. It is therefore often suggested that small time savings below a certain threshold should be ignored. The argument then moves between what time-savings can be perceived and what can be productively used. Although there is relevant evidence to consider very small time savings to have no value, current research has not been able to produce a feasible set of criteria for choosing such a threshold.

The Department of Transport in Britain has given the following reasons for aggregating small time savings in the cost-benefit appraisal of alternatives (Leitch, 1978b).

- (a) Highway corridors are generally constructed and improved in an incremental manner. Thus the aggregate time saving gained on a journey can typically be made up from small disaggregate incremental road improvements. It would be inconsistent to value overall time saving differently from its component parts.
- (b) Historically, the nature of technical improvement in transport has been one of substantial investment to yield small time savings, at each step, which have been desired and paid for.
- (c) Trip characteristics of general road travel show that most trips are of a short duration, resulting in very small time savings.
- (d) The value of time, determined according to economic

theory, is a marginal one and the measurement of benefits in small time units is therefore appropriate.

The foregoing comments have demonstrated that the economic valuation of travel time is fraught with difficulties and implicit assumptions. On account of their importance to the total road-user benefits, more than any other, it is the economic valuation of this category of benefit that has been specifically criticised in the general critique of the cost-benefit approach to project evaluation. Nevertheless, its proponents would argue that if national averages of time are used, then although not perfect, a formalised and internally consistent evaluation can be made between mutually exclusive alternatives.

### 7.3.3. Vehicle Running Costs

One of the benefits resulting in proposed highway improvements is a reduction in vehicle operating costs. Vehicle operating costs can be categorised into two cost elements.

- \* Highway design dependent costs - eg consumption of fuel, tyres, oil, maintenance and repair and a proportion of depreciation costs.
- \* Costs independent of road use - garaging and parking, annual licence and insurance fees, interest on capital, truck driver's wages, etc.

The former category of cost tend to be distance and road use related, whilst the latter category are time related.

It is therefore the costs, usually termed vehicle running costs that are related to highway design which will be considered. Certain other operating costs eg wages of driver and crew, are taken into account in the time-saving element of the cost-benefit approach.

For reasons of feasibility, the analyst must use average figures in determining the vehicle running costs. These average values represent the wide range of performance characteristics of vehicles that will use the highway under study during the analysis period. The NITRR in its regularly updated reports, gives vehicle running costs in terms of the dependent variable, average running speed, for four categories of vehicle; medium-sized car, light commercial vehicle, heavy commercial vehicle and heavy articulated vehicle combination. Thus, knowing the composition of traffic on the highway and the horizontal and vertical geometry of the alternative alignments, the vehicle running costs can be determined and compared. The use of "standard" computer programmes which are presently available, greatly simplifies the quantification of this category of road-user benefits.

#### 7.3.4. Accident Reduction Benefit

The costs of accidents are included in road-user benefits in the sense that the new highway should be an improvement on the existing one as less highway accidents are expected. Like the other road-user benefit of travel time, the monetary valuation of traffic accidents is problematic, since there are no direct market values.

Nevertheless, public highway authorities indirectly place a monetary value on road accidents, for almost every detail of highway design and operation is associated with some safety consideration. Similarly, an authority cannot rationally decide whether it's safety budget is justified unless it relates accident saving to expenditure. The trade-offs between safety and cost are therefore implicit in most highway decisions and policies.

In the evaluation of alternative highway plans, two statistics are required on traffic accidents in order to compute the benefits that will accrue from a reduction in accidents.

- \* The accident rate- ie the frequency of accidents per vehicle km for a particular facility in a given time period. An estimate of the probable reduction in accidents is then made by comparing the accident rate on the existing road as it would be without improvement, with an estimated rate for a similar higher standard of highway to that of the new facility.
- \* Value of the accident reductions - road accidents (like travel time costs) are multi-factorial in nature and are made up of several cost elements. In the first place, there are public sector costs; hospital services, police force, legal and court costs. Secondly, there are private sector costs; goods and property damaged, administrative costs of insurance companies. Thirdly, there are personal costs to cover the pain, grief and suffering that is associated with traffic accidents. Finally, there is a societal cost in that society loses the productive output from the individual's involvement in the traffic accident. This is permanent if the accident is fatal, temporary if the accident is non-fatal. Clearly, the severity of the accident determines the cost of the accident, therefore accident cost data are categorised into two categories; fatal and non-fatal.

Again, the NITRR has developed a formalised approach for the monetary valuation of traffic accidents in the Republic. Currently, the following cost figures (1979 base) are recommended to determine this category of road-user benefit (Goosen, 1980).

- \* Fatal accident - R65 000
- \* Serious injury accident - R7 500

- \* Light injury accident - R2 000
- \* Property-damage-only accident - R1 000

#### 7.4. Closure

The purpose of this overview was to show the scope and the parameters that are normally considered in the traditional cost-benefit methodology. It has been shown that with its many years of use, the development of computer programmes, the many revisions and improvements, a highly formalised method of appraisal has been developed. Plan performance of the different alternative plans is measured in aggregated monetary units using a mixture of market and non-market pricing procedures.

