PRIORITY EVALUATION IN TRANSPORTATION

POLICIES AND PROGRAMMES

MICHAEL STEPHEN ROE

OOCTOR OF PHILOSOPHY

UNIVERSITY OF ASTON IN BIRMINGHAM

JUNE 1983

THE UNIVERSITY OF ASTON IN BIRMINGHAM

PRIORITY EVALUATION IN TRANSPORTATION POLICIES AND PROGRAMMES

MICHAEL STEPHEN ROE

DOCTOR OF PHILOSOPHY

1983

SUMMARY

This work is concerned with the development of techniques for the evaluation of large-scale highway schemes with particular reference to the assessment of their costs and benefits in the context of the current transport planning (T.P.P.) process. It has been carried out in close cooperation with West Midlands County Council, although its application and results are applicable elsewhere. The background to highway evaluation and its development in recent years has been described and the emergence of a number of deficiencies in current planning practise noted. One deficiency in particular stood out, that stemming from inadequate methods of scheme generation and the research has concentrated upon improving this stage of appraisal, to ensure that subsequent stages of design, assessment and implementation are based upon a consistent and responsive foundation.

Deficiencies of scheme evaluation were found to stem from inadequate development of appraisal methodologies suffering from difficulties of valuation, measurement and aggregation of the disparate variables that characterise highway evaluation. A failure to respond to local policy priorities was also noted. A 'problem' rather than 'goals' based approach to scheme generation was taken, as it represented the current and foreseeable resource allocation context more realistically.

A review of techniques with potential for highway problem based scheme generation, which would work within a series of practical and theoretical constraints were assessed and that of multivariate analysis, and classical factor analysis in particular, was selected, because it offerred considerable application to the difficulties of valuation, measurement and aggregation that existed. Computer programs were written to adapt classical factor analysis to the requirements of T.P.P. highway evaluation, using it to derive a limited number of factors which described the extensive quantity of highway problem data. From this, a series of composite problem scores for 1979 were derived for a case study area of south Birmingham, based upon the factorial solutions, and used to assess highway sites in terms of local policy issues.

The methodology was assessed in the light of its ability to describe highway problems in both aggregate and disaggregate terms, to guide scheme design, coordinate with current scheme evaluation methods, and in general to improve upon current appraisal. Analysis of the results was both in subjective, 'common-sense' terms and using statistical methods to assess the changes in problem definition, distribution and priorities that emerged. Overall, the technique was found to improve upon current scheme generation methods in all respects and in particular in overcoming the problems of valuation, measurement and aggregation without recourse to unsubstantiated and questionable assumptions.

A number of deficiencies which remained have been outlined and a series of research priorities described which need to be reviewed in the light of current and future evaluation needs.

EVALUATION   HIGHWAYS   TRANSPORT   MULTIVARIATE
                    PROBLEMS

CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

'On a pitch black, starless night, a solitary man
was trudging along the main road from Marchiennes
to Montsou, ten kilometres of cobblestones running
straight as a die across the bare plain between
fields of beet. He could not even make out the
black ground in front of him, and it was only the
feel of the March wind blowing in great gusts like
a storm at sea, but icy cold from sweeping over
miles of marshes and bare earth, that gave him a
sensation of limitless, flat horizons. There was
not a single tree to darken the sky, and the
cobbled highroad ran on with the straightness of a
jetty through the swirling sea of black shadows.'

Zola, 1885.

PREFACE

The work described in this thesis was supported by an SERC Industrial Case Award and conducted in collaboration with West Midlands County Council, Department of Transportation and Engineering.

Its objective was to develop and improve upon current local authority methods of evaluating large scale highway investment, with specific reference to the West Midlands and in the light of the administrative and legal requirements of the transport planning process. Consequently it has concentrated upon the derivation of an improved evaluation methodology which must operate within the framework of a local authority, committed to incremental improvement of appraisal techniques.

The need to produce results of value to the local authority encouraged use of a case study approach to assess the development of the new methodology. Consequently the structure of the research focussed around the framework of study outlined below:-

  (a) Background. The current situation in transport planning and evaluation, and its deficiencies.

  (b) Identification of the priorities between these deficiencies.

  (c) Assessment of the methods which might improve upon current practice.

  (d) Selection of the methodology.

  (e) Application to a selected case study area.

  (f) Assessment of results in terms of practicality, theoretical robustness, sensitivity, consistency, etc.

  (g) Assessment of the implications of using the new techniques.

  (h) Conclusions and recommendations for further research.

CHAPTER 1 : INTRODUCTION

The Background to Highway Evaluation

Since the financial year 1975/1976 and the passing of the Local Government Act the previous year (1974), County Councils in England and Wales have been required to produce an annual Transport Policies and Programme (T.P.P.) which outlines the authority's proposed transport investment and policies for the following 15 years, the first five years being discussed in detail. These documents form a rolling programme submitted to the Department of Transport for approval. A Transport Supplementary Grant (T.S.G.) is then allocated to cover part of the cost of implementing these proposals which are accepted.

Prior to 1975, specific scheme grants were allocated to individual highway projects without any indication of their comparative value, but now part of each T.P.P. is devoted to an explanation of how projects have been selected and their order of priority. This applies to both small-scale and large scale investments, the latter discussed in detail and their implications carefully analysed. It is largely for this reason that local authorities require a reliable and justifiable highway evaluation technique.

The attitude of central government towards the type of evaluation method for highway appraisal has been inconsistent. Prior to 1975, conventional cost benefit approaches had been widely used, but in the early 1970's, central government circulars urged local authorities to develop techniques which were more responsive to the diverse needs of transport appraisal. (Department of the Environment, 1973, 1974.) Meanwhile, in contrast, both the Departments of the Environment and Transport promoted their own traditional approaches to highway evaluation, the most commonly applied being COBA. COBA is a computer based

approach that was introduced in 1972 and is similar to traditional cost benefit analysis in that it assesses the comparative economic costs and benefits of alternative large scale highway proposals (those costing £500,000 or more) based upon estimates of the changes in travel time, operating and accident costs which would result (DoE, 1972). However, COBA is somewhat unrealistic in practice in that it is applied to the projects under consideration prior to detailed design and assumes that they are all reasonable solutions to real problems. It is described in detail in Appendix 2.

Despite its evident concentration upon those elements of highway investment that are most susceptible to monetary valuation, COBA has continued to be favoured by central government for highway appraisal. Limited moves towards assessing non-monetised effects have been made following growing public disquiet and the publication of the Leitch Report (ACTRA, 1977), and a COBA evaluation is now required to contain a display matrix of non-monetised effects alongside the conventional economic assessment. However, there remains insufficient balance in the appraisal and the method tends to be biased towards the elements of schemes most easily monetised. In contrast, the technique recommended for the appraisal of smaller schemes, valued between £50,000 and £500,000, commonly known as 'Roads 502' (DoE, 1973), is based upon a mixture of conventional cost benefit analysis and points rating techniques and emphasises the need to evaluate schemes from a non-monetised viewpoint as well as using objectively calculated traffic and accident costs and benefits. As a consequence, it pays more attention to non-monetary impacts than COBA for significantly more expensive schemes with substantially wider ramifications.

The importance of central government attitudes towards evaluation methodologies should not be under-estimated for the allocation and distribution of T.S.G. is based upon central government's

assessment of the priorities attached to proposals by the local authority. Evidence of these views is provided by the proliferation of local authority highway evaluation techniques that are clearly COBA based. This trend has not been universal, however, and an increasing number of authorities in recent years have developed their own approaches to evaluation, less based upon monetary evaluation, reflecting local needs and initiatives, and differing in some cases quite substantially from more conventional and popular techniques. A number of factors lie behind the development of these new techniques and the increased interest in highway evaluation in general.

Lack of clear central government directive. Central government attitudes towards evaluation methodologies have been inconsistent and the advice emanating from the Department of Transport has been characterised by conflicting trends typified by the contrasting approaches adopted in COBA and Roads 502. This has not encouraged local authorities to be consistent in their approach to highway evaluation and as a consequence, a number of different techniques have emerged. The characteristics of these techniques reflect practical constraints that exist stemming from contrasting highway networks, political initiatives and opinion, data, manpower and financial availability and various other local issues and requirements. These differing methodologies have brought problems to central government when comparing proposals from different authorities and the logical allocation of T.S.G. has been hindered by this in a way that the introduction of the standardized T.P.P. process was designed to overcome (Mackie and Garton, 1977).

Local Government organisation. In many county councils, highway evaluation is carried out by at least two different groups. Evaluation of proposed sites where highway schemes are considered necessary, but detailed design has not taken place, is usually undertaken by a T.P.P.

team or 'Forward Planning Unit'. The approach adopted is of an inter-disciplinary nature and the interests of many different sectors - e.g. planners, environmentalists, etc. - are taken into consideration. On the other hand, evaluation of detailed scheme options following design, is usually the task of design teams. These teams are often part of Construction Branch and certain issues, particularly those difficult to monetise, are often given little attention. Approaches of the COBA type are preferred.

The implications of this dichotomy, which mirrors that in central government, is that conflicting schemes and scheme designs emerge. Antipathy between the two evaluating groups has clearly developed and local authorities who have recognised these problems have been concerned to develop techniques which can accommodate both monetary and non-monetary variables within a single framework.

Deficiencies of traditional cost-benefit-analysis. Despite their popularity within traditional engineering circles, cost benefit approaches to highway evaluation have suffered considerable criticism from economists, planners and the general public. Problems surround-ing the valuation of costs and benefits, the failure to accommodate satisfactorily issues not readily valued in monetary terms - the environment, accessibility, etc. - the absence of explicit distribu-tional considerations, and the increasing recognition of the inade-quacies of welfare economics as a basis of evaluation (Cooper, 1973; O'Leary, 1979) are just some issues which have led to considerable discredit of the technique (Self, 1975). The opposition to monetary evaluation in general has encouraged the development of alternative approaches most recently characterised by the work of Nijkamp (1975, 1977, 1980, 1981), Massam (1980) and Chatfield and Collins (1931), in the development of multivariate techniques which attempt to overcome

14

the need for an intermediate common metric of points, money, etc., to
handle the disparate variables characterising highway evaluation.

Financial constraints.   A factor which has increased in signifi-
cance since the early 1970's has been the continued decline of public
money available for transport and highway investment.   It has always
been important to ensure value for money in the selection of projects
but this has become of paramount importance as local authorities face
restricted resources and the need to justify large scale expenditure
(Richmond, 1982; Smith, 1982).

Public participation.   The T.P.P. process itself does not pro-
vide for public participation (Bayliss, 1975).   However, the demands
of public pressure through the Structure Plan process and through a
succession of well publicised highway enquiries (e.g. Highgate/Archway,
M40, M42, etc.) has increased the need for local authorities to produce
well thought out appraisals for potentially contentious highway schemes.
Cost-benefit-analysis in particular has failed to convince the public of
the merits or demerits of highway proposals in recent years and altern-
ative approaches to evaluation providing clearer evidence of scheme
value have been sought.   The introduction of display matrices follow-
ing the work of the Leitch Committee reflects this trend (ACTRA, 1977).

The Structure Plan process has had a significant effect upon the
development of evaluation methodologies for since local authorities
have been involved in their preparation it has become necessary to
define policies and objectives in many diverse fields including housing,
employment, recreation, etc.   In each of these areas, alternative
planning options have to be evaluated in a multi-sectoral context, pro-
ducing results which reveal trade offs between conflicting objectives
and the values placed upon each.   Consequently, evaluation methodol-
ogies which could accommodate these wide ranging issues had to be

developed.   Cost benefit analysis alone would not suffice.

Local government reorganisation.   During the late 1960's and
early 1970's, much of the organisation, responsibilities and geograph-
ical boundaries of local government were reorganised.   A significant
change was the creation of a number of Metropolitan Authorities whose
responsibilities included transportation and strategic planning.
These authorities cover the major metropolitan areas of Britain -
Greater Manchester, Merseyside, South Yorkshire, Tyne and Wear, West
Midlands and West Yorkshire.   Greater London, although legally and
administratively a separate type of authority but in practice little
different, already existed established in 1964.   With regards to
transport responsibilities, each of the Metropolitan authorities found
that they had inherited a number of proposed highway schemes from the
District Councils whose functions they had assumed.   Many of these

proposals had been prepared during the 1960's at a time when traffic
and financial predictions tended to be over-estimated.   Consequently,
it was necessary for the new counties to evaluate and compare these
proposals at an early stage so that priorities could be established
and submitted to central government for approval in the new T.P.P.
document.   This need for haste prompted the design and introduction
of new appraisal methods which were both simpler and speedier for
highway evaluation than traditional cost benefit techniques.

This problem was not one faced solely by metropolitan counties
for some of the larger and more heavily populated Shire Counties (e.g.
Hampshire, Kent, Devon and Hertfordshire) also faced problems following
the introduction of the T.P.P./T.S.G. system.   However, their diffi-
culties tended to be less severe and the subsequent developments in
evaluation techniques reflect the less complex situation.

Each of these factors is strongly inter-related.   The failings

of cost benefit analysis weakened the evaluation process in the eyes of the general public. The shortage of public money, meanwhile, strengthened the case for monetary based evaluation and weakened that of the alternatives, whilst the necessities of administrative change that followed local government reorganisation was directly responsible for the attempts to devise methodologies at a speed that precluded rigorous development and has ultimately led to their own discredit. These inter-relationships may have significant ramifications for the development of improved techniques.

Together, these factors stimulated the development of evaluation methodologies that emerged during the 1970's from metropolitan counties and to a limited extent from some Shire Counties. Unfortunately, many were developed quickly and without sufficient consideration and as a result, it is not surprising that many of the problems that they were designed to solve remain unsolved and that other problems have arisen. Developments that have occurred clearly reflect local conditions and resources. A fundamental difference in approach can be seen between methods adopted by metropolitan and Shire counties, stemming from the different priorities of each.

Current practice

(i) Metropolitan Counties

Recent developments in highway evaluation have tended to be concentrated in metropolitan authorities. Three examples that typify current practice are described here - Greater London, Greater Manchester and West Yorkshire. The approach within the West Midlands, its deficiencies and priorities for the research, will be examined in the light of developments in other metropolitan areas and those in a number of Shire Counties described later.

The approach towards evaluation in general has been consistent

17

throughout metropolitan counties. In Greater London, the approach taken was to develop a points rating 'scheme appraisal' system providing a framework for decision making, reflecting the nature of the choice to be made between competing highway expenditure. It is described in detail by Gower (1977) and Roe (1980). Schemes are assessed under a series of criteria to which points are allocated. Ranking then follows so that a programme of proposals can be derived according to the resources available.

Gane et al (1977) describe the Highway Review process of Greater Manchester. Current highway problem conditions are assessed under 9 main headings and calculations carried out to produce Highway Performance Indicators. To aggregate these indicators, measured upon different scales and in different units, points are allocated so that 100 are given to the site exhibiting worst conditions for each indicator. Others are scored in proportion to this. Total scores are calculated by summing these points. Economic evaluation of proposals to meet these problems is carried out producing a First Year Rate of Return. Non-monetary costs and benefits are assessed using a series of surrogates including pedestrian and traffic flow and housing occupancy. The two measures are then combined using a points rating approach, allowing comparison and ranking.

West Yorkshire originally intended to develop an assessment technique which could compare characteristics of highway, public transport, maintenance and other proposals, but practical difficulties led to its abandonment, and a simpler approach for highways alone is now used, based upon the work carried out for the W.Y.T.S. (WYT Consult., 1976; Martin, 1977; Headicar, 1979). Points scores are allocated to measurable criteria which indicate highway problem conditions and scheme achievement. Maximum points reflect worst site

conditions and others are scored accordingly. The scores indicate priorities between problems and the need for investment. The effects of schemes themselves are scored in the same way and comparisons are made of scores before and after implementation. Priorities between proposals can then be allocated. The issue of value for money is introduced by dividing the change in points total by cost.

Criteria used to measure problem condition and scheme achievements are selected in a variety of ways but each reflects practical considerations that exist. In Greater London, highway conditions and scheme value are assessed using as many types of measurable criteria as possible in the hope that coverage of all relevant issues must result. Criteria include strategic factors - both traffic and planning; local factors - environment, public transport and safety; and development factors - effects upon housing, industry, shops, etc. Simple indicators are used based upon readily available data with less attention paid to accuracy, consistency and validity than to availability. Points are attached to each to reflect the highway conditions. An example of this is given on the Scheme Appraisal Form in Figure 1.1.

Greater Manchester uses criteria for traffic overload (bus, HGV and general traffic delay), and environmental condition to provide an indication of highway conditions. The choice of criteria is heavily constrained by data availability and the practical problems of handling disparate information.

In West Yorkshire, information upon highway conditions is assessed under three main headings - traffic (public, private and freight), environment and safety, and subdivided into measurable criteria (e.g. peak traffic flow, noise levels, etc.). For each, a severity (degree of problem) and magnitude (number of people affected) level is calculated. The range of criteria

FIGURE 1.1 - GREATER LONDON COUNCIL SCHEME APPRAISAL FORM

Scheme ....

Project No. ....

Borough ....

Date of completion ....

Scheme	Strategic		Local					Development				Total Points (P)	Cost £m (C)	Rating P/C
	Traffic	Planning	Env.	P.Tr.	Accs.	Traffic	Housing	Comm.	Ind.	Comm.			
1														
2														
3														
4														
5														
6														

are shown in Figure 1.2.

Metropolitan Counties display consistency in their approach towards scheme generation. Greater London has no systematic process of generating highway sites where proposals need to be developed. Problem conditions are assessed at a limited number of sites each year when deficiencies are felt to exist. It is unclear from where these sites emerge, whether they are consistent in characteristics, or whether they form a comprehensive group of priority problems. Consequently, although the Greater London methodology does allow for the assessment of conditions prior to design and evaluation, it does so only for those sites where it has already been decided that scheme appraisal is worthwhile.

Greater Manchester follows a similar process. Although it was originally intended to use traffic model data as a direct means of generating highway problem sites, in fact this has yet to be put into practice. Sites for problem assessment are generated through a process of officer expertise, political and public pressure and a limited review of highway conditions, a process 'ad hoc' in nature and liable to misuse and misinterpretation. The origins of problem sites in West Yorkshire are similarly confused. A pool of known problems exists from which those exhibiting worst conditions proceed to design and evaluation.

Other Metropolitan Counties are little different. The process of scheme generation is characterised by subjective assessment whereby local expert opinion forms the major input.