## REFERENCES FOR APPENDIX A

- ADLER, H.A. (1971) "Economic Appraisal of Transport Projects". Indiana University Press. p. 33.
- \* DE DONNEA, F.X. (1971) "The Determinants of Transport Mode Choice in Dutch Cities : Some Disaggregate, Stochastic Models". Rotterdam University Press, The Netherlands.
- FREEMAN, P.N.W. (1978) "The Costs of Road Traffic Congestion in the Republic of South Africa". The National Institute for Transport and Road Research. Technical Report RT/34/78. pp. 49-52.
- FREEMAN, P.N.W. (1981) Personal communication with the author, technical report soon to be released.
- GOOSEN, J. (1980) "An Estimate of Road Accident Costs in South Africa for 1979". The National Institute for Transport and Road Research. Technical Report RT/8/80.
- JACKSON, R.I. and BURRELL, R.C. (1977) "Guidelines for Urban Transportation Studies". The Professional Engineer. Volume 6. No. 1.
- LEITCH, G. (1978) Chairman for the "Report of the Advisory Committee on Trunk Road Assessment". Her Majesty's Stationery Office. p. 20.
- LEITCH, G. (1978a). Ibid., p. 102.
- LEITCH, G. (1978b). Ibid., p. 20.
- SEARLE, G.A.C. (1978) "Cost-Benefit Analysis : Felicific Calculus or Black Art ?". Paper delivered at the P.T.R.C. Summer Annual Meeting at University of Warwick, England. 10th - 13th July 1978.
- STOPHER, P.R. and MEYBURG, A.H. (1976) "Transportation Systems Evaluation". Lexington Books. p. 39.
- STOPHER, P.R. and MEYBURG, A.H. (1976a). Ibid., pp. 41-49.
- STOPHER, P.R. and MEYBURG, A.H. (1976b). Ibid., p. 59.
- WINFREY, R. (1969) "Economic Analysis for Highways". International Textbook Company. p. 264.
- \* Publication not available to the author.

## APPENDIX B

8. DETAILS OF POST-GRADUATE COURSES COMPLETED

COURSE NO.	YEAR	COURSE NAME	CREDIT VALUE	RESULT
402 506	1974	Properties of Concrete	4	2-
504 811	1974	Transportation Engineering	4	2-
917 402	1975	Fundamentals of Environmental Science	3	2-
917 406	1976	Principles of Environmental Analysis	5	2-
402 531	1977	Urban Transportation Planning & Modeling	4	2+
			Σ 20	

Details of the contents of the above courses and examination papers (where applicable) are enclosed overleaf.

UNIVERSITY OF CAPE TOWN  
DEPARTMENT OF CIVIL ENGINEERING  
UNIVERSITY EXAMINATION: JUNE 1974  
COURSE CE 506 - PROPERTIES OF CONCRETE

M.Sc. IN ENGINEERING

Time Allowed: THREE HOURS

Candidates are required to attempt ALL questions in Part A, and not more than FOUR questions from Part B.

PART A

1. What are the four principle oxides in Portland cement? (1)
2. Give two methods of manufacturing a Portland cement with rapid hardening properties. (2)
3. In what way do the setting time and the ultimate strength of ordinary Portland cement differ from those of rapid hardening Portland cement? (1)
4. Briefly explain the phenomena of bleeding in concrete, and give the beneficial affect and the adverse affects of bleeding. (3)
5. Explain what is meant be self-dessication of a cement paste. (1)
6. Under what environmental conditions does concrete made with high alumina cement undergo an irreversible retrogression of strength? (1)
7. Why does concrete considered in No. 6 above become susceptible to sulphate attack? (1)
8. Calculate the maximum horizontal pressure on the formwork for a concrete column of dimensions 0,5 x 1 x 5 m to be cast at a vertical rate of placing of 5 m/hr at an estimated concrete temperature of 15°C. A vibrator is used with approximately 60% continuity to compact the concrete. The slump of the concrete is 100 mm and there is a delay of approximately ten minutes between the mixing and placing of the concrete.  
  
The placing of the concrete is effected in such a manner that there is no appreciable pressure surcharge due to impact. (The weight density of concrete may be taken as 24 kN/m<sup>3</sup>.) (1)
9. What factor has the greatest influence on the durability of concrete? (1)
10. Why is the sulphate attack of concrete by MgSO<sub>4</sub> regarded as being more severe than sulphate attack by CaSO<sub>4</sub>? (1)
11. Explain two possible ways of increasing the resistance of concrete to freezing and thawing. (3)
12. Why is the triaxial compressive strength of concrete higher than the uniaxial compressive strength? (1)
13. How does the rate of loading affect the uniaxial compressive strength of concrete? (1)

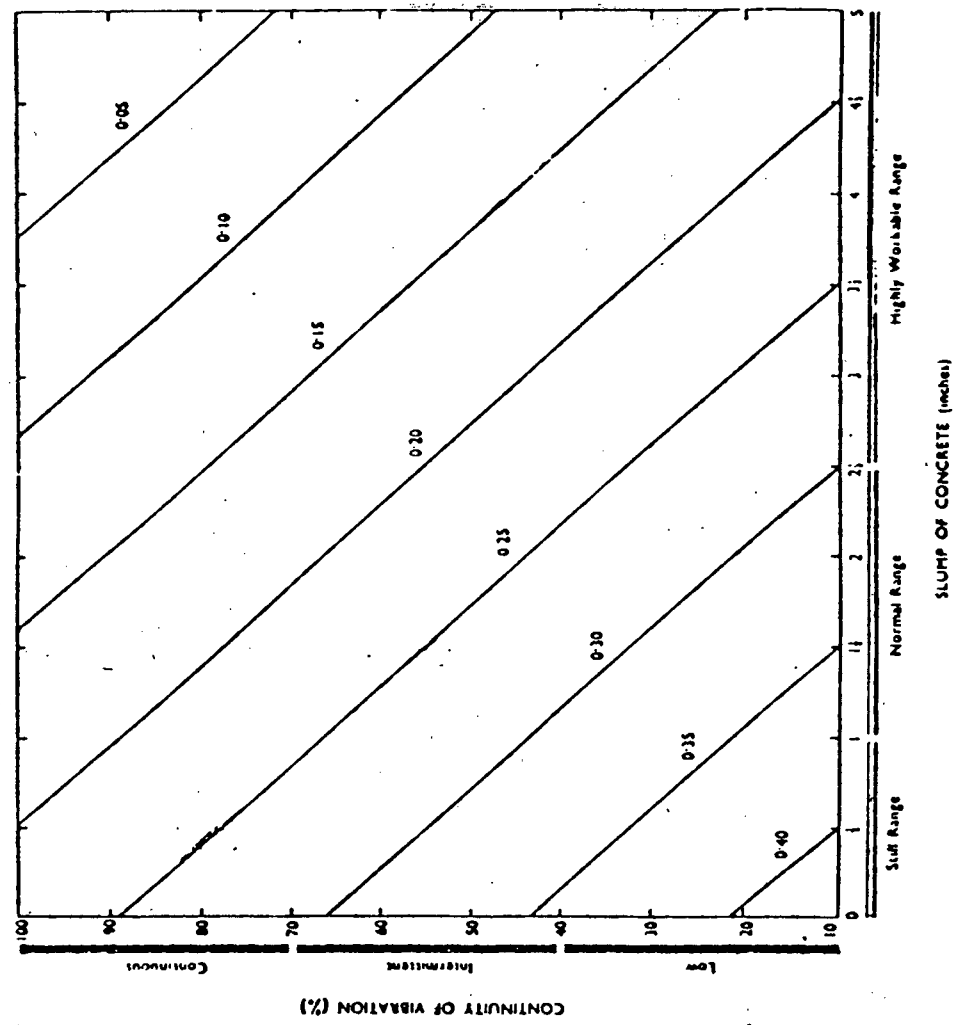
PART A (continued)