Weights are widely used by Metropolitan Counties as a means of introducing priorities between issues, groups and areas. In Greater London, they are used to allocate priorities between housing, highways, environment and other issues in the calculation of total points scores

FIGURE 1.2 - GREATER MANCHESTER SCHEME CRITERIA

Performance indicators were developed to quantify the problems on each study length of road on the existing network. They were defined as follows:

overloading - a function of traffic and carriageway capacity based upon peak and off peak flows, road widths and D.T.P. standards.

speed - calculated for H.G.V., P.S.V. and other traffic from the assignment of local traffic model. 'Actual' compared with D.T.P. standards.

environment (housing) - noise level multiplied by number of properties. Used as a surrogate for noise, air pollution, severance, visual intrusion, etc.

environment (shopping) - as above but for shops.

pedestrians - includes data from pedestrian surveys. Crossing delay * average number of crossing pedestrians. Flow of pedestrians/ footway capacity. Flow of pedestrians * traffic flow.

accidents - rate per mile over previous 3 years.

industry - number of jobs within 1 mile of road.

for schemes. Changing policies result in changed weights and thus the derivation of a set of new priorities. This method is also used by West Yorkshire. However, Greater Manchester is one of the few exceptions to this, since weights are not used explicitly in the scoring and ranking process. Preferences between issues are left to the elected members to introduce by rejecting or accepting schemes presented to them as they wish.

Weights are a popular method of introducing preferences in a systematic and explicit way. The absence of a direct weighting system, as in Greater Manchester, confuses the issue of preferences and it remains unclear how much and to what extent the preferences of elected members, and priorities between policies have been introduced into the appraisal process. This is made more difficult when it is realised that the absence of explicit weights still represents a weighted solution in itself. The choice of criteria, scales and score ranges each reflect a weighted judgement.

The highway evaluation methods of Greater London, Greater Manchester and West Yorkshire are summarised in Figure 1.3. They represent typical examples of current appraisal methodologies in Metropolitan areas. There is marked consistency between the approaches particularly in the use of points ratings and the choice of criteria. Each displays significant deficiencies in handling these issues, but the most serious remains that stemming from scheme generation and the universal absence of a systematic, consistent and comprehensive approach to the identification of problems. If sites and schemes do not have reliable and justifiable origins, then the subsequent stages of appraisal become problematic. Clearly, this is a priority issue for the research.

(ii)   Shire Counties

Recent developments in the evaluation methods used by Shire

FIGURE 1.3 - SUMMARY OF HIGHWAY EVALUATION METHODS IN GREATER LONDON, GREATER MANCHESTER AND WEST YORKSHIRE

	Greater London	West Yorkshire	Greater Manchester
Problem identification scheme generation	No	No	No
Aggregation & valuation method	Points /cost	Points /cost	Points /cost
Cost?	Yes	Yes	Yes
Weights to reflect policy priorities	Yes	Yes	No
Factors included:			
- safety	✓	✓	✓
- private transport	✓	✓	✓
- public transport	✓	✓	✓
- freight	✓	✓	✓
- environment	✓	✓	✓
- pedestrians	✓		✓
- housing	✓		✓
- industry	✓		✓
- community facilities	✓		
- shopping	✓		
Public transport & highways	No	No	No
Structure Plan & T.P.P. policies	Yes	Yes	No
Member input	Yes	No	Yes
Future development	No	No	Yes

Counties reflect the specific demands that exist. A survey of Shire Counties in England and Wales carried out during 1980 and 1981 outlined current trends (Roe, 1981). The majority of Shire Counties continue to evaluate projects using cost benefit techniques which are commonly derivatives from the central government technique, COBA. This is especially true of less populated counties where the number and complexity of highway problems is comparatively small - for example Lincolnshire, Wiltshire and the Isle of Wight. Where new developments have occurred, a move towards points based approaches has tended to emerge, typified by those in Nottinghamshire (Richmond, 1982) and Bedfordshire (Smith, 1982). Occasionally, a matrix approach has been adopted - examples come from Hertfordshire (Fells and Tweedale, 1977) and Hampshire (1980). A few counties have attempted to combine both approaches, including Cambridgeshire, mid Glamorgan and Norfolk. Only Suffolk uses a purely financial technique. A number of others have devised their own specific methods, varying from the purely descriptive (Powys) to the highly complex (West Sussex).

The criteria used to assess problems and scheme achievement are noticeably consistent, including mobility/access, safety, cost and planning/development in almost every case. Environmental factors are commonly used, but range from an aggregated, generalised criterion to one specifically for air or noise pollution levels. In general, the indicators most commonly used are those where existing data is readily available or can be most easily measured. Tradition also plays a major part.

Few Counties based their choice of indicators, scores or weights directly upon T.P.P. or Structure Plan policies or priorities and generally, the importance of scheme generation has remained overlooked. Schemes usually emerge from an unstructured and 'ad hoc' process of

22

political discussion and officer and public pressure, although a number of authorities do use output from regular monitoring procedures. Few counties have proposals to develop their techniques, although Humberside, Bedfordshire, Warwickshire and Shropshire are notable exceptions. Most judged success of their technique upon its ability to produce intuitively correct results and its political acceptability.

Although far from exhaustive, this review suggests a number of conclusions:-

(a) There has been little impetus for Shire counties to develop new appraisal techniques. The developments that have occurred, largely in response to public pressure and the findings of the Leitch Report (ACTRA, 1977), have resulted in the adoption of points based approaches.

(b) In general, the primary criterion for a successful evaluation technique is the simplicity and ease with which it can be used, and its political acceptability. Its ability to identify problems, handle disparate highway criteria and indicate priorities for investment are of secondary importance.

(c) There are many weaknesses in these approaches. In particular, the failure to generate sites and schemes in response to the identification of highway deficiencies undermines any other achievements that might exist. Not a single technique openly recognises the values implicit in the methods used to aggregate disparate criteria, and the assumptions made in their selection and valuation.

Current practice in both Metropolitan and Shire Counties reflects developments in highway evaluation that have notable advantages over the methodologies recommended by central government and typified by COBA. They provide a consistent approach within each county, helping

to structure consideration of proposals and ensure treatment of at least a number of relevant issues. These issues include those items traditionally excluded from cost benefit approaches. They exhibit flexibility in using political weights to represent priorities and have performed a valuable function in helping to reduce a backlog of proposals inherited upon local government reorganisation.

However, they are characterised by a series of deficiencies that detract from their abilities as a resource allocation and scheme selection methodology. These deficiencies range from those of lesser significance - the use of surrogates, data inadequacies and complexity, to those which are clearly very significant - the selection of criteria, the scores attached to them, issues of distribution, equity and uncertainty, and in particular the absence of a consistent scheme generation methodology, responsive to local demands and priorities.

The West Midlands.

The characteristics of these examples of current evaluation practice provide a practical context within which the developments in the West Midlands can be assessed. It is described in some detail in the following sections.

The development of the West Midlands technique of Priority Ranking occurred in response to the same pressures as those in other Metropolitan areas. However, development of the technique has progressed further. Stages in the development of Priority Ranking have been described in detail by Ball (1976, 1977), Chapman (1980) and Roe (1980). The technique is summarised in Figure 1.4. Priority Ranking has been used to allocate priorities to highway scheme proposals since 1976, although it continues to be under development, reflecting changing needs and circumstances.

FIGURE 1.4 - THE PRIORITY RANKING PROCESS

1. Definition of policies and derivation of policy
    weights.

2. Assessment of relationships between policies and
    objectives.

3. Derivation of objective weights.

4. Development of criteria to measure objective
    achievement.

5. Weighting of criteria.

6. Scoring of schemes on the criteria.

7. Multiplication of criterion score by criterion
    weight and by objective weight.

8. Summation over all criteria to produce total
    scheme score.

9. Derivation of ranking.

During its early development, the broad objectives of the technique were that:-

(a) It must be relatively simple and capable of being understood by an intelligent layman.

(b) It must not require masses of data and/or expensive modelling techniques.

(c) It must not require more than two or three staff who prepare the council's T.P.P., to develop and operate the system.

(d) It must be capable of dealing with up to 200 schemes in only 4-6 months. This need stemmed from local government reorganisation in 1974.

(e) The lack of data for a scheme must not totally invalidate the method.

Within the context of these general requirements, a number of specific issues were formulated. The principal specific issue was that Council objectives should form the basis of the technique. Clearly, there is a subjective element in the choice of objectives, since they will differ between individuals and societal groups. These value judgements find their expression through policy statements. It was decided, therefore, that objectives need to be derived from current County policies.

Five detailed requirements of the new evaluation methodology were identified:-

(a) The objectives should cover a large range of interests - e.g. financial, social, engineering, environmental, etc.

(b) Since the achievement of objectives is measured in different ways, it follows that they cannot be directly aggregated for problems arising in reconciling conflicting

objectives. Consequently, the method must develop

explicit trade offs between objectives.

(c) The initial selection procedure must be designed to pro-
duce a short list of schemes that are to be ranked in

priority order.

(d) It must be flexible, responsive to policy changes and to

changes in the number and relative importance of

objectives.

(e) It must be relatively simple to use and produce results

comparatively quickly.

The scope of Priority Ranking was deliberately limited. A
Scheme is not submitted to it until a need for that scheme has been
demonstrated, and the process is not designed to compare a number of
schemes which have potential to solve one particular problem. It
is not designed to evaluate between competing sectoral investments
(e.g. maintenance, public transport, highways, etc.), but to give an
indication of the priorities between schemes allocated to the same
sector. In fact, so far it has been limited to highway and public
transport capital schemes alone. Initially, economic appraisal was
excluded from the methodology due to difficulties of measuring
traffic related effects in complex urban areas, and associated
temporal and practical considerations. Subsequently, however, larger
schemes have been subjected to a limited cost-benefit appraisal in
response to demands both from central government and local politicians.

Priority Ranking can be divided into a number of distinct
stages.
a) Allocation of resources. Financial resources are allocated to
development sector heads (e.g. maintenance, public transport capital,
highways, etc.), and priorities placed upon each.

b) Scheme identification and assessment of needs.   This is an informal process bringing together a variety of routines.   Each year, district councils, the P.T.E. and various sections of the County Council are invited to submit details of schemes which they would like to include in the next T.P.P.   Other schemes emerge from public and political pressure, whilst in the early years many scheme proposals were inherited from local authorities who had lost their highway res- ponsibilities following local government reorganisation.   All these proposals proceed to the 'coarse sieve'.

c) Coarse sieve.   All schemes, regardless of origin or character- istics, are tested against four criteria:

    i)   the scheme should comply with the Structure Plan, local plans or approved development plan.

    ii)   There should be a strong possibility that, given the necessary finance, the scheme could be implemented, e.g. land could be acquired during programme period.

    iii) The scheme being evaluated is the best possible solution to an agreed problem and that economic, environmental and social factors have all been considered in arriving at that solution.

    iv) The effect of not implementing the scheme for five years is substantial.

The coarse sieve produces 3 types of schemes:

-   those that pass to the fine sieve;

-   those completely rejected;

-   those referred back for design modifications and for later reconsideration.

d) Fine Sieve.   This consists of three distinct stages.

i)   Using the policy statements of the County Council as a

       starting point, derived from meetings with members and

       from the T.P.P. and Structure Plan documents, operational

       objectives are specified, each serving one or more

       policies and these generate a series of performance

       criteria (figure 1.5), indicating how the achievement or

       non-achievement of the objectives can be measured.

ii)   The objectives are weighted in order of priority. This

       recognises that some are more important than others and

       that this should be made explicit.

iii]   Schemes are ranked within a given performance criterion

       using a cardinal scale of achievement introduced so that

       the differences between achievements can be assessed.

       For each scheme, the scores on each criterion are added

       together to produce a total score.

e) Objectives and weights.   Specific objectives are derived to re-

phrase the Council policies into more precise form.   It is usual for

a greater number of objectives than policies to be derived.   Con-

sequently, many of the policies may have more than one objective

directed towards them.   The objective weighting factors are

selected to reflect the relationship and number of links between

objectives and policies.   In some cases the link is quite strong, in

others weak.   Policies themselves are weighted by a panel of officers

and elected members to reflect priorities (figure 1.6).   The two

weights (objective and policy) are multiplied together and summed for

each objective.   A rationalisation process produces the objective

weights shown in Figure 1.7 .

f) Performance criteria and weights.   One hundred points are divided

between the criteria associated with each objective, irrespective of

FIGURE 1.5 - EXAMPLES OF CRITERIA IN PRIORITY RANKING (1977)

Criterion	Measurement
1.1 Size of development in relation to dependence.	Change in the number of community facilities that will be placed in a more advantageous position relative to the population using them.
1.2 Size of development in relation to dependence.	Improvement in 'Accessibility Index'.
2.1 Change in journey time of freight vehicles.	Change in capacity of that part of the network affected compared to present inadequacy.
2.2 ..... car users.	
2.3 ..... pedestrians.	
2.4 Strategic importance of the route in relation to the desired highway network.	Subjective assessment.
3.1 Change in journey time for bus passengers.	Time change (minutes).
3.2 Change in walking time to bus stops.	" " (minutes)
3.3 Change in waiting time for bus services, due to increased reliability.	" " (minutes).

FIGURE 1.6 - AN EXAMPLE OF POLICY WEIGHTS IN PRIORITY RANKING (1977)

POLICY	WEIGHT

1. To ensure that roads, footpaths and public lighting are maintained in a safe, serviceable condition. **5**

2. To provide for transport infrastructure to developments, redevelopments and renewal that will provide employment opportunities and homes. **5**

3. To continue to develop and improve the strategic highway network. **3**

4. To work towards a reduction in road accidents by pursuing road safety education and training programmes and by using resources for the improvement of the situation at accident blackspots. **3**

5. To increase the capacity of the existing transportation facilities both for public and private transport. **2**

6. To give priority to the provision of a public transport system that will efficiently and economically serve the needs of the West Midlands. **2**

7. To continue a policy of restraining the use of private cars, particularly in town centres during peak periods, and other areas which can be well served by public transport, and where congestion is a problem. **1**

8. To ensure that in all transportation developments the impact of that development on both the social and physical environment is fully assessed and balanced against the economic benefits. **1**

FIGURE 1.7 – EXAMPLE OF OBJECTIVE WEIGHTS IN
PRIORITY RANKING (1977)

Objective	Weights (Wo)
1. To increase accessibility	5
2. To increase network capacity	5
3. To reduce average total journey time	3
4. To reduce journey time for freight	3
5. To reduce accidents	3
6. To reduce community disruption	3
7. To utilize fully spare network capacity	1

the number.   This is carried out by a panel of officers from the

Planning, Transportation and Engineering Departments and the P.T.E.

Further rationalisation of points scores then takes place (Figure 1.8).

g) Utility curves.   Having obtained a set of objectives and criteria

and assigned weights to each, the final step is to develop the means

of translating differences in performance criteria into quantitative

and cumulative differences for overall comparative purposes.   This

technique was intended to be based upon the utility curve concept -

a graphic display of the relationship between physical condition

(noise level, delay, etc.) and the response of individuals or the

community to that condition.   An example is given in Figure 1.9.

Different curves would be derived for different physical conditions

and ideally for different groups, individuals and activities.

However, the utility curve concept has never been fully

developed due to technical problems surrounding the derivation of

stable and meaningful transformation relationships between physical

conditions and individual and group responses.   Instead, a score

between -4 and +4 is allocated, the sign representing deterioration

or improvement (in objective terms) respectively.   Each performance

criterion possesses a linear transformation relationship with the

objectives which gives a consistent and fixed score for any given

condition.   An example of transformation functions which have been

used is given in Figure 1.10.   The lack of suitable data results in

the allocation of many scores by a panel of officers.

A working sheet is used to perform the operation of Priority

Ranking (Figure 1.11).   A weighted and unweighted score is obtained

for each scheme leading to a weighted and unweighted ranking.   A com-

puter program has been written to carry out the Priority Ranking pro-

FIGURE 1.8 - EXAMPLE OF PERFORMANCE CRITERIA

WEIGHTS (1977)

Criterion	Points allocated	Weighting Factor (Wc)
1.1 Change in no. of community facilities advantageously affected by scheme.	50	12.5
1.2 Change in "accessibility index".	50	12.5
2.1 Change in network capacity compared with present inadequacy.	25	6.25
2.2 Maintenance state of road (M.A.R.C.H.).	20	5.00
2.3 Strategic importance of route in relation to highway network.	15	3.75
2.4 Strategic importance of route in relation to new developments.	40	10.00
3.1 Change in journey time for bus passengers.	30	7.50
3.2 Change in walking time to bus stops.	5	1.25
3.3 Reduced wait time due to increased bus reliability.	10	2.50
3.4 Reduced wait time by changed bus frequency.	5	1.25
3.5 Change in journey time of car users.	20	7.50
3.6 Change in journey time for pedestrians.	30	7.50
4.1 Change in journey time for freight vehicles.	100	25.00
5.1 Change in number of accidents.	60	15.00
5.2 Change in severity of accidents.	40	10.00
6.1 Change in noise levels.	25	6.25
6.2 Change in visual amenity.	15	3.75
6.3 Change in atmospheric pollution.	15	3.75
6.4 Change in no. of community facilities affected by severance.	45	11.25
7.1 Proportion of spare network capacity utilized.	100	25.00
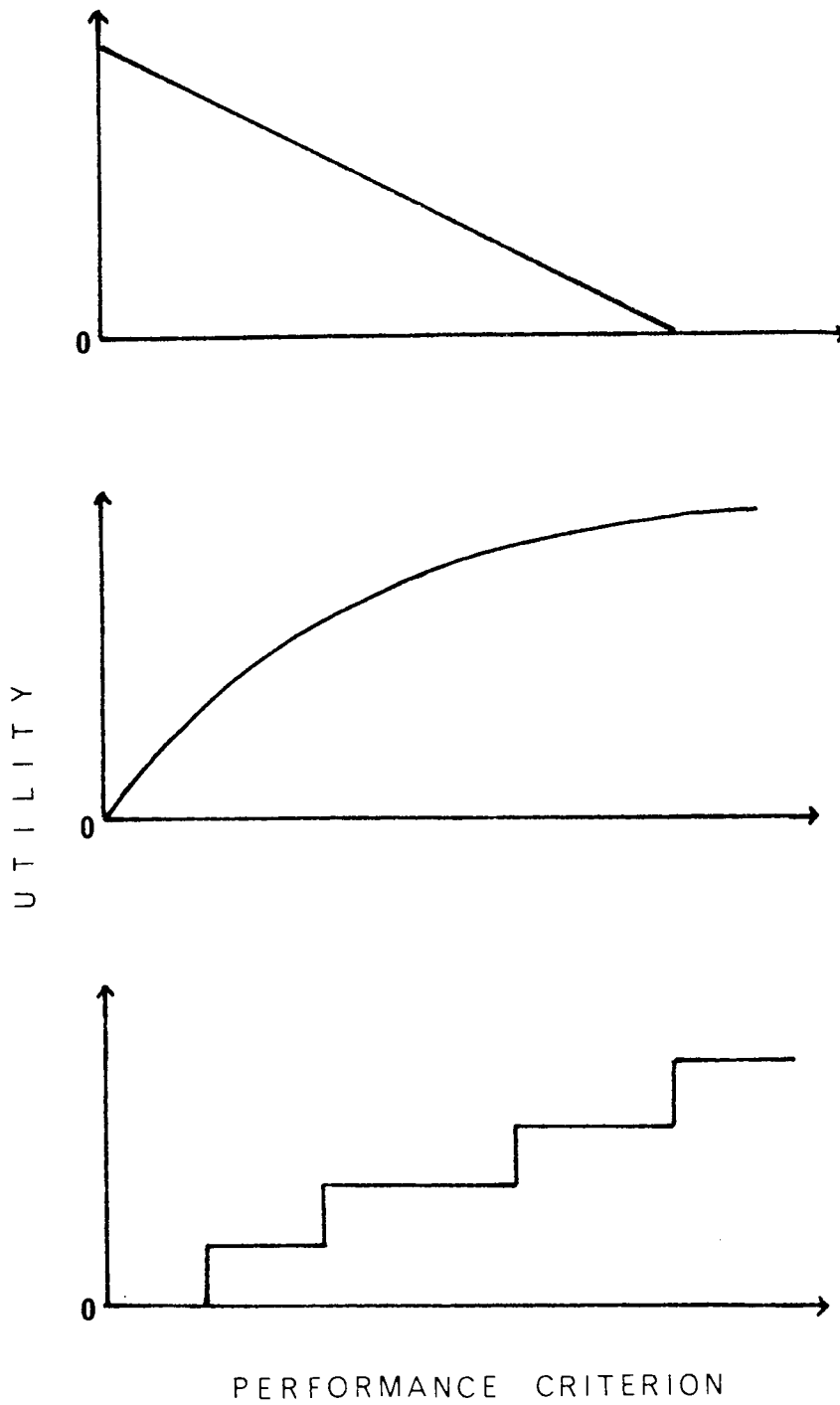
FIGURE 1.9   EXAMPLES OF UTILITY CURVES

Criteria 1.1, 1.3 and 1.6   Size and dependence of development

For each of the criteria this is based upon the following data.

Size (S) is as follows:-

    housing - the number of dwellings provided in the development

    industry - the number of jobs

    community facilities - the number of people attracted per

        day to the community facilities (e.g. school)

Dependence Factor (D) = average number of vehicles per day generated

        by the development that will use the scheme $\div$ total

        number of vehicles per day generated by the

        development.

Total Cost (C) of scheme in £000's.

A factor S/C x D is calculated and score read from

S/C x D	Score
10 +	+ 4
1 - 10	+ 3
0.1 - 1	+ 2
0 - 0.1	+ 1
0	0

Criterion 4.2 severity of accidents.

A subjective assessment based upon:

    (a) change in traffic speed,

    (b) change in number and type of conflicts

(c)   change in pedestrian vulnerability,

(d)   past accident record.

The table below is used to derive a score:

Change in severity	Score
Very high decrease	+ 4
High decrease	+ 3
Moderate decrease	+ 2
Marginal decrease	+ 1
No change	0
Marginal increase	- 1
Moderate increase	- 2
High increase	- 3
Very high increase	- 4

N.B.   Other functions are available for each of the criteria.

FIGURE 1.11 - PRIORITY RANKING WORKING SHEET - 1976/7

OBJECTIVES

Objective	No.	Description	Objective Weight
Increase Accessibility	1		5
Increase Capacity	2		5
Reduce average total journey time	3		3

Criteria

SCHEME	1.1	1.2	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4
CRITERIA WEIGHT	12.5	12.5	6.25	5.00	3.75	10.00	7.50	1.25	2.50	1.25
High Street	+2	+1	+3	+3	+1	+1	+4	+1	+1	+1
Ring Road	+3	+3	+4	+4	+2	+3	+4	+2	+2	+2
A99	0	0	+2	+1	+1	+2	+1	+2	+2	+2
Junction	0	0	+3	+2	+1	0	+2	+1	+3	+2
etc.										

cess. Having previously set the weights and the performance curves
for each criterion, it is necessary only to input the scores to
obtain a priority listing.

It is a relatively simple task to devise a programme of schemes
from the information contained in the working sheets. Only schemes
costing more than £50,000 are subjected to the Priority Ranking pro-
cess. The first step is to divide the proposals between expenditure
heads (Figure 1.12), following which it is possible to select schemes
in priority order to meet required cash flow and financial constraints,
based upon Department of Transport guidelines and borrowing require-
ments and revenue implications for the county council.

Schemes are allocated to a particular year. For example,
schemes to serve new developments are initially placed in the year
most suitable for the proposed development, whilst schemes under the
heading 'development and improvement of the highway network' are
initially placed in the year most appropriate to the statutary pro-
cesses, design requirements and needs of other related schemes.
Any scheme not of sufficiently high priority to make the programme
for the first year (because the limits of financial resources have
been reached) is automatically considered for the second year, but
then has to compete with those schemes originally allocated to that
year. This continues year by year until the fifth year is com-
pleted. Inevitably some schemes do not find a place in any year.
In formulating the programme for each year, expenditure heads are
taken in priority order - for example, starting with 'roads for new
development'. This priority order is subject to change as policies
and priorities change.

A number of developments have taken place since the original

FIGURE 1.12 - EXPENDITURE HEADS FOR THE T.P.P. - WEST MIDLANDS

Highest Priority

Lowest Priority

T.P.P.

Roads for new Developments

Public Transport * Infrastructure and Revenue Support

Maintenance

Road Safety Education and Training

Minor * Schemes

Development * + Improvement of Highway Network

Others

Bus Aids

Traffic Management

Minor Road Improvements

Includes schemes at accident blackspots
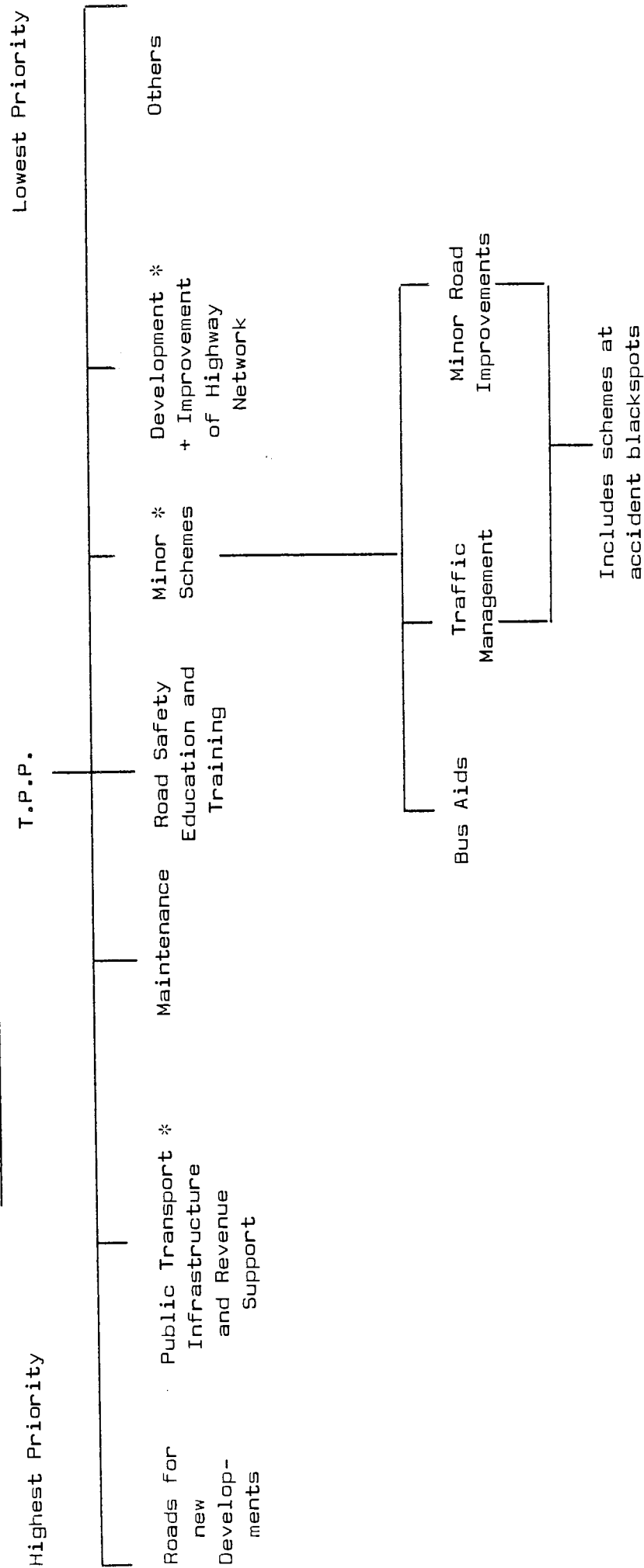
* Schemes under these heads are subject to the priority ranking process.

conception of Priority Ranking. Whilst the Goals Achievement Matrix approach was seen to be of considerable value, it was felt that it might be linked formally to a cost-benefit and more specifically, a Planning Balance Sheet approach (Lichfield, Kettle and Whitbread, 1975). However, problems clearly existed. They took the form of two principal incompatibilities:

(i) Whilst the Goals Achievement Matrix essentially is orientated towards societal goals, cost-benefit analysis and P.B.S.A. focus upon different groups. Ideally, goals would be specified explicitly with respect to groups, but currently this does not occur.

(ii) Whilst Goals Achievement methods purport to use societal values to weight various goals and criteria, cost-benefit analysis uses aggregation of individual preferences. Factors are not weighted explicitly, the assumption being that the weights are reflected in the monetary values employed.

Thus difficulties in linking the two approaches were expected. The outcome was the Scheme Assessment Balance Sheet. There were seven headings for evaluation, the first three those most usually covered within a cost-benefit analysis (Figure 1.13). Although the headings, to some extent, represent affected groups, this is not entirely the case. Space is provided for a discussion of the dif-ferences between total scheme score and the cost-benefit assessment, the latter usually in the form of a first-year rate of return or N.P.V./C. Listing of monetary and non-monetary costs and benefits of a scheme allows comparisons to be made of the origins and distri-bution of scheme value and effects and the relative importance of each.

More recent developments have seen revision of the working form (Figure 1.14). The new version is simpler and marks a return to the

FIGURE 1.13 - SCHEME AS!

1978 T.P.P. SUBMISSION; !

Scheme No. ....

District ....

Description ....

Summary of scheme costs ....

Price base ....

	HEADINGS FOR EVALUATION	:NTAGE CONTRIBUTION ΓO TOTAL SCORE	COMMENTS
MEASURABLE IN MONETARY TERMS	USER BENEFITS AND DISBENEFITS	2. 2. 3.	
	NETWORK EFFICIENCY	3.	
	EFFECTS ON ACCIDENTS	4. 4.	
NOT MEASURABLE IN MONETARY TERMS	USER BENEFITS AND DISBENEFITS	2. 3. 3. 3.	
	STRATEGIC DEVELOPMENT	1. 1. 2. 3.	
	NETWORK EFFICIENCY	2. 2. 2.	
	ENVIRONMENTAL EFFECTS	5. 5.	

DISCUSSION OF DISTF

31(11)

FIGURE 1.13 - SCHEME ASSESSMENT BALANCE SHEET (1978)

1978 T.P.P. SUBMISSION; SCHEME ASSESSMENT BALANCE SHEET

Scheme No. ....   Scheme Title ....

District ....

Description ....

Summary of scheme costs ....

Price base ....

	HEADINGS FOR EVALUATION		SUB-HEADINGS FROM GOALS ACHIEVEMENT MATRIX (GAM)	BENEFIT (+) OR COST (-) £ p.a.	SCORE MAX.SCORE	PERCENTAGE CONTRIBUTION TO TOTAL SCORE	COMMENTS
MEASURABLE IN MONETARY TERMS	USER BENEFITS AND DISBENEFITS	2.1	Journey time for freight vehicles				
		2.2	Journey time for car users				
		3.1	Journey time for public transport users				
	NETWORK EFFICIENCY	3.5	Change in public transport operating costs				
	EFFECTS ON ACCIDENTS	4.1	Change in number of accidents				
		4.2	Change in severity of accidents				
NOT MEASURABLE IN MONETARY TERMS	USER BENEFITS AND DISBENEFITS	2.3	Journey time for pedestrians				
		3.2	Walking time for P.T. users				
		3.3	Waiting time for P.T. users				
		3.5	Other effects on P.T. users				
	STRATEGIC DEVELOPMENT	1.1	Size of development : attractor				
		1.2	Size of development : generator				
		2.4	Strategic importance of highway route				
		3.4	Strategic importance of P.T. route				
	NETWORK EFFICIENCY	2.6	Proportion of spare capacity used				
		2.7	Maintenance cost saved				
		2.5	Change in capacity with respect to present inadequacy				
	ENVIRONMENTAL EFFECTS	5.2	Change in noise and pollution				
		5.1	Change in other environmental effects				

DISCUSSION OF DISTRIBUTIONAL EFFECTS

First year rate of return .... 4.6 %

Net present value/cost .... N/A

Total score from GAM .... 348 (Total score possible 1000; Score of highest ranking scheme 447)

Scheme rank from GAM .... 9 (Total number of schemes ranked 59)

Scheme cost necessary to produce
acceptable return (where applicable) ... £1.7 m.

Main factors explaining difference
between economic return and score/rank
on GAM (where applicable) .... The scheme produces a low economic return, mainly because an expensive solution is needed to cater for pedestrian flows. Also, accident benefits are not calculated. However, the scheme produces benefits over a wide range of factors, and this is reflected in the relatively high GAM score.

Comments .... The scheme scores well under a wide range of headings; this must be set against the relatively poor first year rate of return.

FIGURE 1.14 - PRIORITY RANKING WORKING SHEET, 1980

TITLE ....

OBJECTIVES	OBJECTIVE WEIGHT	CRITERIA WEIGHT	TOTAL WEIGHT	CRITERIA	SCORE	SCORE X TOTAL WEIGHT
To provide access to development				1.1 Size of development generating movement in relation to dependence		
				1.2 Size of development attracting movement in relation to depencence		
To promote the efficient operation transport				2.1 Change in journey time of freight vehicles		
				2.2 Change in journey time of car users		
				2.3 Change in journey time of pedestrians		
				2.4 Strategic importance of the route		
				2.5 Change in network capacity		
				2.6 Proportion of spare capacity utilised		
				2.7 Maintenance cost saved		
To promote the efficient operation of public transport				3.1 Change in journey time of public transport users		
				3.2 Change in walk time to bus stops/stations		
				3.3 Reduction in waiting time by increased frequency increased reliability		
				3.4 Strategic importance of the route		
				3.5 Change in other benefits to public transport		
To reduce accidents				4.1 Change in number of accidents		
				4.2 Change in severity of accidents		
To reduce the harmful effects of traffic on the environment				5.1 Change in environmental effects including visual amenity		
				5.2 Change in noise and atmospheric pollution levels		

TOTAL SCORE

earliest style. This form was used for the 1980 T.P.P. submission. Meanwhile, discussions over the Structure Plan for the West Midlands and the need to integrate its policies with those of the T.P.P. has led to the introduction of an expanded set of objectives and the derivation of new weights, scores and working forms to reflect this. Much of the process of Priority Ranking remains the same, but the extended range of objectives can be seen in the new forms (Figure 1.15) used to prepare the 1981 and 1982 T.P.P. submissions.

Priority Ranking has achieved a great deal. It has reduced a large number of highway schemes inherited in 1974 to a manageable and realistic total. It incorporates a weighting mechanism to reflect political priorities, accommodates issues neglected by traditional cost benefit analysis and yet does so relatively quickly and easily. It demands little data and thus consumes few resources, whilst reflecting the demands of both the Structure Plan and T.P.P. process. The results it produces have gained widespread accept- ability, particularly from the Department of Transport and within W.M.C.C., providing practical guidelines for priorities.

However, a number of inadequacies remain, many of which are recognised by W.M.C.C. They can be summarised under three main headings - theoretical, practical and methodological.

Theoretical deficiencies stem from the treatment given to scoring and valuing highway condition. Implicit bias is introduced through the score ranges adopted for performance criteria and the assumptions of linearity. There is little evidence to support these assumptions. Many criteria are valued subjectively, with minimum recourse to quantified data or evidence of community or individual values. The use of a variety of criterion scales (interval, ratio,

FIGURE 1.15 - PRIORITY RANKING WORKING SHEET 1981/2

Structure Plan Review: Date:

TRANSPORTATION SCHEME ASSESSMENT   SCHEME NUMBER:

SCHEME TITLE:

COST £

Objectives	Criteria		Score
		weight +	
(1) To provide access to developments	1.1 Size of employment development in relation to dependence	+	
	1.2 Size of housing development in relation to dependence	0	
(2) To reduce accidents	2.1 Change in the number of accidents	+ 1	
	2.2 Change in the severity of accidents	0	
(3) To promote the efficient use of private and public transport	3.1 Change in journey time of freight vehicles	0	
	3.2 Change in journey time of car users	+ 1	
	3.3 Change in journey time of pedestrians	0	
	3.4 Change in journey time of public transport users	+ 2	
	3.5 Strategic importance of the route in relation to the desired highway network	0	
	3.6 Improvement in network capacity compared with its forecast inadequacy in 1991.	0	
	3.7 Strategic importance of the route in relation to the desired public transport network	+ 4	
	3.8 Change in other benefits to public transport users	+ 1	
(4) To reduce the harmful effects of traffic on the environment	4.1 Change in environmental effects, including visual amenity, social	+ 2	
	4.2 Change in noise, fumes and vibration	+ 2	
(5) To improve the network in the priority areas	5.1 Birmingham Core Area (D.O.E.)	+ 2	
	5.2 Other designated inner districts (D.O.E.)		
	5.3 Priority areas (County Council)		

etc.) without consideration of the limitations this imposes upon
translation, interpretation or aggregation devalues the process as a
whole.

In methodological terms, there are a number of fundamental
deficiencies. The most significant is that Priority Ranking assumes
that all schemes presented to it are optimal solutions to real
priority problems of the highway network, whereas the actual process
of scheme generation is characterised by political and public pressure,
discussion and officer 'expertise'. Undoubtedly, the majority of
significant highway problems are identified and schemes which produce
'value for money' are selected and implemented. However, it remains
unclear whether some problems are missed, particularly those at the
margin, or if inadequate assessment of problem conditions results.