14. Give three reasons why the transverse bending test overestimates the true tensile strength of concrete. (3)
15. Briefly state the possible mechanisms of creep in concrete. Indicate whether the creep is recoverable or irrecoverable in each instance. (5)
16. In what way does aggregate influence the creep of concrete? (1)

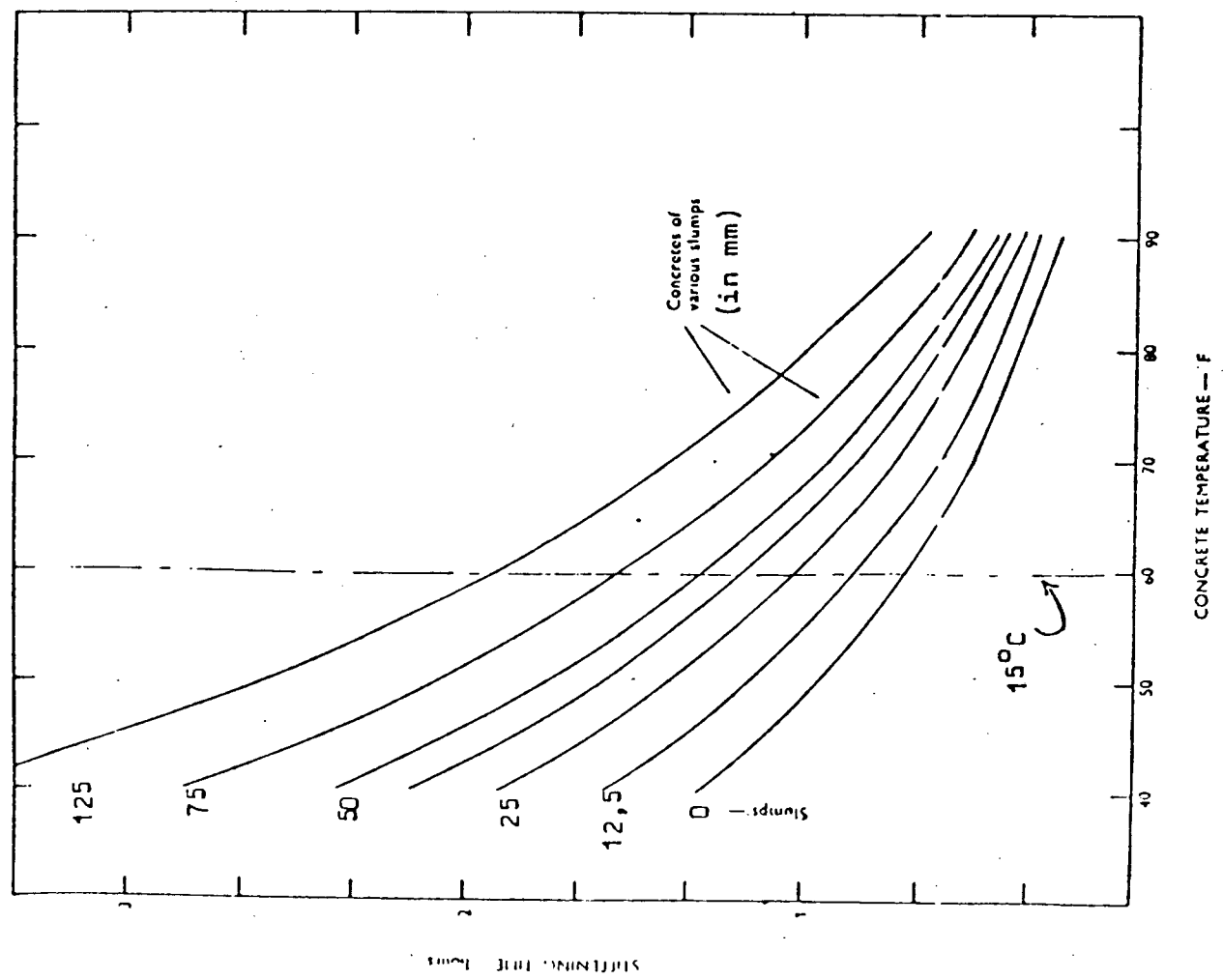
(TOTAL : 30 MARKS)