The importance of this methodological deficiency is hard to
over-emphasise. Without a consistent approach to scheme generation,
the danger of selecting inappropriate schemes from an incomplete pool
of problems becomes very real. No matter how accurate and sophis-
ticated highway evaluation techniques become, if an inadequate
selection of projects are considered, then the results are limited in
value. All other deficiencies of Priority Ranking become significant
only once scheme generation has been accommodated adequately. The
existence of this deficiency in Priority Ranking has been recognised
for some time (Ball, 1976, 1977; Chapman, 1980) and as we have seen,
it is a characteristic of the majority of Metropolitan and Shire
Counties' techniques. It is surprising that it has not attracted
more adverse comment, particularly since the traditional view of the
planning and highway evaluation process almost invariably begins with
a formal scheme generation stage (Hall, 1962; Chadwick, 1971;
Perraton, 1974; Eddison, 1975; Lichfield, Kettle & Whitbread, 1975).

Priority Ranking displays other methodological deficiencies although they are of less significance. Issues of risk and uncertainty in project appraisal and data prediction are unrecognised. Single year assessments of costs and benefits are used as the basis for evaluation, despite considerable evidence of their inadequacy (Pouliquen,1970; Reutlinger, 1970; Arrow and Lind, 1970; Mackie and King, 1974) and the existence of techniques to accommodate them (Friend and Jessop, 1969; Raiffa, 1970; Gilbert and Jessop, 1978). Evaluation is carried out for individual sites alone, without assessing the network ramifications of introducing improvements except for a limited appraisal of the physical implications using the County model. This is despite developments elsewhere (West Sussex C.C., 1981) and recognition of the importance of network costs and benefits some time ago (Beesley and Walters, 1970).

A consequence of the inadequate generation of schemes prior to design and evaluation is that the linkage between highway problem and scheme selection is poor. It is important to realise that substantial problem size does not necessarily mean substantial benefits will result from implementing an optimal solution. Smaller problems may give rise to schemes which result in greater value for money. Somehow the net benefits inherent in the optimal solutions to a problem need to be assessed prior to design and evaluation and without relying entirely upon problem size as an indicator. This is impossible without adequate problem identification. Another consequence is that solutions cannot take account of inter-related problems if the identification of these problems is not detailed and comprehensive. The current evaluation process easily can lead to partial or even inappropriate solutions to ill-defined problems. Priority Ranking cannot compare proposals from different sectors of

34

transport expenditure (e.g. highways, public transport, maintenance, etc.). Each is considered separately after budget allocation and without recourse to information upon problem condition within other sectors or the priorities for expenditure that this implies. This may result in the inequitable distribution of resources between sectors, whilst the comparative merits of investing in one sector rather than another, are unknown. Finally, distributional implications are largely ignored, although policy weights could be used to reflect priorities between areas or groups. It is recognised, however, that this is inadequately explicit.

There are a number of practical deficiencies, although they are of less significance. Priority Ranking is unwieldy and, to the inexperienced, somewhat complex. Consequently, its results are not necessarily clear to decision-makers. There are political implications as well. The results of the Priority Ranking process are presented to decision-makers for their approval or rejection. However, the nature of the process and Member involvement at an early stage, places pressure upon them to accept the output - even though they have little if any control over many of its inputs. A spatial difficulty arises from problems which cross the county boundary or are caused by factors operating outside the West Midlands.

Many of the inadequacies of Priority Ranking can be seen to stem from failure to respond to the demands of the stimuli which originally encouraged much evaluation research. The speed of development necessitated by the introduction of the T.P.P. process and the creation of the new Metropolitan Authorities a very short time before this, caused many of the current inadequacies. In particular, it affected the process of scheme generation, for the need to identify

problem sites at that time, did not exist.   It also had ramifications

for the treatment of scoring, scaling and weighting processes which

have not been developed with any consistency.   Many of the theoretical

deficiencies of Priority Ranking are common to other local authority

evaluation techniques and there is little doubt, that given more

support, they could be overcome.   The financial problems of the

1970's and 1980's have not helped.   Finally, practical problems have

stemmed, in part, from the failure to adapt to the needs of a multi-

dimensional planning system typified by the demands of the Structure

Plan and T.P.P. process (Broadbent and Mackinder, 1973; Bayliss,

1975; Parker, 1978).

Clearly, there are a number of issues in Priority Ranking in

need of further development.   The issue of scheme generation stands

out in particular, and its significance is reflected in the funda-

mental position it holds in the overall highway scheme selection

process which forms part of the evaluation context within which any

new developments must operate.   This process, a model of which has

been derived by Roe and Johnson (1979) is summarised in Figure 1.16.

It can be divided into 3 separate stages, each composed of a number

of elements.   For a highway scheme selection process to be effective,

it must cover each of these elements adequately and achieve their

integration in a rational manner (Johnson, 1978).   Element B - the

specification of projects - encompasses the process of scheme

generation, and it has a significant relationship with other elements

in the scheme selection process, a factor evident from Figure 1.16.

The fundamental role it plays has been widely recognised (Kitchen,

1972; Houghton, 1974; Lichfield et al, 1975; Quarmby, 1977), and

since scheme generation forms an initial stage of the highway

evaluation process, all subsequent stages, including design, evaluation

FIGURE 1.16 - ELEMENTS OF A SCHEME SELECTION PROCESS

A   Specification of attributes

B   Specification of projects

C   Specification of incidence groups

D   Measurement of impacts

E   Individual utilities on attributes

F   Trade-offs between attributes for individuals

G   Trade-offs between groups

H   Specification of inter-relationships between decision areas

I   Assessment of uncertainty

J   Assessment of robustness

K   Integration of alternative techniques

L   Consolidation for decision making

M   Precentation for decision taking

Relationships
between the
Elements
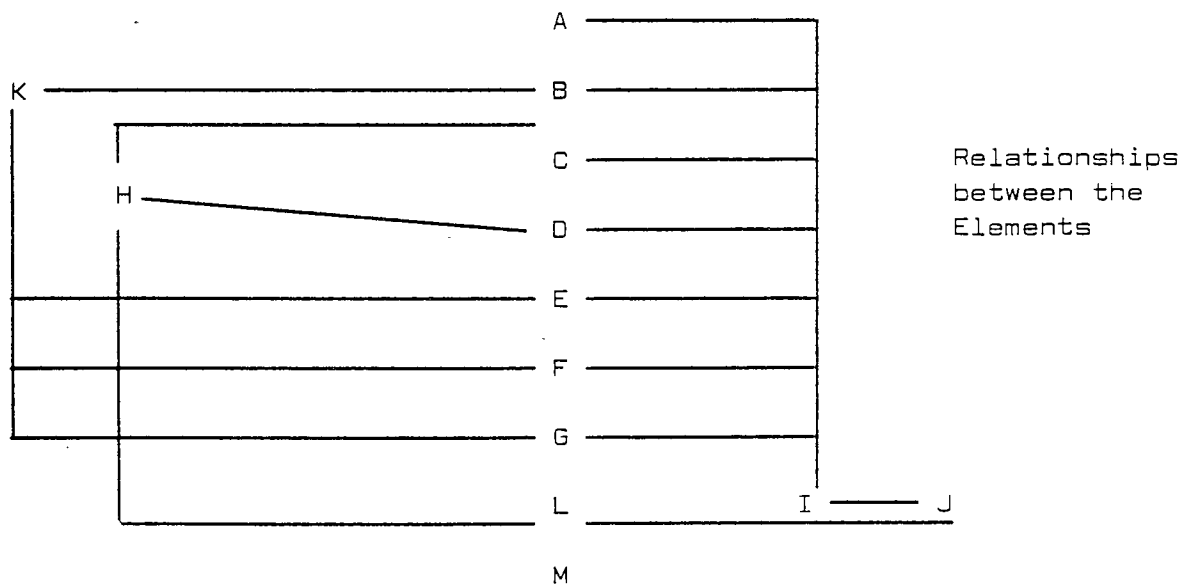
and implementation, rely upon it to indicate priorities between highway conditions. It needs to be consistent and comprehensive in assessment of site conditions and to provide details of their characteristics and requirements. Currently, this is far from the case. Only once the scheme generation process provides satisfactory information can the problems of distribution, points allocation, valuation, measurement and the like be resolved adequately. As a priority deficiency in current practice, both in the West Midlands and elsewhere, it is the stage of scheme generation upon which this research needs to concentrate. In particular, it will examine the form it should take in producing a pool of sites where priorities exist for scheme design and evaluation. The specific issue in question will be how to derive this pool, consistent with local needs, responsive and flexible to change and in a manner that is robust and consistent in its assessment, valuation and aggregation of the criteria used to measure highway conditions.

CHAPTER 2 : THE CONTEXT FOR HIGHWAY EVALUATION

Introduction

Deficiencies of Priority Ranking in the West Midlands are typical
of many other highway evaluation methodologies and they detract from
the ability of the technique to indicate priorities. Despite this,
it remains a relatively sophisticated technique for highway project
appraisal and developments designed to overcome residual inadequacies
must be incremental if the advantages that exist are to be safeguarded.
Consequently, efforts were not concentrated upon radical restructuring
of the transport evaluation process as a whole but focussed upon
deficiencies in the current technique - more specifically, upon scheme
generation. Clearly, at the same time, developments needed to have
regard for the wider processes of planning and evaluation and the
research aimed to make improvements in that context. This had rami-
fications for how changes in highway evaluation procedures should be
judged. .

Problems v. Goals

Highway scheme generation can proceed either from the explicit
identification of deficiencies or from the specification of planning/
transport goals. In the latter case, projects would then be designed
to achieve future goals rather than solve existing problems. Goals
based planning has been widely advocated by Faludi (1971) and
supported by Chadwick (1971), who suggested that there was little
difference between the two concepts. In effect -

PROBLEM = GOAL + IMPEDIMENT TO THAT GOAL

Despite clear support for the goals based approach, it was
rejected for a number of reasons. Firstly, current financial and
resource limitations have affected attitudes to planning. No longer

38

are there seemingly limitless resources available to be spent upon achieving planning goals and the situation is now one of improving upon inadequacies in the planned environment. Remedial action is taken when and if it can be afforded. Secondly, in practical terms, it is certainly much easier to define problems in need of attention than goals needing to be achieved. The latter often appear both 'remote and utopian' (Benevolo, 1967). Thirdly, the formal definition of problems, and planning to solve them, makes the distinction between planning ends and means considerably clearer. Fourthly, problem definition helps to improve relationships with the general public, who tend to understand problems much more clearly than abstract goals (Needham, 1971).

The relationship between goals and problems is close - but the relevance of an approach that aims to improve upon deficiencies is clear from the discussion above. This is particularly the case in the financial and political context that surrounds local highway planning. Consequently, in improving Priority Ranking, and particularly the coverage of scheme generation, the only rational means of deriving a set of proposals is through a process of identifying highway problems. Solutions are then designed for those in most need of attention or which provide greatest value for money. The problems based viewpoint has attracted support, including Barrell and Hills (1972), whilst Evans and Holder (1978) conclude that -

> "a danger of not considering problems
> explicitly before working up schemes is
> that none of the schemes may meet the
> most pressing problems, or there may be
> better schemes that never occur to anyone.
> There is also the danger that the choice
> of schemes for approval may pre-empt to a
> greater or lesser extent choice about what
> problems are tackled."

Without scheme generation based upon an initial identification of problems measured in a reliable and consistent way, the process of impact measurement, trade off, design and assessment of solutions becomes a misleading exercise characterised by inconsistancy and irrationality. Specific difficulties arising from inaccurate prediction, uncertainty and the like, are of little relevance until the problems that they measure are defined rigorously. Problem identification is fundamental to the entire evaluation process and the basis upon which alternative solution designs and decisions are made (Hall, 1962). However, problems are not easy to define or measure in these terms. Different groups and individuals have differing views of the priorities attached to highway problems. As administrative and political opinion changes, so will priority issues, and consequently the preference attached to problem types. Clearly, however, if problems are to form the basis of scheme generation, a consistent approach to their definition is needed.

It was outlined in the earlier discussion of Priority Ranking that local objectives derived from policy statements form the basis for the assessment of highway schemes - acting as a consistent framework flexible to changing opinion and conditions, and yet reflecting local needs and aspirations. With this in mind, and the advantages which would emerge from utilising a consistent set of objectives throughout the evaluation process (from problem identification to scheme evaluation), a similar approach was adopted. Problems would be defined in terms of highway objectives, derived from local T.P.P. and Structure Plan policy statements, measured using a set of criteria reflecting failure to achieve those objectives. As political administrations and highway conditions change, so would policies, objectives and criteria, and the subsequent definition of problem priorities. This process is summarised in Figure 2.1.

POLICIES   A   B   C   D

WEIGHTS   × 5   × 4   × 2   × 4

OBJECTIVES 1   2   3   4   5

(Weights
measuring
achievement
of policies)

CRITERIA a b   a   a b   a   a b c

(Weights
measuring
failure
to achieve
objectives)

PROBLEM RANKING SCORE

=

$\leqslant$ (Policy * Objective * Criterion Weight for
a Site)
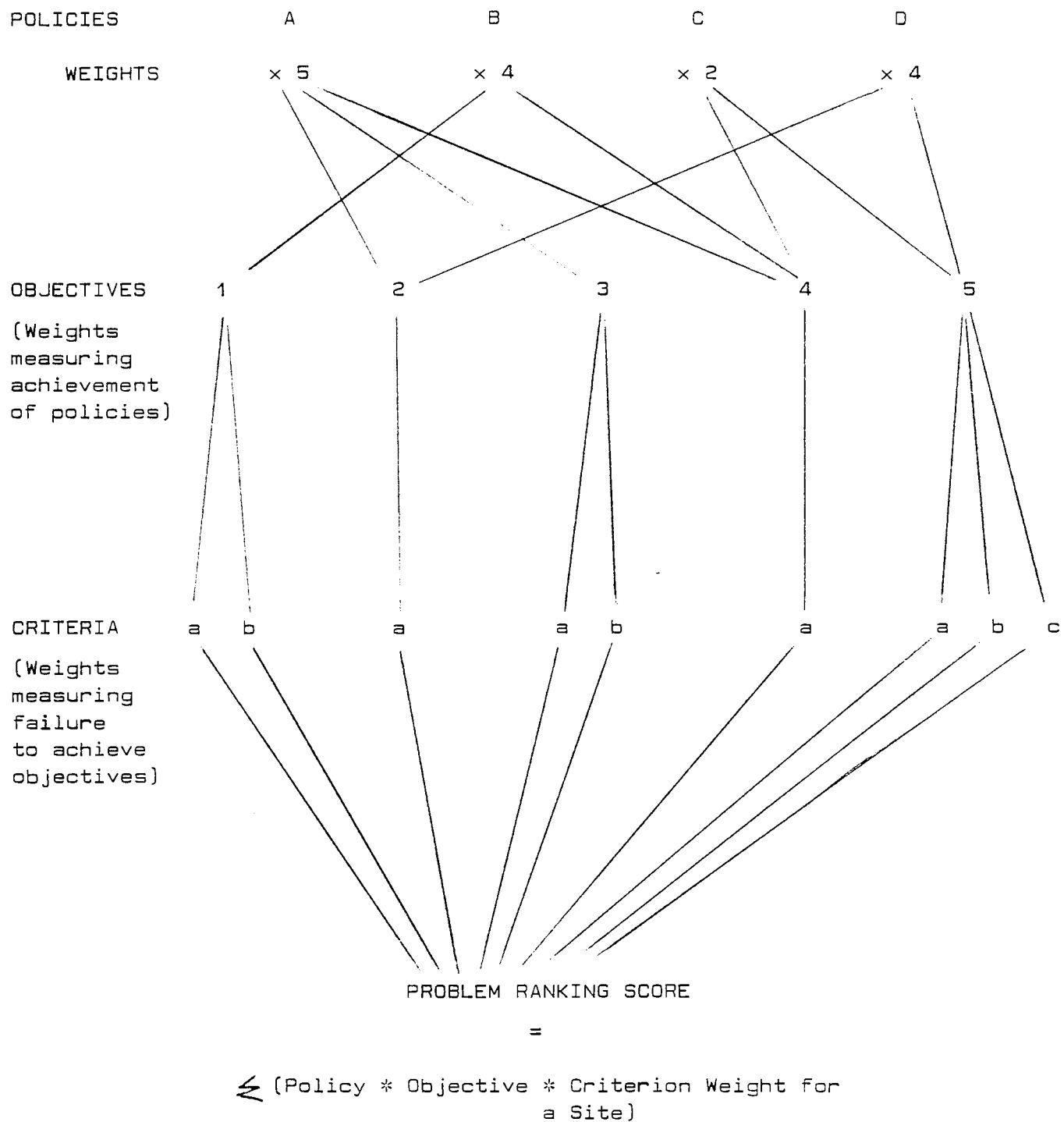
Clearly, difficulties remain in defining policies and objectives in precise terms, in selecting criteria to measure their achievement, and so on. However, despite this, it is clear that it would be advantageous if local objectives formed the basis for problem definition.

A problem based approach to highway scheme generation has been advocated by the Department of Transport through proposals for an 'ideal' planning framework (Department of Transport, 1977, 1978A, 1979), and through a succession of circulars to local authorities. Circular 43/75, 'Transport Supplementary Grant Submissions for 1976/7' emphasised that:

> 'The stated objectives and policies
> outlined in the Council's T.P.P. should
> be seen to arise directly from a critical
> appraisal of their transport problems'.

This was reaffirmed in Circular 125/75, 'Transport Supplementary Grant Submissions for 1977/78', which reflected central government disappointment at the failure of county councils to take a problem based approach:

> 'Previous circulars have referred to the
> need for the stated objectives and policies
> contained in the Council's T.P.P. to be
> seen to arise directly from a critical
> appraisal of their transport problems,
> both current and future. Only in a
> small number of second year submissions
> was it possible to trace the planning pro-
> cess from the identification of problems to
> the specification of a programme of proposals'.

This state of affairs was further discussed in Circulars 1/77 and 3/78 (Department of Transport, 1977, 1978A), and central government views remained firmly in favour of a problem approach in Circular 4/79, 'Transport Policies and Programmes; Submissions for 1980/1. T.S.G. Settlement':

> '.... only rarely are (problems) defined
> in terms which can be measured and

41

monitored and it is correspondingly
difficult to assess the progress which
is being made by Counties in meeting
the needs of their areas'.

Central government argues that the highway scheme selection
process should be served by a formal planning process ensuring
through problem identification, relevance of schemes that are gener-
ated.   Traditional models of this process (typified by Priority
Ranking) are inadequate insofar as evaluation of projects or plans
at a late stage assumes that they are correct and that problem iden-
tification need play no formal part.

Roe (1980) has discussed a rudimentary form the highway plan-
ning process might take if problem identification is to play an
important part.   Figure 2.2 outlines this process.   It is assumed
that there are a common set of concepts underlying this approach as
a whole.   The starting point is the identification of problems, and
schemes are then designed to solve priority problems, and the best
combination of best alternatives is selected.   An important advan-
tage is in terms of the comprehensive analysis of problems it
implies - a full review of conditions must form the basis.   Figure
2.3 indicates the elements which Priority Ranking adequately covers.
It is clear that major developments are needed at the problem iden-
tification stage to ensure a fuller information source upon which to
base utility (or disutility) and trade off estimates.