PART B

1. Explain and illustrate the following:
- the hydration of the mineral compounds constituting Portland cement with particular reference to their respective contributions to strength and heat of hydration,
  - the structure of hardened cement paste, with particular reference to the different categories of water contained in the paste. (18)
2. (a) Show why a cement paste having a W/C ratio  $< 0,36$  (by mass) and continuously cured under water will never achieve 100% hydration.
- (b) Three cement pastes made with 314 g cement and having W/C ratios of 0,2; 0,4 and 0,6 respectively are placed in stoppered test tubes:
- What is the maximum hydration that is possible for each of the respective pastes?
- At maximum hydration of the 0,6 W/C ratio paste calculate:
- the volume of gel formed,
  - the chemically combined water and water in the gel pores,
- At maximum hydration of each of the pastes calculate: (16)
- the water in the capillary pores.
3. The results from a trial mix of 33 kg of water : 50 kg of cement : 140 kg dry sand : 170 kg dry stone are slump of 130 mm and a real mortar excess of 6%. It is assumed that the densities of water, cement, sand and stone are 1000, 3100, 2600 and 2800 kg/m<sup>3</sup> respectively and that the dry stone contains 50% voids. What mix would you suggest if the slump and real mortar excess required are 75 mm and 1% respectively? (16)
4. Discuss: (a) factors which influence concrete strength, and (b) the stress/strain relation of concrete in terms of crack initiation and crack propagation. (18)
5. Discuss drying shrinkage and carbonation shrinkage of concrete. (18)



(1" = 25 mm)



Course No. 504811 TRANSPORTATION ENGINEERING

## COURSE DESCRIPTION

A substantive overview of the concerns of transportation planning, the nature of transportation, and the techniques of transportation analysis and evaluation, with special reference to urban transportation problems in South Africa and the applicability of approaches from abroad.

## OBJECTIVES

To create understanding of the role of the transportation planner as distinct from that of the transportation engineer.

In so doing, to create awareness of the social purpose of transportation.

To generate awareness of the politics of transportation, the constraints manifest, and the legislative, administrative, and fiscal requirements for establishing sound planning.

To create understanding of, and ability as a planner to deal with, the complex interrelationships between transportation and land use.

To provide insights into a multi-modal systems approach to transportation planning.

To present the techniques of transportation analysis and evaluation.

To create awareness of innovative thinking and legislation in connection with transportation systems research and design, transportation planning, and evaluational criteria and methods encompassing the community.

## EXAMINATION REQUIREMENTS

The examination will take the form of a transportation project on a team basis to be completed in a period of six weeks.

The project will place the student in the role of transportation planner where he will have to make certain decisions in relation to social goals, test and evaluate these decisions, and establish the requirements for their implementation.

The examination of the course thus involves the application of concepts, principles, and techniques assimilated to a particular problem situation.

The project will be handed out immediately before the mid-term vacation. By this time sufficient knowledge of transportation planning will have been gained to commence working on the project. The vacation period can be used by teams to establish a method of approach and to re-affirm and establish basic planning ideas for further development.

Concurrent with the remaining three lectures after the mid-term vacation a studio series will be run by participating lecturers in the course, to assist teams in overcoming basic technical difficulties.

A further two weeks will be allowed for final completion of the project.

## LECTURES

JULY 25 4 hrs.	INTRODUCTION Raeburn Chapman	<p><u>Structure of the City and Structure of Movement</u> Nature of transportation: definition and theories of communication, linkages, networks, transportation. Influence of transport technology on city form. Relation between internal structure of the city and structure of movement: the characteristics of travel and their identification. Emerging concepts of urban structure in relation to above.</p>
		<p><u>The Issues of Transportation: Its Complex Dimensions</u> Metro area as transportation problem area: nature of problems. Transportation as the metro (social) problem. Political, social, economic and physical problems related to transportation and transportation planning.</p>
AUG. 1 4 hrs.	EMERGING APPROACHES TO TRANSPORTATION PLANNING, RESEARCH AND EVALUATION Raeburn Chapman	<p><u>The Transportation Planning Process</u> Development of transportation planning since World War II. Content and interrelationships of the rational planning process. Comprehensive framework of analysis, design, evaluation. Use of simulation techniques. Evaluational rationale. Critique of rational transportation planning model: need for synopticism in transportation.</p>
		<p><u>Innovative legislation abroad</u> Environmental impact statement Public participation Development of mass transit. Joint development including the integrated corridor. Highway beautification.</p>
		<p><u>Systems Research and Design</u> A conceptualisation of classes of transportation systems in relation to social goals and urban structure, on a scale basis.</p>
AUG. 8 2 hrs.	PERFORMANCE OF MODES Eric Pas	<p><u>Definitions and Concepts.</u> Relation between speed, volume, capacity, levels of service, standards creating uninterrupted flow et al.</p>
		<p><u>Traffic: Cars and Trucks</u> Characteristics in relation to road systems and land use. Role of the freeway: Physical, economic and social aspects. The total road network: Hierarchical characteristics and environmental considerations. On-street and off-street parking requirements in relation to land use.</p>

- AUG. 15 Johan Barnard  
4 hrs. Buses in Relation to Planning: A Structural Overview  
Service characteristics on a geographical basis of the present bus system in Cape Town. Capital and operating costs. Storage.  
Achieving intermodal balance: Potential of public bus movement vs. private car. Socio-economic considerations  
Impedances to creation of an integrated bus service.
- Louis de Waal Express Buses: Tapid Transit  
The area-wide high-capacity express bus transit system. Reserved bus lanes on freeways: the integrated ROW. Bus patronage demands and characteristics.  
Operational requirements including terminals.  
Costs and advantages including freeway optimisation and environmental considerations.
- AUG. 22 J.F.M. Zoutendyk  
4 hrs. Railways and Rapid Transit in Relation to Planning.  
Role and characteristics of harbours, canals, airports, and their relation to railways.  
Railway standards, source of power, railways and land use.  
An overview of rapid transit systems on a comparative basis.
- Louis de Waal Organisation of Transportation Planning and Administration  
Planning, implementation, and administration.  
The situation in South Africa.  
The Metropolitan Transportation Authority - its role, structure, financial aspects.
- AUG. 29 COMPUTERISED  
2 hrs. TRAFFIC MODELS  
Eric Pas Trip Generation : Forecasting Land Use  
Methods of estimating the number of trips that result from activities that occur on a given area of land. Use of demand simulation and projections in which future zone-by-zone distribution of population and employment areas is forecast for the purpose of traffic analysis.
- SEPT. 5  
2 hrs. Modal Split : Achieving Intermodal Balance  
Methods of estimating the percentage of trips from or to a given area that select a particular mode of travel.  
Estimation of peak hour modal splits for trip productions and attractions for each analysis zone.  
Factors to be considered in modal split models.
- SEPT. 12  
2 hrs. Trip Distribution : Gravity Model  
Methods of estimating the manner in which trips generated in one zone distribute themselves to all other zones.  
Use of the gravity model in distributing previously generated trips.
- SEPT. 19  
2 hrs. Trip Assignment  
Methods of estimating the manner in which trips from one zone traverse the transportation network to reach another zone, and the subsequent assigning of internal volumes to each link.

Course No 504811 TRANSPORTATION ENGINEERING

OCT. 3  
2 hrs.    **TRANSPORTATION  
ECONOMICS**  
Ron Jackson

The Economics of Metropolitan Transportation  
The development of demand for transportation as a result of metropolitan area growth in South Africa. The provision of adequate urban transportation systems in relation to the cost of traffic congestion and accidents.  
Revenue-cost aspects.  
Approach to transportation planning in Johannesburg.

OCT. 4  
2 hrs.

Transportation Evaluation  
User and community factors as a basis for analysis: direct economic effects versus community effects.  
Methods for evaluating plans including benefit-cost analysis.  
Quantifiable and non-quantifiable measures in relation to types of costs.  
Methods for monetising benefits.

OCT. 17  
2 hrs.    **IMPLEMENTATION**  
Johan Barnard

Transportation Legislation  
An overview of legislation and administrative procedures in South Africa critical to transportation planning, implementing, financing, and administration in our urban areas.

## SCHOOL OF ENVIRONMENTAL STUDIES.

COURSE No. 917402Fundamentals of Environmental Studies.

Text: K.E.F. Watt, Principles of Environmental Science, McGraw;Hill, 1973. (Available from Technical Books OR Student Bookshop.)

Course Details:

There will be 23 formal lectures in the course, these will be given at 10.15 a.m. Tuesdays and Thursdays in the Botany Lecture Theatre.

In addition to the lectures, readings and exercises will be assigned, and students should anticipate spending a minimum of six hours of study per week on these assignments. Certain assignments will be graded for D.P. purposes.

An essay, selected from the list of appended topics, will also be required on or before May 13, 1975. The essay should be fully referenced, should not exceed 3,000 words and must be legible, (preferably type-written).

A final D.P. requirement is that all students attending the course participate in the preparation and presentation of a group project. The class will be divided into groups once the overall composition is known; project topics will relate to real-world environmental problems in the Cape Town area and will be specified.

EXAMINATION:

The final examination is tentatively scheduled for 19th June 1975 but there is a possibility that the examination may take place after the July vacation. The class will be notified as soon as details are final.

Course No. 917402 FUNDAMENTALS OF ENVIRONMENTAL STUDIES

2

LECTURE SCHEDULE:

March 4 to April 1.	Professor P.G. Holland	(8 lectures)
April 3 and 8	Dr. G. Branch	(2 lectures)
April 10 and 15.	Dr. E. Moll	(2 lectures)
April 17 to 24	Professor R.F. Fuggle	(3 lectures)
May 13 to 22	Professor I. Spencer	(4 lectures)
May 27 to June 5	Professor R.F. Fuggle	(4 lectures)
June 10 & 12	Presentation of Projects	(2 periods)
June 19	Examination.	

ESSAY TOPICS:

1. Self-regulating mechanisms are an intrinsic part of natural systems. Critically analyse Man's apparent ability to circumvent self-regulatory feedback in his activities.
2. It is believed that "climax" communities of plants have net annual productivities approximately equal to zero. Under certain conditions of stress, however, NPP can be greater than zero. Over the period of cultural development how has Man been able to shift community growth behaviour from the former to the latter strategy, and at what biological and ecological cost ?
3. Many persons and groups are currently calling for ecological solutions to problems. Evaluate the potential and limitations of an ecological approach in determining a site for a copper smelter in an agricultural area of the south-west Cape.

TOPICS: (Each project group to select a different topic).

In each of the topics listed below a hypothetical development is proposed which would affect the existing environment in several ways. Analyse the positive and negative environmental impacts of the proposed schemes. Also make suggestions supported by reasoned argument, as to how the development should proceed so as to minimize or alleviate deleterious environmental consequences.

1. Development of two hectares of the Rondebosch Common for cluster housing.
2. Construction of a network of paths on the Western table of Table Mountain.
3. Development of a landscaped riverside recreation area along the Black River between Settler's Way and the N9 National Road.
4. Expansion of the Constantia Nek - Hout Bay road to accommodate 4 lanes of traffic.

GENERAL:

1. Each group should nominate a co-ordinator to schedule group activities, liaise with other groups and with University Staff.
2. By mutual agreement students may change groups before the projects get underway provided that the balance of subjects in each group remains the same as scheduled. Each group must comprise at least four different specialisms.
3. It is expected that groups will undertake on-the-spot field investigations, data collection, and/or interviews.
4. Final group reports must be typewritten and illustrated with relevant materials and maps.

UNIVERSITY OF CAPE TOWN  
UNIVERSITY EXAMINATIONS: JULY 1975

FUNDAMENTALS OF ENVIRONMENTAL STUDIES.

Time: TWO HOURS

Candidates must answer a total of TWO questions selecting one question from each section.

SECTION A - Principles of Environmental Studies.

1. Review the concept of diversity, and the predictions based on it, as developed by biologists and comment on their applicability to the social sciences.
2. Outline the possible advantages and disadvantages to an omnivore species which opts to draw all its food from low in the food chain.
3. One of Watt's basic environmental principles is that matter, energy space, time and diversity are all categories of resources. Illustrate that you appreciate the significance of this principle in an essay on human food production.
4. Studies of pre-industrial as well as post-industrial societies have substantiated recognized environmental principles. Discuss this statement.