Two key advantages of concentrating attention upon problem
identification exist.   It contributes directly towards coverage of
Element B (the specification of projects) in Figure 1.16, which is
clearly a fundamental element.   Secondly, it provides a firmer basis
for other elements of this process, in particular the measurement of
utility and in trade off estimation.

FIGURE 2.2 - RUDIMENTARY PLANNING PROCESS

Problem Identification   )
)
)
)
Development of alternative   )
solutions to each   )
problem   )
)
)_____ Planning
)
)   Process
)
)
)
Selection of best   )
alternatives   )
)

Programme   )_____ Selection
Selection   )
)   Process
)
)
Implementation   )
)
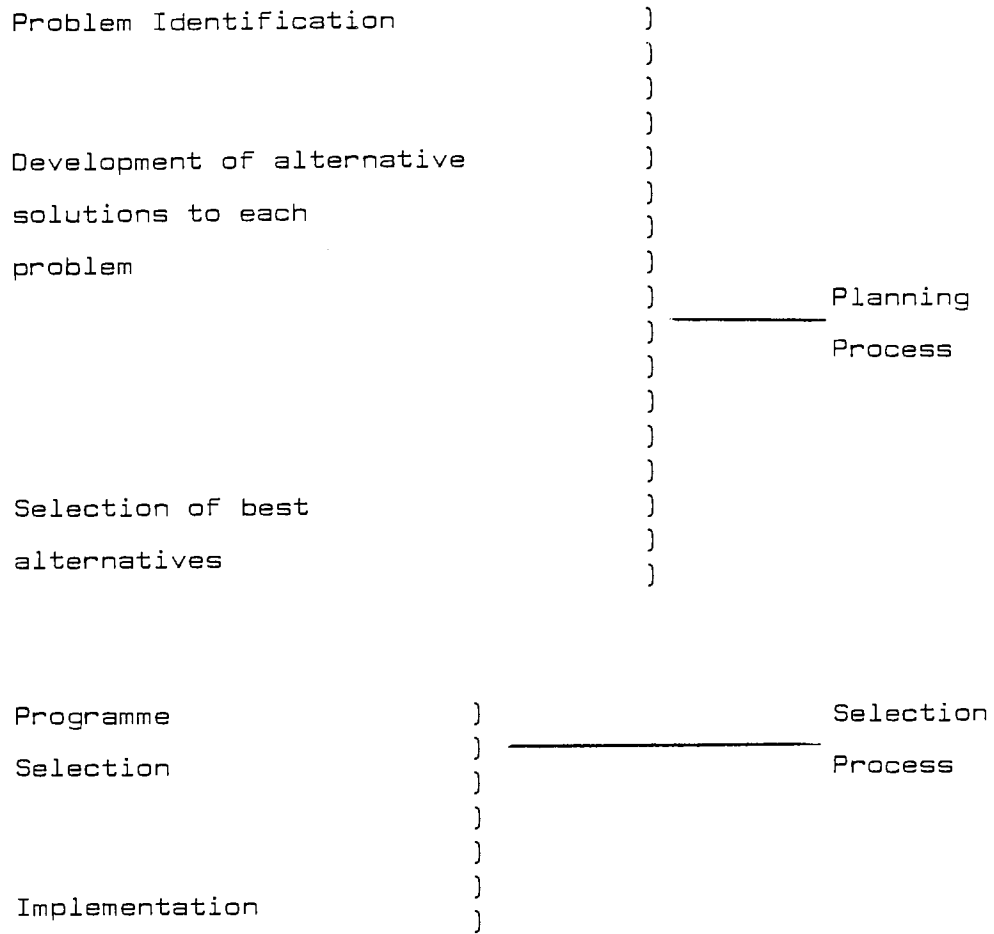
FIGURE 2.3 - PRIORITY RANKING AND THE SCHEME
SELECTION PROCESS - COVERAGE OF THE ELEMENTS

ELEMENT	DEFINITION	COVERAGE
A	Specification of attributes	✓
B	Specification of projects	None
C	Specification of incidence groups	Partial
D	Measurement of impacts	✓
E	Individual utilities on attributes	Partial
F	Trade-offs between attributes for individuals	Partial
G	Trade-offs between groups	Partial
H	Specification of inter-relationships between decision areas	Partial
I	Assessment of uncertainty	None
J	Assessment of robustness	None
K	Integration of alternative techniques	Partial
L	Consolidation for decision-making	✓
M	Presentation for decision-taking	✓

Concentrating research upon highway problem identification

must not be entirely at the expense of developments directed towards

other deficiencies. Despite their secondary role in highway evalua-

tion, these other deficiencies remain notable drawbacks and their

relative importance in undermining the value of the process as a

whole can only increase as more serious issues are resolved.

The Context for Highway Problem Identification

Definition of highway problems requires careful consideration

of the assumptions and choices to be made. Two issues dominate

further development - the contextual constraints within which any

methodology must work, and the issue of the disparate criteria that

characterise highway evaluation, their measurement, valuation and

aggregation.

i) The Contextual Constraints

Clearly, the development of a problem based approach to scheme

generation cannot take place without recognising the context within

which it, and the T.P.P. process as a whole, must operate. Although

significant deficiencies in current approaches have been identified,

potential developments are constrained by a number of factors.

These factors form the contextual framework which controls and

directs the research. Two such factors can be identified. Although

alternative arrangements could have been derived (see, for example,

Johnson, 1978), the following framework provides a reasonable basis

for discussion:

    a) practical context - this includes

            i) resource element - the financial, technical,

                manpower and data resources which are avail-

                able;

            ii) feasibility element - the potential that

exists for development;

iii) political element - the political ramifications.

b)   theoretical context - the theoretical constructs that both facilitate and constrain the generation process.

These elements comprising the contextual structure are shown in Figure 2.4.

a)   The Practical Context

The resource element - is dominated by financial considerations. Three issues can be identified - financial limitations, competing expenditure, and resource availability.

Financial limitations increasingly constrain proposed developments and threaten existing patterns of expenditure.   Highway proposals for the T.P.P. must take account of these constraints and problem identification needs to recognise resource limitations imposed by central and local authorities.   Submission of programmes of proposals exceeding available financial support may lead to their rejection in response to the failure of the local authority to produce a 'rational' T.P.P. submission.

A closely allied contextual element arises from competing demands for expenditure.   Other departments within the authority have plans for expenditure as well as the highways department.   Allocation of central government grant between projects is the responsibility of the local authority and highways must expect to face competition from planning, development and other sectors (including other transport sectors), particularly since the changes in funding and the increased flexibility in local resource allocation that has occurred since 1980.

Scheme generation must recognise that it has to work within a

44 (i)

FIGURE 2.4 - ELEMENTS COMPRISING THE

CONTEXTUAL STRUCTURE
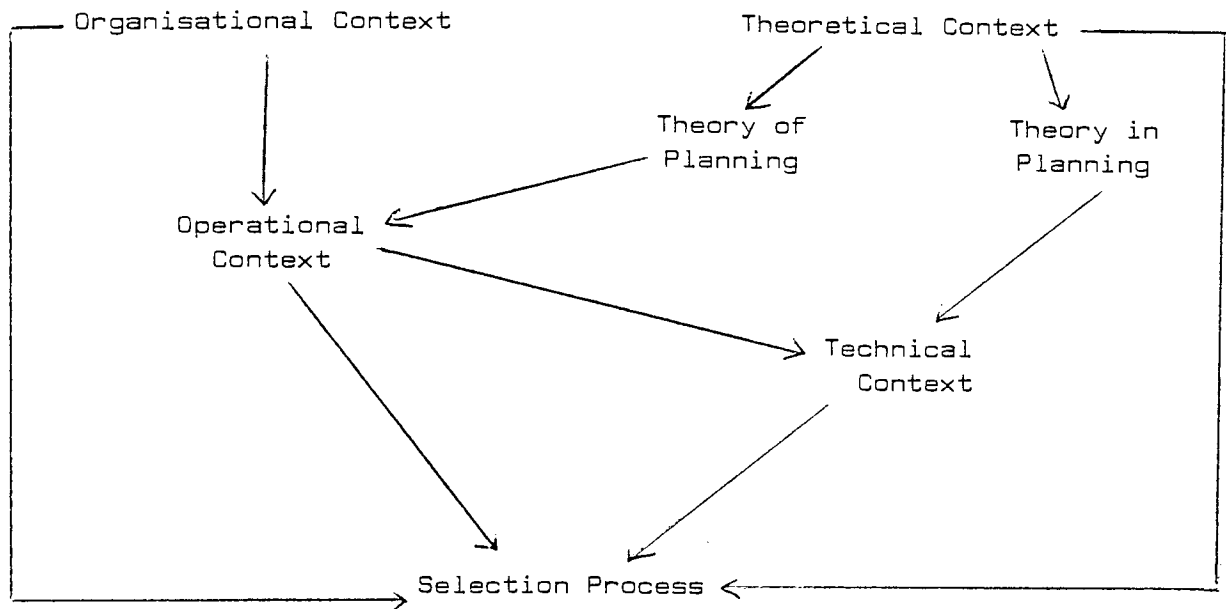
financially competitive situation. At the same time, it must have regard for the requirements of those who allocate financial resources and ensure that they appreciate the problems, needs and priorities that exist.

Resource constraints are effective in other ways. Manpower constraints can be highly significant and with recent trends in staffing are likely to increase. Problem identification must recognise the availability of manpower, its skills, organisation and the likelihood of change. Specific constraints imposed by West Midlands County Council were an important factor in the selection and development of a methodology.

Computing and technical constraints also exist. Any technique must be readily translated into computing terms - another specific requirement of the County Council - so that results can be produced quickly and accurately. Finally, data constraints. In the West Midlands, the data requirements of scheme generation must not be so great that additional collection is necessary. Nor must it be so arranged that complex manipulation imposes an unbearable demand upon financial, administrative and manpower resources. Reliability and accuracy of data prediction must be noted as well; ideally, the proposed technique should not be based upon single year predictions of highway condition when future uncertainty clearly exists.

The feasibility element - includes a wide range of organisational and technical factors impinging upon scheme generation. It is closely allied to the resource and political elements in that both these issues can make any specification of problems unacceptable. However, the feasibility element refers only to factors which lie outside political or resource areas.

An important part of the feasibility element is formed by the
influence of outside organisations upon the T.P.P. process.   The
most important of these is the Department of Transport to whom the
request for T.S.G. is made.   Although responsibility for producing
the T.P.P. rests with the local authority, central government retains
a major influence exercised through its allocation of T.S.G.. Whilst
it argues that it does not intervene at a detailed level, it is clear
that the process used to identify priorities must be acceptable to it.
At the same time, the influence of central government is apparent
from the characteristics of proposals put forward by many County
Councils.   Developments in South Yorkshire remain an exception (South
Yorkshire, 1980).   There is also a marked tendency for many T.P.P.
documents to contain highway policies similar in outlook regardless
of local political objectives (Mackie and Garton, 1979).

A further set of relationships with outside organisations stems
from the influence of other local authorities.   Neighbouring County
Councils may share highway problems which could be solved by co-
ordinated schemes.   District Councils, in whose areas proposals lie,
must be amenable to those proposals if they are to succeed.   Scheme
generation needs to accommodate these potentially conflicting demands.
An allied issue is that the framework of evaluation methods used by
local authorities needs to be compatible if a rational allocation of
T.S.G. is to result.   Confusion apparent in central government advice
has not helped.   Views of other organisations need to be considered
- P.T.E., B.R., pressure groups, etc.   Although their agreement is
not essential, it is highly preferable.

Another important feasibility issue stems from temporal con-
straints which impinge upon the T.P.P. process.   In the West Midlands,
they include:

(i)   annual budgetting;

(ii)   3-year county strategy;

(iii)   5-year T.P.P.;

(iv)   5 - 15 year Target Design Programme;

(v)   15-year Structure Plan and T.P.P. process.

Of these, budgetting and the Structure Plan are most relevant
to the T.P.P. and, therefore, scheme generation.   In the short term,
the T.P.P. is intimately allied to the budgetary process and it is
essential that scheme generation produces options within that frame-
work.   In the longer term, the Structure Plan forms the context for
the T.P.P. and central government envisages a common process for the
two (Department of the Environment, 1973A).   The other temporal con-
siderations are less significant but need to be noted.

A third constraint derives from the internal structure of West
Midlands County Council.   The output from problem identification must
be acceptable to a number of departments and conflict should be
avoided whenever possible.   Thus common and conflicting problems
need to be identified so that investment proposals can be based upon
a coordinated approach.   Meanwhile, the organisational and adminis-
trative arrangements of each department must be recognised.   The
division of functions between Treasurers, Transport and Planning
departments, corresponds with the three main temporal horizons of the
T.P.P., and coordination between them is especially important.

Another feasibility problem stems from the need to specify site
conditions and solutions for pre-set locations.   To be manageable,
the highway network needs to be sub-divided into small sections and
conditions measured for each.   These conditions are then associated
with those specific sites and solutions designed for each.   However,

this has the effect of constraining problem location, delimiting their effects. Definition of site boundaries is a difficult decision with widespread ramifications for problem identification. The form and availability of data is fundamental in determining the choice of sites - an issue we return to later. An allied technical issue surrounds availability of data, its detail and characteristics. It is no use developing a method of problem identification that requires data which is generally unavailable. Resource constraints imposed by W.M.C.C. preclude further collection.

Further constraints stem from problem definition. Problems tend to be varied in characteristics and impact, and consequently are measured in different units, upon different scales, with differing effects upon individuals in differing circumstances. It is common practice amongst local authorities to assess highway schemes using fixed standards - which implicitly equate highway conditions lying at these standards (raising questions of value) and assumes conditions worse than standards are problems (with increasing severity as the divergence increases); those above are not. Widely accepted physical standards exist for common highway problem criteria, expressed in terms of level of service (traffic delay), noise levels for compensation purposes, air pollution, health implications, etc., and it has proved possible to derive a wide range of standards which reflect minimum acceptable levels. Occasionally, if conditions change radically, standards may be altered, but in general this is uncommon.

Techniques of this type have been applied by New York State (NYSDOT, 1979) and advocated for West Yorkshire following the West Yorkshire Transportation Study (W.Y.T.Consult, 1976). Martin (1977) and Headicar (1979) outlined the advantages that an approach of this

48

type brings. However, they centre upon the assumption that a poorly structured evaluation technique is both inefficient and unjust and that the establishment of clearer objectives, measured against 'acceptable' standards assists problem definition and resource allocation.

However, it remains questionable whether there is always a need for 'rigid', acceptable standards, against which highway conditions can be compared. Alternatively, flexible standards could be used, whereby average conditions would be used as the benchmark against which highway conditions could be compared.

As the average conditions change, so would standards, allowing continuous redefinition of highway problems in relative terms. This does not avoid the difficulties of aggregating disparate criteria, but it does overcome the imposition of a single set of values upon highway conditions. It has other advantages:

(i) Standards derived from the West Yorkshire Transportation Study used a wide range of measurement techniques and this would be the case elsewhere (including the West Midlands). Each makes differing assumptions about the values they reflect and use different types of measurement criteria. For example, traffic noise standards might be based upon annoyance caused through interruption of speech or sleep; air pollution standards upon health; road safety and traffic delay upon monetary costs. These differing criteria make comparisons between fixed standards and the assumptions of equal value that this implies, questionable.

(ii) Allocation of T.S.G. to local authorities is calculated using a pre-specified, set formula (see Appendix 1). Central government sets aside an amount for T.S.G. to be distributed each

year regardless of absolute highway conditions, and sufficient problem sites are found to exhaust it. Within the local authority, once the allocation of T.S.G. has been received, this money is used regardless of whether acceptable standards have been reached. Consequently, problem identification needs to be able to allocate priorities between sites rather than indicate sites exhibiting conditions specifically above or below a series of pre-set standards. A technique is needed which indicates relative needs, provided by a method that adjusts to changing conditions. Standards are then redefined constantly, so that central funds continue to be attracted (Hall, 1962).

(iii) Application of relative standards has been encouraged by advice from central government emanating through the Leitch Committee (ACTRA, 1977) and reaffirmed in the 1978 'Policy for Roads' White Paper (Department of Transport, 1978). Meanwhile, the Department's 'Interim Memorandum on National Traffic Forecasts' (1978) took explicit account of uncertainty in respect of design flows, by identifying ranges of traffic flow and suggesting that standards should be adapted to accommodate them. Davies and Worsley (1979) reaffirmed central government opposition to fixed standards and the need to be wary of applying rigid planning assumptions.

(iv) It is desirable to introduce political preferences at an early stage in highway evaluation. Problems should be defined and weighted to reflect these priorities. It is spurious to define standards (i.e. acceptable conditions) at an early stage, and then to introduce a weighting system which affords greater priority to the achievement of some standards against others. The definition of a series of set standards implies equating the values which are attached to them.

Another significant issue surrounds the choice of measurement

level in the assessment of physical problem conditions.   Two altern-

ative approaches can be taken in measuring highway problem conditions.

Either direct measurement of physical conditions (traffic delay,

noise level, etc.) and their aggregation and comparison, or measure-

ment of those conditions upon individuals and the aggregation and

comparison of those impacts.   The former is simpler (although not

easy), data on physical conditions is readily available and resource

demands are less.   It still necessitates a means of aggregating

disparate variables, but it obviates the need to measure individual

valuation of problem conditions.   The second approach relies upon a

method with the ability to accommodate individual response and

facilitate aggregation in a meaningful way.   Although this is pre-

ferable, it remains riddled with difficulties additional to those of

physical measurement (e.g. visual intrusion, accessibility, etc.),

and aggregation.   Problems associated with inter-personal comparison

of values attached to a wide variety of highway criteria, assumptions

in their aggregation, and extensive problems of obtaining sufficient

reliable data are compounded by the effect of varied circumstances

upon individual response and difficulties of deriving stable

relationships between criteria and responses (Hodgins, 1976).   These

issues will be considered further in the assessment of the evaluation

options available.   An important consideration will be the character-

istics of the area in question - the West Midlands.   If highway

conditions and land use vary considerably, then the activities,

numbers and responses of individuals to highway conditions are also

likely to vary.   Direct physical assessment would not be able to

accommodate this.   However, the West Midlands is not characterised

by notably wide discrepancies in urban conditions, justifying, at

least partially, the simpler approach.   Coupled with advantages of

simpler data needs and greater reliability, and the inadequacies of
stimulus-response methods, it is considerably more appealing.

A final issue in the feasibility element is that the definition
of priorities must recognise the interaction of highway problems and
accommodate their inter-related effects.   Thus, for example, the
effect of highway congestion and its relief upon other highway links
should be included in the assessment.