SECTION B - Applications.

5. Discuss the applicability to the study of human societies of Margalef's principle that mature exploit immature biotic communities.
6. Discuss the concept of ecological balance in relation to the health of Man.
7. Of all the habitat types in South Africa, estuaries are the most vulnerable to man's activities. Discuss this statement giving actual examples to illustrate your arguments.
8. Write an essay in which you examine the distribution and ecological relationships of range systems in South Africa.

-----

SCHOOL OF ENVIRONMENTAL STUDIES

PRINCIPLES OF ENVIRONMENTAL ANALYSIS

AIM: The aim of this series of seminars is threefold.

1. A review of procedures for environmental impact assessment.
2. Analysis of various types of Environmental Impact Studies.
3. Critical analysis of man-environment interactions through case studies.

METHOD:

The course will be run as a series of seminars led by members of staff but drawing upon student reaction to prescribed readings. In addition a joint class project directed by members of staff will be undertaken and each student must prepare a term-paper based on one of the course aims outlined above.

SEMINAR TOPICS:

1. Review of the U.S.Environmental Policy Legislation and of procedures for environmental impact assessment. (RFF; 27/7/76)
2. Detailed review of the Matrix-Analysis and Map Overlay techniques. (RFF; 3/8/76)
3. Detailed review of the Battelle Laboratory techniques for environmental evaluations. (JRG; 10/8/76)
4. The Delphi technique for sociological evaluations (RFF; 17/8/76)
5. Case study of Township Development Scheme, Southwestern Cape. (RFF; 24/8/76)
6. Case study of South African Marina Developments. (JRG; 31/8/76)
7. Case study of man-environment interactions in a group of oceanic islands. (NW; 7/9/76)
8. Case study of man-environment interactions in a continental island group. (NW; 14/9/76)
9. -Reviews of major ecosystem studies. (JRG; 28/9/76)
10. Reviews of selected South African ecological studies. (JRG; 5/9/76)
11. Review of an Environmental Impact Statement as required by the National Environmental Policy Act of the U.S.A. (RFF; 12/9/76)
12. Review of environmental impact reports which have been prepared in South Africa. (JRG; 19/10/76)

UNIVERSITY OF CAPE TOWNDEPARTMENT OF CIVIL ENGINEERINGCOURSE CE 531 - URBAN TRANSPORTATION PLANNING AND MODELLINGA S S I G N M E N T NO. 1

AS AN INDEPENDENT CONSULTANT, YOU ARE REQUIRED TO CRITICALLY REVIEW THE STUDY DESIGN FOR THE CAPE METROPOLITAN TRANSPORTATION STUDY, A COPY OF WHICH YOU RECEIVED LAST WEEK.

1. INTRODUCTION

The study design, dated May 1976, states in the introduction "A transportation study of the Greater Cape Town Metropolitan Area is to be conducted and, towards this end, the design of the study is outlined in this report".

Other possibly relevant information, contained in the section which has been deleted from your copy for reasons of confidentiality, is as follows :

- (i) A Metropolitan Transport Advisory Council was duly constituted and a Steering Committee was formed to direct and supervise the execution of the study. The Steering Committee consists of representatives of local and provincial government, the South African Railways and the Cape Metropolitan Planning Committee.
- (ii) The consultants appointed to carry out the study recognized that the complex problems involved required expertise from several specialist disciplines, and a multi-disciplinary team has been assembled to assist the principal consultants.

2. TASK DESCRIPTION

You have been appointed as an independent consultant to review the study design document and to report on your findings to the Steering Committee. As noted above, a critical review is required. In other words, tell the Committee what you do and do not like about the study design. What would you do differently, better?

In carrying out your assignment, keep in mind that the study design should inform the Committee as to what the consultants propose to do, and how the various tasks will be carried out. You should therefore also report on the extent to which you think the study design serves this function.

### 3. SPECIFICATIONS

The following specifications should be strictly adhered to in your submission :

- \* Length must not exceed 15 pages - this excludes the cover sheet, graphics and bibliography (if these are used). This, of course, does not mean that your report cannot be shorter than 15 pages.
- \* All papers are to be typed, double spaced, with reasonable margins (i.e. approximately 2,5 cm).
- \* The way the report is written (e.g. style and grammar) will be considered in the assessment.
- \* Your paper should be linked as closely as possible to the lectures and associated readings. If you wish to take an opposing viewpoint at any stage, feel free to do so. However, your arguments must be clearly presented, and substantiated wherever possible.

NOTE : The mark for this assignment will contribute approximately 40% to the final mark for the course.

April 27th, 1977.

UNIVERSITY OF CAPE TOWNDEPARTMENT OF CIVIL ENGINEERINGCOURSE CE 531 - URBAN TRANSPORTATION PLANNING & MODELLINGASSIGNMENT NO. 2

A household level least-squares trip generation model has been calibrated for a hypothetical city called LAPABURG. The hypothetical model is as follows :-

$$Y = 0,20 + 1,75 X_2 + 2,50 \sqrt{X_6} \quad \dots\dots(1)$$

where Y = number of home-based trips per household per day,

$X_2$  = number of people per household,

$X_6$  = number of cars per household.

You are required to use this model to estimate the future home-based daily trip generation for zone number 105 of LAPABURG. The forecast characteristics of this zone are given in Table 1 below. (In carrying out this calculation you should apply the model given by equation (1) only once).

Note :

- (i) The Due Date for this assignment is Wednesday 25th May 1977.  
(ii) This assignment will count approximately 5% to your final course marks, and is to be completed on an individual basis.

Number of Households (i.e. Frequency)	Number of People ( $X_2$ )	Number of Cars ( $X_6$ )
50	1	0
100	2	0
100	3	0
50	4	0
25	5	0
25	6	0
50	1	1
150	2	1
200	3	1
150	4	1
50	5	1
25	6	1
-	1	2
25	2	2
50	3	2
100	4	2
50	5	2
50	6	2

NOTE: No household have more than six people or more than 2 cars.

TABLE 1 : Forecast Household Characteristics for Zone 105 of LAPABURG.

## UNIVERSITY OF CAPE TOWN

## DEPARTMENT OF CIVIL ENGINEERING

## COURSE CE531 - URBAN TRANSPORTATION PLANNING &amp; MODELLING

## ASSIGNMENT NO. 3

Consider the hypothetical city of INDIANIS shown in Figure 1. The city has been divided into five hypothetical zones (1 through 5). You are required to estimate the future trip distribution and modal split of work trips for INDIANIS, using a number of different approaches.

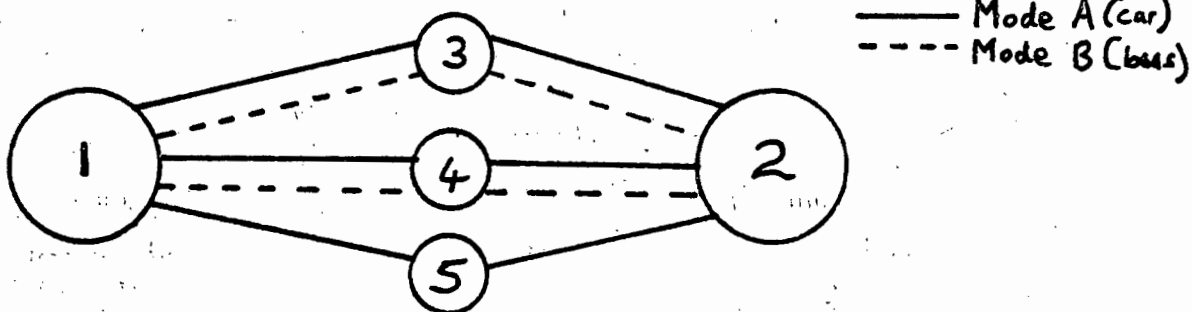
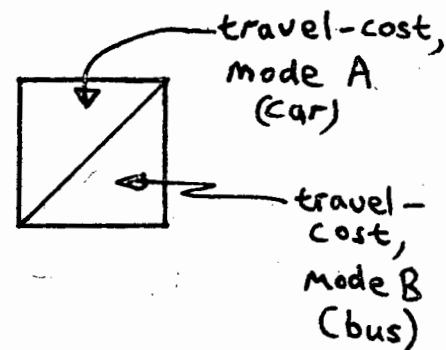


Figure 1

Zones 1 and 2 are residential areas and zones 3, 4 and 5 are employment locations. The following is the estimated future travel-cost matrix.

	3	4	5
1	10 / 15	10 / 8	15 / N/A
2	10 / 10	5 / 10	5 / N/A

N/A = not available



Zones 1 and 2 are expected to have 1 000 and 1 500 households respectively in the design year. It is anticipated that 15% and 20% of the households in zones 1 and 2 respectively will not have a car in the design year. On the average, it is expected that each household will have one worker in the design year.

Zones 3,4 and 5 are expected to have the following number of jobs available in the design year :-

Zone	No. of Jobs
3	750
4	1000
5	750

- A. Use a hypothetical trip-end modal split model which assumes that all those workers living in a household in which at least one car is available utilize a car for the work trip, and that all those workers living in car-less households use the bus. Distribute the work trips by each mode using a gravity model, with a travel-cost factor function of the form  $f(C_{ij}) = C_{ij}^{-2}$  for each mode. State any (reasonable) assumptions you make.
- B. Use a gravity model with a travel-cost factor function of the form  $f(C_{ij}) = C_{ij}^{-2}$  to distribute all the work trips over the car network. Then apply a hypothetical trip-interchange modal split model of the form :-

$$\frac{T_{ij}^B}{T_{ij}^A} = \frac{C_{ij}^A}{2C_{ij}^B} \quad \begin{array}{l} \text{mode A = car} \\ \text{mode B = bus} \end{array}$$

where  $T_{ij}^m$  = trips from i to j by mode m

and  $C_{ij}^m$  = travel-cost, i to j, by mode m.

- C. Use the hypothetical trip-interchange model described in B above, but first distribute the trips using a 'weighted uni-modal network' and a gravity model with the same travel-cost factor function as above. (Use the hypothetical trip-end model described in A above to determine the weighting factors).
- D. Comment briefly on your results for A, B and C above.

- E. Demonstrate how one might use an iterative process to improve on the results obtained in C above.

NOTE :-

- (i) The due date for this assignment is Wednesday 1st June 1977.
- (ii) This assignment will contribute approximately 7 1/2 per cent to your final course mark, and is to be completed on an individual basis.

EIP/1977

## UNIVERSITY OF CAPE TOWN

## DEPARTMENT OF CIVIL ENGINEERING

## COURSE CE531 - URBAN TRANSPORTATION PLANNING &amp; MODELLING

## Assignment No. 4

Consider the following brief extract from the book by Stopher and Meyburg<sup>[1]</sup>.