The Political Element

Four political implications for problem identification exist.
Firstly, both the T.P.P. and problem identification processes must
be acceptable to local decision-makers, reflecting their political
aspirations.   Secondly, the aim should be to inform members of the
issues at stake and to obtain inputs from them through the T.P.P.
process.   This has its main effect in problem identification through
the introduction and selection of objective weights, and the choice
of highway criteria, each of which aims to reflect local priorities.
Thirdly, the absence of a statutory public participation process must
be noted, although the Structure Plan process has allowed some
limited provision for the expression of public opinion about trans-
port policies and proposals.   It is important that decision-makers
are made aware of the aspirations and opinions of the electorate.
Finally, the demands of the national electorate have a bearing upon
the T.P.P. process through the influence of central government.
Proposals conflicting with national considerations can have ramific-
ations for T.P.P. approval.

Without clear identification of local political views and their
incorporation into highway scheme generation, the T.P.P. process will
fail to reflect demands of the electorate and may also fail to gain
central and local acceptance.   It would also fail in its major

purpose of identifying highway needs in local terms.   Scheme gener-
ation needs to reflect political aspirations, to clarify public

opinion and to inform decision-makers of the issues at stake.

(b)   The Theoretical Context

The theoretical context provides a framework for the develop-
ment of scheme generation.   Too often, in the past, its requirements

have been overlooked.

The view of the Department of Transport (1977) is that the

transport evaluation process should take the form of a 'rational and

comprehensive model' (Edison, 1975).   However, in reality this model

has to conform to the lack of rationality displayed by the transport

budgetary process, and developments of T.P.P. scheme generation must

recognise the conflict that exists between central government

ambitions and local authority practice.

However, of more practical significance are issues which stem

from the definition, measurement and valuation of criteria used to

assess problem conditions, and the choice of social criteria that

must be made - issues discussed by J.U.R.U.E. (1976).   Within

definition, there is a need to identify relevant attributes and

groups, since the effect of highway problems varies between them.

Difficulties emerge in the definition of policies, which for traditional

and political reasons are vaguely expressed.   No general theory exists

to guide us from these vague statements to operationally measurable

attributes, and it is here that the value of redefining policies into

objectives and measurable criteria is apparent.   Further difficulties

stem from the need to frame attributes and conditions in a particular

way to meet theoretical demands of valuation - the most frequently

encountered being the need for independence.

53

Valuation has two components - measurement and valuation itself. It is possible that direct measurement of problem impacts is feasible, and thus is highly desirable if it can be achieved, but in practice it has been normal for measurement in physical terms to precede valuation, the latter achieved through an intermediate common metric of points or money to facilitate comparison and aggregation. This is a response to the difficulties in measuring highway impacts both in scalar terms (stemming from the variety of scales used) and in physical assessment (visual intrusion, accessibility, etc.). It is difficult to achieve meaningful aggregation of impacts unless the problems of valuation are resolved. In general, the scheme selection process has avoided this problem and trusted itself to techniques which either ignore fundamental dilemmas that exist, or cope with them inadequately. Problem identification cannot afford to do this.

The selection of social choice criteria is widely recognised as important (Thompson, 1965; Wilson et al, 1969; Hutchinson, 1970), providing the distributional basis for problem identification, and yet the choice of any one is essentially an ethical and political judgement. Distributional considerations are of relevance because the highway evaluation process is able to redistribute costs and benefits of investment amongst society and geographical areas. Harvey (1973) suggests that this occurs because highway problems alter accessibility levels to employment, shops, etc., and redistribute or create additional external effects unevenly spread. Although there are dissenters to this view (e.g. Harrison and Holterman [1973]), considerable evidence exists suggesting that highway investment (or its absence) has marked beneficial and detrimental economic, social and environmental effects. Syrnick and Harvey (1977) and Dalvi and Nash (1977) have discussed this role, and Hoachlander (1979) describes the redistributive effects of the B.A.R.T. public transport scheme in

54

California, stressing its significance and the fact that it remained unassessed.

The 'Consultation Document upon Transport Policy' (Department of the Environment, 1976), also showed concern for the distributional impact of highway investment, whilst Dalvi and Nash (1977) gave two reasons for the importance of examining its implications:

(i)   to see to what extent they lead to a redistribution of real income;

(ii) to assess implications of adopting a social welfare function which attaches weights to highway objectives achieving certain redistributive effects.

Dalvi (1973) stressed that there was a need to incorporate redistributive effects into the evaluation framework so that policy-makers could choose between options in terms of equity and efficiency. Barrell and Hills (1972) supported this, citing Mishan (1971):

> "(satisfying an economic criterion, whereby economic benefits are greater than economic costs) is quite consistent with an economic arrangement which makes the rich richer and the poor poorer ...... with transparent inequity and where direct and substantial injury is (often) inflicted on others."

Despite widespread support for incorporating distributional effects, little tangible has been achieved. Barrell and Hills describe how current highway evaluation (characterised by COBA) utilises Pigou's (1932) modification of the pareto principle (Little, 1957) such that, providing the gainers can more than compensate the losers, then society is better off as a result of the investment. This assumes a process of redistribution which is clearly unrealistic. Syrnick and Harvey (1977) suggest that:

> "the presumption is made that it is more
> advantageous to maximise total benefits
> regardless of their distribution than to
> strive for a (highway) network with a
> desirable allocation of assets and
> liabilities ..... A more reasonable
> approach would be to evaluate alternative
> systems, not only from an aggregate stand-
> point, but also from the standpoint of the
> distribution of the benefits and costs
> amongst various social, economic and geo-
> graphical groups."

Two reasons are cited why traditional evaluation continues to ignore distributional effects.

(i)   The Hicks-Kaldor compensation test is an adequate assessment of problem/scheme value as it will result in an increase in overall community welfare;

(ii)   The practical difficulties of obtaining disaggregate data and assessing their distributive effect.

Weisbrod (1968) and Dalvi (1973) discuss this further, including the difficulties of estimating a social welfare function capable of evaluating alternative income distributions.   If such a function could be obtained, it is easy to assess such effects.   However, these difficulties are so great that attention has been focussed upon allocative efficiency instead.   However appealing this may be, political decisions involving public expenditure have equity con-sequences which ought not to be ignored.   Mishan (1960) provides a full account.   In practical terms, a variety of criteria might be used to judge distributional merits.   Mead (1973), Runciman (1966) and Harvey (1973), provide alternative views.   However, it is not the intention here to discuss the merits of each, merely to point out that alternatives exist and that explicit use of one set is a necessary choice of problem identification.   It thus forms an important element of the theoretical context, requiring careful attention.

These contexts focus attention upon constraints which face development of problem identification in the West Midlands. Many are pertinent elsewhere. They serve two functions:

(i)   They describe the feasible solution space that exists and thus indicate possible progress;

(ii) they indicate the framework for new developments.

In attempting to improve upon inadequacies of current approaches to highway evaluation, the contexts make clear the progress that is possible. It is clear from this discussion that optimal solutions may have to be sacrificed to meet unavoidable practical considerations. However, this will not detract from the need to achieve the maximum possible within this practical framework.

(ii) Disparate Variables

Grigg (1978, 1981) has discussed the second major issue that any problem identification technique must recognise - the existence of disparate variables. In this case, they comprise the varied criteria that characterise highway conditions. These criteria may include accident rates, noise levels, traffic delay, etc., and a variety of scale types will be involved (e.g. ratio, ordinal, nominal, etc.) and differing units (number/km, dBA, time, cost, etc.), each resisting meaningful aggregation and comparison. Difficulties presented by data of this type were touched upon in the discussion of the theoretical context, and problem identification could avoid them by proceeding without aggregation and comparing criteria in pairwise sequence. However, apart from the difficulties of trading off dBA's with time costs, monetary values with CO levels, etc., this is only a practical option where there are a limited number of variables and the decision-making process is simple. Neither, normally, is the

case. The number and complexity of highway problems and policies, the intricacies of political decision-making and the need to display clear and unambiguous proof of the relative severity of conditions makes aggregation highly desirable.

The difficulties presented by disparate criteria and the need to bring them together into a single indicator of highway condition are far from new. Rational decisions are difficult without aggregation, and yet meaningless if that aggregation fails to take account of data characteristics and the restrictions that this implies. It is an issue that has attracted scant attention despite fundamental significance. Problem identification must recognise the constraints it implies and accommodate them within its framework.

Harvey (1969) discusses problems of handling differently scaled units, suggesting that measurement in general, and scaling in particular, has a number of definitions, citing Stevens (1959), Ackoff (1962) and Nunally (1967) as examples. However, each has the common idea that rules exist which must be followed. These rules manifest themselves in the classification of scaling methods (nominal, ordinal, etc.), and the uses to which data allotted to each can be put (Figure 2.5). This has obvious ramifications for highway problem identification.

Ideally, all highway criteria would be measured upon a single ratio scale facilitating full mathematical manipulation and comparison. The introduction of other scalar values complicates this process and makes aggregation difficult. Traditional solutions, using a single intermediate common metric (and thus a single scale), have failed to overcome a fundamental problem - that of allocating values to the metric. These deficiencies have been compounded by the apparently

FIGURE 2.5 - EXAMPLES OF STATISTICAL MEASURES APPROPRIATE TO THE VARIOUS

CLASSES OF SCALE (after Harvey, 1969)

Scale	Basic Empirical Operations	Measure of central tendency	Index of dispersion	Association or correlation	Significance tests	Typical examples
NOMINAL	Determination of equality	Mode		Contingency correlation	Chi square	"Numbering of football players" Nationality
ORDINAL	Determination of greater or less	Median	Percentiles e.g.quartile deviation	Rank-order cor-relation (type 0)	Sign test Run test	Hardness of minerals Pleasantness of landscapes
INTERVAL	Determination of equality of intervals or differences	Arithmetic mean	Standard deviation Average deviation	Product-moment correlation	t Test F Test	Temperature (Fahrenheit or Centigrade) Calendar dates
RATIO	Determination of equality of ratios	Geometric mean Harmonic mean	Coefficient of variation			Length, weight, etc.

satisfactory solutions presented by cash benefit analysis and points based approaches, but which are far less adequate in the assumptions they make.

The requirements of criteria scales have been lessened by the development of a number of multi-dimensional and multi-variate techniques capable of handling multi-scaled problems.   Torgersen (1963) and Nijkamp (1980), amongst many others, provide reviews.   Both have clear potential for handling complex issues of this sort, overcoming many inadequacies apparent in current methods.   They consequently form the basis of one of the techniques acting as candidates for the research problem.

However, the difficulties of disparate criteria do not end with scalar problems.   An issue of equal significance surrounds how varied units characterising the criteria can be brought together in a meaningful way, for even if each were ratio scaled, each would be in differing units.   Kaplan (1964) discusses the relationships of measurement, scientific enquiry and the problems of combining such units.   His discussion is specifically in terms of the behavioural sciences, but it remains pertinent here.   He stresses that one of the basic characteristics of human behaviour is that it is purposive, and purposes and their corresponding goals and values are far from simple or uni-dimensional, as measurement theory seems to require.   This is also true of the interpretation of physical conditions by individuals, and issues such as highway evaluation become increasingly complex as values and objectives are incorporated and accounted for.   These values and objectives, and their measurement, vary between individuals, times, places and activities, but more significantly, they are heavily interwoven so that many differing reactions are involved simultaneously. The issue as a whole cannot be broken down into its constituent parts,

each measured and then reassembled, but must be assessed as a single composite bundle.

Aggregation of highway criteria to produce this bundle is no easy task. Certain criteria are difficult to measure in themselves (e.g. visual intrusion, severance) and most are incomensurable with one another. In terms of deriving a single unit of measurement, Kaplan suggests that a basis for comparison may exist and indices such as points or money can be useful without implying that their own value is inter-changeable with the one being measured (although this seems dubious). Meanwhile, measurement is not necessarily limited to scalars (i.e. magnitudes subject to a simple ordering) - vectors and multi-dimensionally scaled units may also be used and the value of the latter has been demonstrated. Alternatively, a configurational method could be used whereby broad scenarios are presented and individual reaction to them is measured in common units (e.g. of annoyance).

Whichever approach is taken, an effective solution must be found if highway evaluation is to develop in meaningful terms. Too little attention has been paid to this problem and recourse made to well tried but inadequate methods.

Requirements of Problem Identification

Discussion of the issues facing development of a meaningful and practical highway evaluation process helps to focus attention upon the requirements that problem identification must recognise, and which form a series of constraints in themselves.

(i) It must indicate highway problem condition, priorities between problem types and sites, and facilitate comparison between them. In so doing, it must indicate clear priorities between those sites lying on the margin. Sites exhibiting few or severe problems are easily

recognised, but it is in the confused middle ground where problems
are ill-defined and priorities less clear, that formal problem iden-
tification will play its most significant role. This is given
additional emphasis by the requirements of the current resource alloc-
ation process. Larger, more obvious problems will normally attract
the bulk of the money available; small problems attract little, for
potential benefits are far less. Remaining resources go to schemes
at marginal problem sites. There is clear need to develop a problem
identification technique that can allocate priorities in these circum-
stances, if resources are to be used most effectively.

(ii) It is important that developments take account of contextual
constraints. Serious violation of these constraints will make
developments unworkable in practice, weakening the impact of their
results.

(iii) Problems of handling disparate variables have serious ramific-
ations. It is important that proposed developments provide a means
of overcoming these problems.

(iv) Aggregation of disparate criteria must not be at the expense
of the detail of highway conditions. Both overall and individual
problem detail is needed to provide a means of comparison and infor-
mation for solution design.

(v)   Problems must be seen to derive from policies, and priorities
between them must be reflected in problem definition. Values
attached to problem indicators must be explicit and reflect local
preferences.

(vi) The technique must be sensitive and flexible enough to accom-
modate changes in priorities and problems. Fluctuations in political
administration will dictate such changes and require a responsive

61

technique.

(vii) There should be a means of relating problem condition to the value of optimal solutions to those problems.

(viii) Problem identification must be geographically comprehensive and ensure coverage of all potential problem types.

(ix) It should provide a means of project generation which stems from a review of current and future problems, avoiding intuitive and subjective project selection methods that characterise current highway evaluation. The need for a formal stage of problem identification has been widely recognised, and Lichfield et al (1975), Houghton (1974), Needham (1971) and Kitchen (1972) have each advocated it as a basis for scheme generation. Kitchen emphasised the lack of resources allotted to project generation when discussing options available for siting the 3rd London Airport. Problem identification has a fundamental role to play in providing the basis for effective scheme generation.

The development of an evaluation methodology may violate some of these constraints and leave some requirements unresolved and priorities between constraints and requirements will have to be considered. It is clear that practical aspects of highway evaluation sometimes will take precedence over the theoretical constructs even though this may detract from the consistency and reliability of problem identification. If this is the case, then it must be made explicit, and the consequences made clear.

The Techniques for Problem Identification

A variety of techniques applied to a number of evaluation contexts have potential for highway problem identification. The discussion that follows concentrates upon those with greatest application.

Three popular evaluation methodologies have been excluded at an early

stage - matrix techniques, for their structure is difficult to apply

to comprehensive problem identification, and ranking and display

methodologies - because they provide inadequately detailed information.

However, four groups of techniques remain:

(a)   cost utility techniques;

(b)   points rating techniques;

(c)   stimulus-response techniques;

(d)   multiple-criteria techniques.

(a)   Cost Utility Techniques

This group includes the most frequently used techniques for

highway appraisal.   The majority are easily adapted to the identifi-

cation of highway problems.   Popularity has stemmed from ease of

application, apparent simplicity and the appeal of results produced

in monetary terms.   Tradition has also played a part.   A consequence

of this is that their application is often unquestioned, ignoring

deficiencies that stem from a number of unsubstantiated assumptions.

Cost benefit analysis is the most familiar technique, typifying

the cost utility approach as a whole.   Social cost-benefit analysis

is the version most commonly applied (J.U.R.U.E., 1976).   It is pro-

posed as a comprehensive evaluation methodology aiming to cope with

issues of valuation, measurement and aggregation of disparate criteria

by calculating a single index of the social welfare implications of

proposed actions.   Ratings forming this index are measured by

reference to market information upon willingness to pay (or receive

compensation) for costs and benefits incurred.   Discounting allows

for costs and benefits occurring in different years.   Some impacts

have obvious monetary transactions because they are regularly

exchanged in markets.   Others do not, and indirect evidence must be

used - shadow prices - to derive an indication of monetary value. Prest and Turvey (1965), Layard (1974) and Mishan (1974), amongst many others, provide an extensive discussion of its application.

Clearly, social cost benefit analysis could be used to assess highway problems. Highway conditions (for example accident rates, noise levels, etc.), could be valued using market information and the total costs of problems assessed by aggregating these monetary values. Sites could then be compared using total costs. There are a number of obvious advantages. In resource terms costs could be directly compared with financial limits and with competing expenditure. Manpower and technical facilities are already widely available for cost benefit approaches. In feasibility terms, other organisations with input to the evaluation process are familiar with cost-benefit analysis and would accept the method. The Department of Transport and other local authorities already use it extensively. Temporally, it would create few difficulties, since it is familiar to operate and involves limited complex calculation - neither the annual budgetary nor T.P.P. process would be adversely affected. Consequently, it would not cause problems for the internal structure of W.M.C.C. It is less satisfactory in handling the inter-relationships of problems and solutions. In political terms, it is particularly attractive, widely acceptable to decision-makers, providing detail of the issues at stake and matching the objectives of central government.

However, in other terms it is less satisfactory. Its basis in welfare economics requires a number of conditions to be met if the results are to be meaningful. Assumptions of perfect market competition and the ability to sum and aggregate individual preferences are unrealistic (Hutchinson, 1970; Self, 1975). The selection of a discount rate is central to the method, but the range in practice

has been large (frequently between 4 and 12%), whilst sensitivity to small changes (1 - 3%) is known to be highly significant (Starkie, 1976; Dalvi and Martin, 1976). However, it is in theoretical terms that it exhibits most problems. Distributional issues, including definition of groups and attributes, are largely ignored by widespread application of the Hicks-Kaldor criterion (whereby gainers supposedly compensate losers), tending to give preference to projects (and therefore problem sites) with long-term benefits at the expense of short-term losses. This tends to concentrate costs upon those least able to afford them, regardless of equitable intentions. Mishan (1974) amongst others has questioned the 'willingness to pay' criterion and suggested that individual values expressed in this way mean little due to a combination of ignorance, the inadequacies of the market place and difficulties in appreciating extreme values. Physical assessment of criteria (e.g. visual intrusion, severance, etc.) present enormous problems both in measurement and valuation, typified by the difficulties experienced by the Third London Airport Commission (Commission of Third London Airport, 1971).