*Elasticity Properties of Multiple-logit Models*

A general logit model may be written as equation 16.32.

$$P_k = \frac{\exp[G_i(X_k)]}{\sum_j \exp[G_i(X_j)]} \quad (16.32)$$

It is assumed that  $G_i(X_j)$  is a linear function of the vector of characteristics of the alternative  $j$ . Since it has been established that the characteristics of the individual,  $S_i$ , cannot be linearly additive in the function, it will be assumed that these characteristics enter the utility function through the vector of coefficients of the  $X_j$ s. The function  $G_i(X_j)$  may therefore be written as equation 16.33.

$$G_i(X_j) = a_0^i + \sum_{t=1}^T a_t^i X_{jt} \quad (16.33)$$

where  $T$  = the number of characteristics in the common utility of alternative  $j$

and  $a_t^i$  = the coefficients of the characteristics  $X_{jt}$

The direct-elasticity of demand for alternative  $k$  with respect to characteristics  $X_{ks}$  of that alternative is given by equation 16.34.

$$\varepsilon_{kks}^i = a_s^i X_{ks} (1 - P_k^i) \quad (16.34)$$

In words, equation 16.34 states that the direct-elasticity ( $\varepsilon_{kks}^i$ ) of demand for alternative  $k$  with respect to attribute  $s$  is proportional to the amount of the attribute possessed by alternative  $k$  ( $X_{ks}$ ), to the weight or importance of that attribute in the utility function ( $a_s^i$ ), and to the share of the market that alternative  $k$  has not yet obtained ( $1 - P_k^i$ ). The first two dependencies of the direct elasticity appear to be intuitively reasonable; that is, that the elasticity is a function of both the importance and amount of an attribute. The final dependency modifies the strength of the direct elasticity by the market share of the alternative. The larger the market share, the smaller will be the direct-elasticity of demand, all other things being equal. Again, this is an intuitively reasonable statement of elasticity and is conformal with concepts of consumer behavior in economics.

You are required to derive the expression for the direct elasticity shown in equation (16.34). (Hint :- First use equation (16.32) to find an expression for  $P_k^i (1 - P_k^i) a_s^i$ . Then find an expression for the relevant partial derivative).

Note

- (i) Due date for this assignment is Wednesday 8th June 1977.
- (ii) This assignment will contribute approximately 5% to your final course mark, and should be completed on an individual basis.
- [1] Stopher, P.R. and Meyburg, A.H., Urban Transportation Modelling and Planning, Lexington Books, 1975.

UNIVERSITY OF CAPE TOWN

DEPARTMENT OF CIVIL ENGINEERING

COURSE CE 531 - URBAN TRANSPORTATION PLANNING & MODELLING

ASSIGNMENT NO 5.

1. Assume that, for a particular individual, the utility of the car (for a given trip) is  $U_A$ , and the utility of the bus (for the same trip) is  $U_B$ . Assume also that this individual is indifferent to the colour of his car (i.e. a change in colour does not change his utility).

Now consider the introduction of a "new" mode, which is a blue car, where previously the individual under consideration had a red car. Except for colour, the two cars have identical "observed attributes".

- (a) For each of the values of  $U_B$  and  $U_A$  given in table 1 below, use the logit model to compute the probability that the individual chooses the bus for the given trip :-
- (i) assuming that the IIA axiom holds,  
(ii) assuming that the IIA axiom does not hold.
- (b) Compute the difference in the results (as a percentage), for each combination of values for  $U_A$  and  $U_B$ .
- (c) Comment very briefly on your observations.

TABLE 1 :

$U_A$	$U_B$
6	1
4	1
3	1,5
3	2,5
3	3
2,5	3
1,5	3
1	4
1	6

2. Consider a binary mode-choice logit model of the form :

$$P_k^i = \frac{e^{G(X_k)}}{\sum_{j=1}^2 e^{G(X_j)}}$$

Now consider the following hypothetical utility functions :-

$$G(X_1) = 0,5 - 0,190 T - 0,060 C$$

$$G(X_2) = -0,190 T - 0,060 C$$

where T = travel time(in minutes), C = travel-cost (in cents).

NOTE : - All the variables in these utility functions were found to be statistically significant.

- (i) Have travel-time and travel cost been included as generic or alternative-specific variables in this model? Explain briefly.
- (ii) Assume that this model was built (i.e. estimated) for a hypothetical set of travellers having the following values of the attributes of the 2 alternatives facing them :-

Number of Travellers (in Homogeneous Group)	Attributes of Alternatives			
	T		C	
	Mode 1	Mode 2	Mode 1	Mode 2
25	10	10	20	25
50	15	10	25	30
25	20	10	30	35
100	25	10	40	45
25	10	15	20	15
75	15	15	25	25
125	20	15	30	35
25	25	15	40	45
100	10	20	20	15
50	15	20	25	30
75	20	20	30	35
125	25	20	40	45
100	10	25	30	20
100	15	25	25	20
50	20	25	30	40
50	25	25	40	40

What percentage share of the travel market do each of the two modes have for this set of people? Explain why you could carry out the computation in this case.

- (iii) The logit model assumes that travellers make trade-offs between the levels of the attributes of the alternatives available to them. Consider the above data set, and comment on the applicability of this set of data (or parts thereof) for the estimation of a logit model.
- (iv) Based on the coefficients of the above logit model, what is the "value of time" for this set of travellers (Express your answer in R/hr).
- (v) "There is a modal bias towards mode 1 for this set of travellers". Explain this statement, and comment briefly on the desirability of such a "modal bias" in a model of mode choice.

NOTE :

- (i) Due date for this assignment is Wednesday 29th June 1977.
- (ii) This assignment will contribute approximately 10% to your final course mark, and should be completed on an individual basis.

EIP/GF/1977.

.....  
UNIVERSITY OF CAPE TOWN  
 .....

DEPARTMENT OF CIVIL ENGINEERING

COURSE CE 531 - URBAN TRANSPORTATION PLANNING & MODELLING

ASSIGNMENT NO. 6

Brief and concise responses are required from you to the following questions. Therefore, you must please answer each question in the space provided.

1. Define and give an example of each of the following, ensuring that the examples are appropriately interlinked :-

CONCEPT

DEFINITION

EXAMPLE

GOAL

OBJECTIVE

CRITERION

STANDARD

NOTE : Your examples need not specifically be in a transportation context.

2. What are the advantages which can be obtained by the use of "disaggregate" (individual) choice models in forecasting travel behaviour?

3. All of the early applications of individual choice models have been in the analysis of mode-choice. Briefly discuss the reasons for this phenomenon.