Cost benefit analysis fails to provide an acceptable method of handling problems associated with disparate criteria. Valuation through willingness to pay, although theoretically sound, in practice is highly dubious and often proves impossible. Aggregation of these individual values attached to conditions is spurious, since they are liable to vary with conditions and between individuals. Meanwhile, the theoretical basis of cost-benefit analysis, in welfare economics, has been questioned by Cooper (1973) and O'Leary (1979), raising doubts about the validity and relevance of the approach as a whole. Despite these inadequacies, it remains popular.

Cost benefit analysis satisfies a number of the requirements of

problem identification - it would indicate problem conditions (albeit in questionable terms) facilitating comparison and priority allocation. It provides a mechanism for handling disparate variables, allowing retention of problem detail and their aggregation. However, it makes little progress towards achieving problem-solution linkage and site specification, and exhibits severe theoretical deficiencies.

Financial techniques represent the other extreme to social cost benefit analysis within the cost utility group of methods. They consider only financial costs and returns which flow from the existence of (highway) conditions. Externalities are ignored (unlike social cost-benefit analysis) and existing prices and financial performance rules are the tests of acceptability.

Financial techniques were once popular for highway scheme appraisal. Until 1972, and the introduction of COBA (Department of the Environment, 1972), calculation of the value of proposals was carried out using a First Year Rate of Return.

$$ERR = \frac{\text{1st year benefits}}{\text{capital costs}} \%$$

Benefits were restricted to delay, road safety, and operating gains. Each proposal was evaluated using data revalued to a specific year (1974) to ensure comparability.

COBA introduced the concept of discounting through discounted cash flow techniques. Moss (1979) describes the approach producing a Net Present Value:

$$NPV = Bo - Co + \frac{(B1 - C1)}{(1 + i)} + \frac{(B2 - C2)}{(1 + i)_2} + \dots \frac{(Bn - Cn)}{(1 + i)_n}$$

where NPV = net present value

Co = Costs year 0

Bo = benefits year 0

i = discount rate

Cash flows are defined as the incremental cash receipts and expenditures solely attributable to the commencement of the project.

Clearly, financial techniques could be applied to highway problem identification and would represent an approach which was simpler, but closely allied to social cost-benefit analysis. Conditions would be valued in monetary terms, derived from market information upon willingness to pay and an aggregated valuation obtained by summation. However, financial techniques possess all the deficiencies of cost-benefit analysis as well as the additional failure to accommodate all relevant issues (and, thus, problem types). The development of social cost-benefit analysis reflected widespread recognition of this. Financial techniques also lack popularity amongst central and local government. Examples of their application to highway appraisal come from the London Transportation Survey (1962) and Bettison (1979) in Australia - however, neither provides convincing evidence of merit. Moss (1979) suggests that their only contribution is in providing a financial estimate of costs between mutually exclusive highway conditions where intangible and external effects are inconsequential.

Despite popularity and tradition, cost utility techniques provide no answer to the needs of highway problem identification. They violate many constraints and meet few requirements, particularly failing to respond to the theoretical demands that exist. Specific applications - including threshold theory (Kozlowski [1968, 1970], Kozlowski and Hughes [1967] [1971], Simpson [1977]), cost effectiveness and cost minimisation (Teitz [1968], English [1968], Lichfield [1970], Treddenick [1979]) contribute little to the debate, since basic assumptions of valuation and measurement are the same.

67

(b)   Points-based Techniques

Points-based techniques are similar to those of cost-utility in
that all costs and benefits are translated into a common metric (in
this case points), facilitating aggregation and comparison.   Many
deficiencies are shared since, clearly, this involves assumptions of
valuation and aggregation which are difficult to uphold.   Points
methods have become increasingly popular in recent years in local
authority highway appraisal (typified by developments in Greater
London, Greater Manchester and West Yorkshire) because they imply less
subjective valuation;   apparently accommodate intangibles;   and suggest
'emotive neutrality' (Bovaird, 1980).   Although this facilitates
decision-making, it disguises the deficiencies in valuation, measure-
ment and aggregation that exist.   Practical application suggests that
many other deficiencies - particularly the failure to include a dis-
counting procedure, also remain.   In resource terms, they provide
little information about the limitations that exist, although they
allow direct comparison of competing expenditure.   Manpower, skills
and technical resource needs present no problems.

In feasibility terms, they are acceptable to other counties,
the O.T.P. and internally - although some measure of financial costs
is also often needed.   In political terms they are acceptable to
decision-makers, provide information about the issues at stake, and
are flexible to changing policies and preferences through the selec-
tion of criteria and use of weights.

However, the major deficiencies are theoretical, for points-
rating methods lack any sound conceptual basis (Hutchinson, 1970).
The allocation of points to highway conditions is achieved without
recourse to market information upon willingness to pay, and is norm-
ally a subjective process using local knowledge and expertise.

68

Reference to national standards is occasionally made (e.g. minimum
acceptable speeds) and points allotted to equate them. Although this
is an improvement upon the 'intuition' that typifies many approaches,
it relies upon the relevance of standards to local conditions and the
validity of equating them. Despite the objectivity that points
appear to give to evaluation, scores tend to reflect the values of
the decision-maker rather than those of the individuals affected.
Detail of individual reaction, the allocation of costs and benefits
between them and the explicit definition of social choice criteria,
are not possible.

Clearly, requirements of problem identification are not met,
and the deficiencies in valuing, measuring and aggregating disparate
criteria, which appear to be resolved, in fact remain. Popularity
stems from their simplicity and apparent objectivity. In practice,
they form an inadequate adaptation of social cost benefit analysis,
and, as such, are of little value.

(c) Stimulus/Response Techniques

The emphasis with stimulus-response techniques is upon repre-
senting the sum total of individual responses to highway related
stimuli, in a single index. This index could be used to compare
highway problems and sites, and would consist of the products for each
physical highway criterion, the intensity of the individual response
to that criterion, its importance and the numbers affected. Each
highway criterion is related to individual response through a
generalised transformation relationship, which needs to be appropriate
to every individual in given conditions. By obtaining this relation-
ship, the level of criterion, the numbers affected and their relative
significance, an aggregate response to any condition can be obtained
by summing individual responses (each measured in terms of 'annoyance'

Problems abound in application, discussed in detail by Waller (1973) and Hodgins (1976). They centre around deriving a single index of response to conditions, appropriate to a wide variety of individuals. It is by no means certain that individuals can register responses in absolute rather than relative terms, although if this is possible, then annoyance caused by highway conditions could be measured in common 'annoyance' units and then aggregated. If not, further analysis is constrained and it is not possible to say, in absolute terms, whether a given change in one effect is of more or less value than a change in another. It is also impossible to compare conditions in absolute terms even if they relate to the same condition (e.g. road safety), nor to say whether the value attached to a given change in level of effect is of the same magnitude when the change occurs at different absolute levels. J.U.R.U.E. (1976) discusses these problems further.

If it is not possible to construct a single index, then the problem arises of aggregation and of comparing between indeces and between indexed and non-indexed items. There are also dangers of aggregating responses, particularly where the index is based upon subjective response (Hodgins, 1976). Stanley (1974) discusses this problem with reference to the development of a cardinal utility approach to evaluation. If a consistent relationship between stimuli and response can be obtained, then it is possible to reach conclusions about any single individual's response to a given highway condition. However, when used to evaluate a problem, it relies upon aggregating numerous individual responses and the validity of so doing. It also brings into question the ability of individuals to respond reliably and consistently. Are they expressing their own feelings or some sort of moral responsibility? Are they capable of expressing what they feel even if they can assess it?

The activity context is also important. Individuals involved in different activities, and even the same individual under different circumstances, respond in different ways. Consequently, information is needed upon the activity context. This information is not readily available.

These comments imply that reliable relationships between stimulus and response can be derived. However, there is little evidence for this. Hodgins (1976), in a detailed study of individual response to traffic related stimuli, failed to develop any conclusive relationships, suggesting that practical problems remain largely unresolved.

Despite this, stimulus-response techniques provide a means of handling the deficiencies of Priority Ranking in a relatively successful way. They provide clear indication of the individual response to highway conditions and priorities to be attached to them. Policy preferences can be incorporated through the selection of stimuli (criteria) and the introduction of weights. Although an intermediate common metric is used (in a similar fashion to points and money), annoyance ratings are derived directly from individual response. Only the absence of reliable and consistent transformation relationships interrupts their application. Sites could then be assessed in terms of the sum total of these annoyance units.

Stimulus-response methods also go some way towards solving a number of other deficiencies of current practice. They contribute to the linkage of problems and solutions by indicating the nature of problem conditions and the priorities attached to them. In this way, they would aid the design process. Inter-sectoral problem comparisons (e.g. public transport and the environment) ought to be possible

given careful choice of criteria. However, difficulties are clearly apparent in incorporating risk and uncertainty into the process.

In terms of the requirements of problem identification, the ability to comply with the policy needs of problem identification have already been outlined. Similarly, the ability of the methodology to indicate priorities and facilitate scheme generation is clear. In theoretical terms, they provide the best solution so far, to the needs of problem identification, accommodating many issues emerging from valuation, measurement and aggregation, and working well within the 'rational comprehensive' model of the planning process envisaged by the Department of Transport. Distributional considerations can be included within criterion definition and in assessment of the relationship of highway stimuli and individuals.

However, in resource terms, problems begin to emerge. Data is not freely available upon activity patterns, the numbers affected by highway problems or their response to them. The organisation and resources to gather this data does not exist. Temporal constraints, restricting opportunities to process and update this data, if it were available, are prohibitive. In feasibility terms, organisation of the West Midlands C.C. is not accustomed to the collection or analysis of data of this type. Similarly, the inter-relationship and co-ordination of sections and departments within the County Council would not be facilitated by the introduction of a new and unfamiliar concept in problem measurement. Acceptance of a technique which is also unfamiliar to most organisations contributing to the highway planning process (e.g. B.R., P.T.E.) is hardly assured, and as a result, it may prove difficult for problem sites identified in this way to proceed through the planning process.

In political terms, we have seen that stimulus-response

techniques are capable of reflecting policy priorities and, consequently, the ambitions of decision-makers and the electorate. Simply by reflecting individual response to highway conditions, problem identification becomes more responsive to individual and community views.

It is in practical terms that stimulus-response methods fail to meet a number of requirements. Data is currently unavailable in the form needed and costly to obtain. Transformation relationships to link stimulus and response have not been derived satisfactorily. Meanwhile, many of the basic assumptions underlying the derivation of such relationships must be in doubt - including summation of individual responses, the ability of individuals to formulate their own responses in a consistent way, and so on.

Overall, practical problems place doubts against the feasibility of this type of approach. Methodological problems compound these difficulties and despite many theoretical advantages, stimulus-response methods remain impractical. However, future potential is noteworthy.

(d) Multi-criteria Approaches

Multi-criteria approaches subsume a large number of different techniques, each with the notion that the disparate criteria relevant to the evaluation problem need to be brought together in a rational manner without recourse to an intermediate common metric of money, points or annoyance. The multiple and often conflicting nature of planning goals is recognised and handled explicitly. Six approaches were identified following Nijkamp (1977, 1979, 1980).

(i)   conventional approaches (including matrices, P.B.S.A., P.P.B.S.,);

(ii)   multiple-criteria analysis (m.c.a.);

(iii) decision analysis;

(iv) programming;

(v) strategic choice;

(vi) multivariate analysis.

A number of these have only limited application to problem identification. In particular, conventional approaches, programming, and strategic choice are each difficult to adapt and will not be discussed further. Attention is focussed upon the remaining three options - m.c.a., decision analysis and multivariate techniques.

(i) Multiple-criteria analysis (m.c.a.)

M.c.a. is a relatively recent development having its origins in the French school of regional science (Nijkamp, 1975). Gigou (1971), Roy (1972), Nijkamp (1977) and van Delft and Nijkamp (1976) provide seminal references. Lin and Hoel (1977) review utility based methods which have much in common.

Application of m.c.a. to problem identification begins with an accurate description of all sites and the selection of relevant decision criteria (e.g. noise levels, speeds, etc.). From this, a Problem Impact Matrix can be constructed where:

$$I \quad = \quad \text{alternative sites}$$

$$J \quad = \quad \text{decision criteria}$$

$$P_{ij} \quad = \quad \text{outcome of jth criterion for site i.}$$

These impacts can be expressed in any units, including rankings. By definition, this makes the matrix multi-dimensional and the difficulties of aggregation become clear. They are overcome through normalisation by one of a variety of methods described by Paelinck and Nijkamp (1976). Most commonly, problem impacts (P_{ji}) are

74

divided by a normalised outcome corresponding to a desirable state on each criterion (pj*) to produce a normalised outcome - Vji.

$$V_{ji} = \frac{P_{ji}}{P_{j*}}$$

Belenson and Kapur (1973) review other methods and the fact that no single preferable method emerges suggests that analysis (and aggregation in particular) within m.c.a. is not entirely value free.

The second input to m.c.a. are priority weights. They represent the relative priority attached to a particular decision criterion and are defined using information about the whole set of alternatives. This often presents problems, for decision-makers find it difficult to appreciate the consequences of a complex set of weights. Eckenrode (1965), Hutchinson (1974) and Saaty (1977a, 1977b) discuss these problems. If a set of weights can be produced, four methods of assessing problem severity exist (following Nijkamp [1979]).

Expected value - is the simplest. Preference weights (Wji) are treated as semi-probabilities. By multiplying normalised problem outcomes (Vji) by corresponding weights, the expected outcome of each problem (ei) is:

$$e_i = \sum_{j=1}^{i} W_{ji} \cdot V_{ji}$$

This produces a rank order. Baumgartner (1977), Schimpeler and Greco (1968) and Schlager (1968) each present applications.

Concordance analysis - is described by Guigou (1971) and Roy (1972) and operationalised by Nijkamp (1977), and relies upon pairwise comparison. Dominance of a problem is measured using preference weights and represented by a concordance index. A discordance index represents the degree to which a problem is dominated by all others.

Priorities are attached to those problems showing maximum concordance and minimum discordance indices. Measurements are ordinal and distance between sites on the scale are unavailable.

Entropy - is derived from information theory and measures the expected information content of a message (Theil, 1967). The P.I.M. contains information and the principle of entropy can be used to measure its impact. It is particularly useful in investigating contrasts between data sets and defining diversity within the problem information.

Discrepancy analysis - measures the extent to which a site differs from the ideal, with the weighted discrepancy between normalised outcome and 1.0 serving as a measure of condition:

$$Si = \sum_{j=1}^{i} Wji \; Vji - 1.0$$

Qualitative (ordinal) versions of each of these methods have been derived by Nijkamp (1979), utilising mathematical manipulation of rank orders. None are robust, each replete with value judgements and a number of unspecified assumptions.

M.c.a. has advantages for problem identification, but certain issues remain unresolved. In terms of constraints, it exhibits flexibility by using maximum and minimum conditions as measures of 'good' and 'bad', resulting in relative and changing assessments of highway conditions. Explicit use of impact weights reflects priorities between individuals, areas and objectives. Changing political attitudes are reflected sensitively and quickly through choice of criteria and the weights attached to them. Both aggregate and disaggregate detail is available, facilitating scheme design and encouraging links between problem conditions and solutions. Data and manpower

requirements are unexceptional; inputs are conventional planning
information. Temporal constraints are unaffected.

However, difficulties stem from two considerations; practical
acceptability and theoretical constructs. Inevitably, there are
doubts surrounding acceptance of a complex and unfamiliar mathematical
technique, both within W.M.C.C. and other relevant groups. Political
acceptability also may not be forthcoming, and the level of experience
of m.c.a. techniques is generally low. In theoretical terms, a series
of issues need clarification:

(i) Problem impact matrix. Problems arise in measuring
impacts directly and in meaningful terms. It is difficult
to ensure that the range of criteria is comprehensive and
adequately defined.

(ii) A linear utility function is assumed. Lin and Hoel
(1977) describe this as unrealistic.

(iii) Extreme problems can distort overall ranking of alter-
natives, particularly in terms of transformation functions
(Figure 2.6).

(iv) Measurement and valuation. Maximum, minimum and mean
entries have great significance. The maximum score achieved
by a criterion is often used as a parameter in defining impact
scores, implying that maximum attainable scores represent full
achievement, maximum attained, the failure to achieve them.
Is this justifiable?

Decisions in this area will affect priorities attached to sites.
Arbitrary definitions of 'good' and 'bad' can have the same effect as
the extreme value problem discussed earlier. Meanwhile, utilities
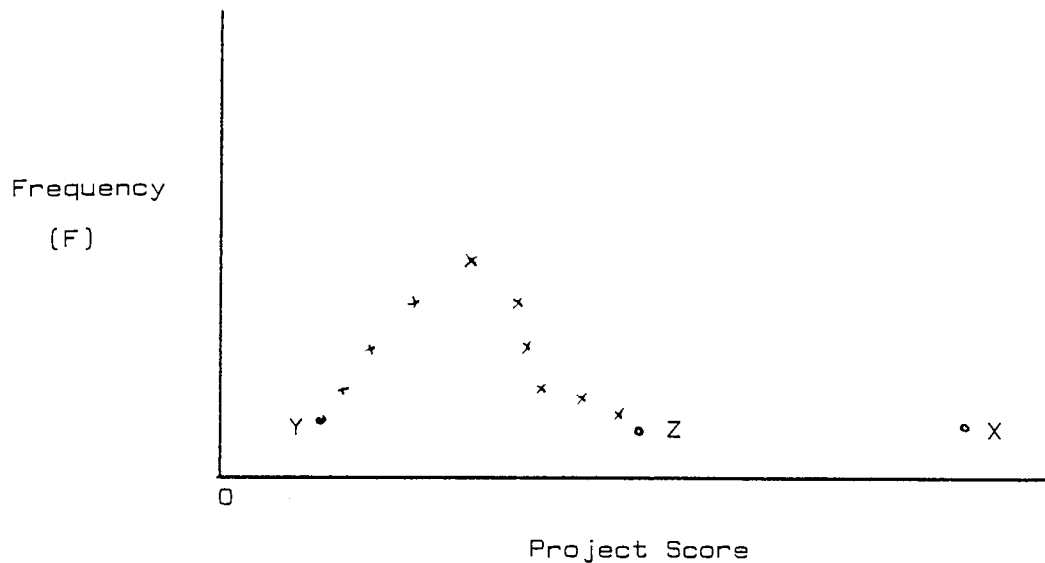
Many methods in m.ca (including those suggested by Belensen and

Kapur (1973) and Nijkamp (1977) rely on maximum and minimum scores

to define the transformation that occurs.   In the example above,

if value x is used (a maximum), it will tend to under-emphasise

the variation between points Y and Z and the transformation will

be heavily influenced by a single value.   A similar situation

with an extreme minimum value, would have the same effect.

still need to be attached by decision-makers to criterion values and then traded off against other criteria.   This presents difficulties similar to those experienced by cost utility and points methods, and a suitable procedure remains elusive.

In particular, a number of theoretical and practical deficiencies detract from the advantages of m.c.a., and make application to problem identification difficult.   Despite this, it represents an approach with much potential, meeting many of the requirements and constraints that exist.   In time, it is likely to prove valuable, but further development is needed.

(ii) Decision analysis.

Decision analysis focuses closely upon decision theory whilst retaining the same basic philosophy as m.c.a.. However, it is less clear how it could be applied to problem identification.   There are five basic stages: (Keeney and Raiffa, 1976)

(a)   structuring and decomposition of the decision problem;

(b)   assessment of utilities for outcomes in the decision tree;

(c)   assessment of probabilities for uncertain events;

(d)   folding back the decision tree - i.e. working back from the end points towards the start of the decision tree, the principle of expected utility is applied to eliminate all but the optimal strategy;

(e)   sensitivity analysis.

Utility theory is the most common method to choose preferences (Hull et al, 1973).   The basic principle is that 'rational man' has a utility function (u) with the following properties:

(i)   u is defined on the set of all possible outcomes;

78

(ii)   outcome A is preferred to B only if u(A) $>$ u(B);

(iii) a decision giving chances pi of achieving outcomes Ai is

preferred to one giving chances qj of achieving outcomes

Bj only if:

$$\sum_{i=1}^{n} Pi\, U(A_i) \quad \leqslant \quad \sum_{j=1}^{m} qj \quad u(B_j)$$

where

$$\sum_{i=1}^{n} Pi = \sum_{j=1}^{m} qj = 1$$

Thus, rational man acts to maximise his expected utility, using dis-
utility as the basic unit for problem assessment.   Despite providing

a structure for problem identification, there are many problems in

application, similar to those exhibited by stimulus-response techniques.

Leaving aside problems of unidimensionality, the approach decision

analysis takes in assessing multi-dimensional utility is questionable.

Certain simplifying assumptions are made in measuring and aggregating

utilities including those of linearity and additivity.   The former

implies constant trade offs between dimensions in a way similar to

cost benefit analysis where effects are exchanged at fixed rates of

money.   Additivity implies that utility of the whole equals the

utility of the sum of its parts and that the rate of trade off of the

two variables depends solely upon their values and not the values of

other variables.   Clearly, neither necessarily holds true.

Practical difficulties present the greatest problems.   Appli-
cation is constrained by its sophisticated and complex characteristics

and time consuming analytical requirements.   It relies upon the will-
ingness of decision-makers to participate in a detailed analysis of

factors affecting a decision in order that preferences can be ascer-
tained (i.e. the utility attached to a highway condition).   If this

information is unavailable, then the methodology cannot work.

Despite these drawbacks, there are occasions when the principles of decision analysis could be useful, and the notions of utility and preference could serve to refine the process of a m.c.a. approach. However, theoretical and practical implications detract from any potential that it exhibits. Some concepts remain of value, particularly application at a late stage within a m.c.a. framework, but in general, it remains difficult to adapt and apply to the needs of problem identification.

(iii) Multivariate Analysis.

Multivariate analysis includes a large number of techniques amongst which are factorial, cluster, discriminant and interdependence analysis. They have been widely applied in the natural and social sciences but rarely used in engineering sciences or planning. This is more a consequence of tradition than methodological or theoretical inadequacies. Exceptions can be found in Leathers (1967), Kain & Quigley (1970) and Stewart (1981). The most commonly applied variant is factorial analysis, which also possesses greatest potential for highway evaluation, incorporating both an aggregation and multi-dimensional scaling methodology. The discussion hereon is limited to that category. It is described in detail in Appendix 3 and further discussion of the approach and its derivatives can be found in Fruchter (1954), Harman (1960), Torgersen (1963), Rummel (1967, 1970) and Nijkamp (1979, 1982).

Factorial analysis searches for order within a body of data. In the case of highway problem identification, this would be a matrix of problem criteria (accident rates, noise levels, etc.) for each site in question. Patterns of inter-relationship within this data are

expressed in the form of correlation coefficients between pairs of criteria. From these inter-relationships, composite factors are derived which describe the maximum possible variance within the original data matrix, achieved through a process closely allied to regression analysis, whereby best fit lines (the factors) are fitted to the criteria patterns in geometric space, each describing the greatest possible amount of information in the matrix. Each of these factors is a composite, made up from all the original variables, those it is closest to comprising the major part, those furthest away, the least. The first factor so defined describes the maximum possible amount of information in the matrix and is thus the best fit line of the whole data set. However, as a consequence it tends to be generalised in nature, minimising the distance between itself and every variable, rather than maximising its proximity to any one. The next factor describes as much as possible of what is left and con-sequently is more specific, but less able to describe the data set as a whole. This continues until all the variance is explained, by which time there is the same number of factors as variables. At this stage, the original data matrix has been redefined in terms of a set of composite factors - so called because they are each composed of parts of the original variables.

Inevitably, those factors derived at the later stages describe successively smaller amounts of variance and can be discarded with little loss of detail. This leaves a smaller number of composite factors which still describe, reasonably well, the original data matrix. This process, by reducing the number of composite factors, enables the user to simplify and aggregate information, without recourse to any intermediate metric and with relatively little loss of useful data. It thus has significant potential to overcome many of the theoretical deficiencies of current evaluation methodologies.

81

Following discard of those factors explaining least, 'geometric rotation' can then take place. This involves moving the complete structure of factors in geometric space, searching for a location which better describes the data as a whole. Although each factor was originally selected to describe maximum possible variance, it is common for all factors as a complete set to be suboptional in their description of the data as a whole. Rotation helps to improve the overall descriptive capabilities of the set, but in the process may upset the variance describing capabilities of each individual factor. Thus, factor number one may no longer describe the most information, but will now form part of the optimal overall description of the original data.

Initial derivation of factors is carried out orthogonally - i.e. each is located at right angles to one another and thus are uncorrelated. The second factor explains as much variance as possible whilst being uncorrelated to the first - and so on. This orthogonality can be retained, if desired, by rotating the structure about a common origin. Conversely, factors can be allowed to 'float' into positions that are optimal in describing criteria. It is possible, but unlikely, that this new 'oblique' solution will remain orthogonal - consequently factors often become correlated. This is likely to reflect the real situation more accurately (e.g. factors describing highway conditions are likely to be correlated), but tends to be more difficult to interpret.

Factorial analysis can also be used to rank - in this case, highway problems - using the composite factors. It produces a ranking on a scale which allows the user to compare problem conditions both between highway sites and between problem types - however, it does not allow full mathematical manipulation (for example, one cannot say that a problem condition is twice as bad as another) since it

is not a ratio scale.   It achieves this through the use of factor

score coefficients, a process described by Lawley and Maxwell (1963)

(Appendix 4).   These coefficients reflect the relationship between

the original pieces of data at each site, and each of the composite

factors.   By standardising the raw data to a mean of zero, and

standard deviation of 1, comparisons between problem conditions are

possible (Appendix 3).   This standardised data can then be multiplied

by the appropriate factor score coefficient to produce a factor score

for each factor at each site and for each criterion.   These can be

summed for each site to produce a problem score for each site on each

factor.   Due to the process of standardisation, and the existence of

scores derived from composite factors, ranking can then take place

and comparisons made using the scores between both factors and sites

(Figure 2.7).

Through the earlier process of factor derivation, each factor

tends to be closely associated with a limited number of criteria and

poorly associated with all others.   This is a consequence of the

clustering of similar criteria (e.g. noise and air pollution levels)

which are closely correlated.   As a result, it is possible to 'name'

factors according to the criteria with which they are mose closely

related (e.g. an environmental factor) and ranking by factor can be

seen as ranking by factor type.   Different rankings can be expected

according to the factor used.   Detail of problem conditions remains

available as a result, and one would expect, for example, an environ-

mentally poor site to rank highly on the environmental factor, and

not necessarily poor on others.   At the same time, an overall problem

assessment can be derived by summing the scores for each site on each

factor after making allowance for the variance explained by each (and

thus its contribution towards describing the original data matrix).

This information upon variance is produced earlier in the factorial

FIGURE 2.7 - FACTOR SCORING : FACTORS 1 - n

DATA VARIABLES 1 - m

FACTOR
SCORE
COEFFICIENT
FACTOR 1

FACTOR
SCORE
COEFFICIENT
FACTOR 2

FACTOR
SCORE
COEFFICIENT
FACTOR n

RAW DATA
STANDARDISED
N = 0
σ = 1

FACTOR SCORE
COEFFICIENTS   *
FACTORS 1 to n

STANDARDISED DATA
FOR EACH SITE

FACTOR 1 SCORE
FOR STANDARDISED
VARIABLE 1 AT
EACH SITE

FACTOR 1 SCORE FOR
STANDARDISED VARIABLE
2 AT EACH SITE

FACTOR n SCORE FOR
STANDARDISED VARIABLE
m AT EACH SITE

TOTAL FACTOR 1 to n SCORE FOR EACH SITE

TOTAL FACTOR SCORE FOR EACH SITE
= $\leqslant$ FACTOR SCORES 1 to n * VARIANCE EXPLAINED

INDIVIDUAL
RANK

TOTAL
RANK

process and forms the basis for discard of unwanted factors.

Final output from factorial analysis is thus a series of site lists, ranked by factor scores representing the relationship of site condition to overall conditions for that area. Comparisons are possible between sites and factors because problem 'units' are standardised, each possessing the same mean (0) and standard deviation (1). However, the scales used are not ratio and anlysis is thus limited. This, however, still permits the allocation of priorities and comparison across problem boundaries. Two major advantages can be identified:

(a) It can reduce a problem matrix to a limited number of composite factors, each of which can be associated with specific facets of highway condition. If desired, a single problem factor can be derived through successive factoring, but with consequential loss of information. Problem criteria can be of any form, measured upon a variety of scales and units - aggregation is achieved without recourse to an intermediate metric and is based upon the inter-correlation of the data. Problems of valuation are consequently lessened, although assumptions are made in equating conditions through standardisation.

(b) It presents a scaling methodology, based upon local, topical conditions and is flexible to change. Pre-set standards are not used and problem definition fluctuates to meet changing needs and resources.

Application to highway problem identification would take the form outlined below:

(1) Derivation of problem criteria from transport policies in T.P.P. and Structure Plan.

(2) Construction of data matrix of problem conditions by sites.

(3)   Derivation of correlation matrix between problem criteria.

(4)   Factoring process, producing composite factors describing the original matrix.

(5)   Discard factors contributing little to the description of data (judged by their explanation of variance).

(6)   Rotation of factored structure to an improved position - if one exists.

(7)   Calculation of factor score coefficients reflecting the relation-ship of factors to site data.

(8)   Introduction of weights to reflect priorities to geographical locations and between policy issues.   These weights are applied to site scores calculated in stage 9.

(9)   Calculation of site scores using coefficients and standardised problem data.

(10) Summation to produce aggregate site scores.

(11) Ranking by individual factor and aggregate scores.

(12) Allocation of site priorities.

(13) Selection of sites for Priority Ranking.

(14) Implementation.

In terms of both requirements and constraint, factorial analysis provides a method which dies not require revision of existing scheme evaluation procedures, but is designed to cope with the problems of disparate criteria and their valuation and aggregation.   It provides information upon the inter-relationships of problem condition through

the use of correlation measures indicating scheme design needs and the nature of possible solutions. It provides site scores reflecting specific problem types, and an overall aggregate problem score with which they can be compared. By producing both aggregate and disaggregate information, the details of highway conditions are retained.

However, a list of highway problem sites ranked in order of severity is no guide to the value inherent in an optimal solution to a given problem. Disaggregate problem information does provide useful guidance. Only relatively severe problems are of interest for T.P.P. purposes, for the minimum cost of schemes which are evaluated in detail is £50,000 and to have any possibility of achieving benefits notably greater than this figure (necessary if a scheme is to be selected and implemented) then it must exhibit relatively severe problems. Sites not ranked highly in any list, total or disaggregated, are very unlikely to generate sufficient benefits from any scheme of improvement. Sites at the top of each list are very likely to be worth further investigation - although it is by no means certain that they will produce schemes of value since severe problems may require such expensive solutions as to render them unacceptable. In the area between these two categories the most likely sites to generate high net benefits at reasonable cost are those with substantial problems but of only one type - environmental, congestion, etc. In terms of total problem score, they would rank mediocrely, but in terms of individual rankings, they would tend to exhibit severe problems upon at least one. The user can interpret individual factor scores and ranks as a means of selecting marginal sites where schemes might be profitable.

By virtue of the methods adopted in standardisation, it encourages the assessment of problems in relative terms and, as Mackie and Garton

(1977) stress, meets the needs of a grant allocation system which
continuously adapts to the redefinition of problems and the resources
available.   From a political viewpoint, problem criteria can be
selected to reflect current policy requirements whilst weights can be
used to adjust scores, and allocate preferences between geographical
areas and criteria.

In resource and feasibility terms, it has a number of advantages.
It uses conventional planning data and remains largely unaffected by
its scale, unit or form.   Thus it requires few specific resources.
At the same time, it can be used to indicate which pieces of data con-
tribute little to explaining overall (problem) condition, thus pro-
viding a means of rationalising the requirements of data collection
with little loss of detail.   It is flexible to changes in data,
policies or highway characteristics and its computer basis - essential
for the complex calculations of factoring - makes integration with
Priority Ranking easier.   It can accommodate comprehensive geo-
graphical coverage with few problems in handling the mass of data
this involves.

In theoretical terms, factorial analysis provides the only mech-
anism for measurement and aggregation that is clear in its assumptions
and which implies little spurious objectivity.   It is by no means
value free - standardisation, for one, is a value-laden choice - but
it overcomes the need to translate conditions into money, points,
annoyance, etc., and the difficulties this brings.   By relying upon
statistical methods to aggregate disparate criteria, it avoids
questionable assumptions that underly more traditional approaches -
assumptions that if resolved would result in reliable and useful
techniques, but which in effect remain unresolved.   Overall, factorial
analysis is explicit in its values and helps to expose the nature of
problems and choices to be made.   Equity issues can be accommodated

through weights (if desired) and sensitivity testing could be used to determine the importance of criterion and weight choice.

A considerable number of variants of factorial analysis exist, and the choice of one is determined by the objectives of the exercise and the data that is available. Flexibility in approach (typified by the choice available of rotation methods) is an inherent characteristic and factorial analysis can be adapted to many needs. However, this can make interpretation of the results difficult.

Other drawbacks are limited to doubts over acceptability by other organisations and within W.M.C.C. (discussed by Massam, 1980) and the skills needed to operate and understand such a method. It is an approach not without critics (e.g. Chatfield and Collins, 1980), but adverse comment has centred around difficulties of application rather than theoretical or methodological inadequacies. These practical difficulties are far from insurmountable, although they must be noted and accommodated within the highway evaluation framework.

Conclusions

Multi-criteria approaches to highway evaluation emerge clearly as offering significant advantages over traditional methodologies and over alternative new techniques. They were boosted in general by the recommendations of the Leitch Committee (ACTRA, 1977), who commented:

> "The use of multi-criteria approaches ....
> between different road improvement schemes,
> should ensure that a wider range of consid-
> erations can be taken into account."

Further support came from Pearman (1979) in a report to the Department of Transport, concluding:

> "Given the will to make it work, there seems

to be no reason why some sort of formal
multi-criteria appraisal of marginal
schemes could not make a worthwhile con-
tribution to improved decision-making in
this part of the public sector."

He also discounted the problem of complexity:

".... if the comparability issue (of pro-
posals) needs rather complex forms of
analysis in order to ensure a good alloc-
ation of society's limited resources, then
their complexity alone should not stand in
the way of application."

Multi-criteria approaches are, thus, viewed favourably by central

government and appear to have considerable potential for highway problem

identification.   One specific approach stands out - factorial analysis,

itself one method within multi-variate analysis.   Its ability to meet

requirements and work within existing constraints is clear and con-

sequently it was chosen as the basis for further development.   This

should not imply that other methods have nothing to offer - clearly

m.c.a. and stimulus-response methods both have advantages - nor that

it can solve all deficiencies that exist.   However, it does offer a

number of significant advantages and because of this justified

further development.

CHAPTER 3 - CASE STUDY

Introduction

Factorial analysis emerges from this examination of techniques with potential for highway problem identification as the methodology offering the most significant advantages and violating least constraints. Consequently, it was chosen for further development. Clearly, its basic framework needs some adaption to make it suitable for problem identification and we have seen already how it can be designed for general highway evaluation. This chapter looks at the choice of highway data inputs in the light of those available and the practical structure of factorial analysis applied in the West Midlands. The discussion is focussed around a number of separate issues:

computer structure and requirements;

highway problem data;

referencing methods;

site definition;

weighting methods.

Computer Structure

The structure of problem identification outlined in the last chapter, indicated the movement from County transport policies through objective and problem criteria, to the definition of highway problems, ranking and scoring of sites and selection of priorities for project design and evaluation. There are a number of reasons why this framework needs to be designed for computer application, many of which have been discussed in principle by Newton (1981).

(i) It is a complex and detailed approach requiring considerable care in application. Use of computer facilities will ensure continued accuracy and quicken the process as a whole.

(ii) Priority Ranking is computer based and the design of problem
identification for computer application will help to ensure continuity
and integration of the two techniques.

(iii) Much of the relevant input information is already stored on com-
puter and it would be pointless to transfer this data for problem
identification before once again returning it to the computer for
Priority Ranking purposes.

The following computer structure was derived and is outlined in
Figure 3.1.   Five stages can be identified:

(i)   Creation and maintenance of highway database(s).

(ii)   Data manipulation - to create revised data variables,
       e.g. accident rates.

(iii) Factorial process.

(iv)   Weighting and scoring.

(v)   Ranking of sites and output of priorities.

The Case Study Area

The development of problem identification in the West Midlands
assumed from the outset that it would be necessary to apply the method-
ology in a practical case study.   The choice of case study area took
into account a number of factors, not least of which were the
advantages of restricting trials to a limited area, ensuring data
manageability, limiting preparation time and minimising computer and
data resource requirements.   A number of other factors dictated final
choice.

(i)   It was selected to include the widest possible combination of
highway problems to test the capabilities of the problem identification
methodology.   It also included a variety of land uses (industrial,
commercial, residential, open space, etc.) and route types (orbital,

FIGURE 3.1 - THE COMPUTER STRUCTURE

HIGHWAY DATA BASE ⟵————————————— MONITORING

FACTORIAL PROCESS

ROTATION

FINAL FACTOR SOLUTION

PRIORITY
WEIGHTS

FACTOR SCORE COEFFICIENTS

WEIGHTED FACTOR SCORES
AND AGGREGATION

RANKING AND LISTING

Site Selection

PRIORITY RANKING
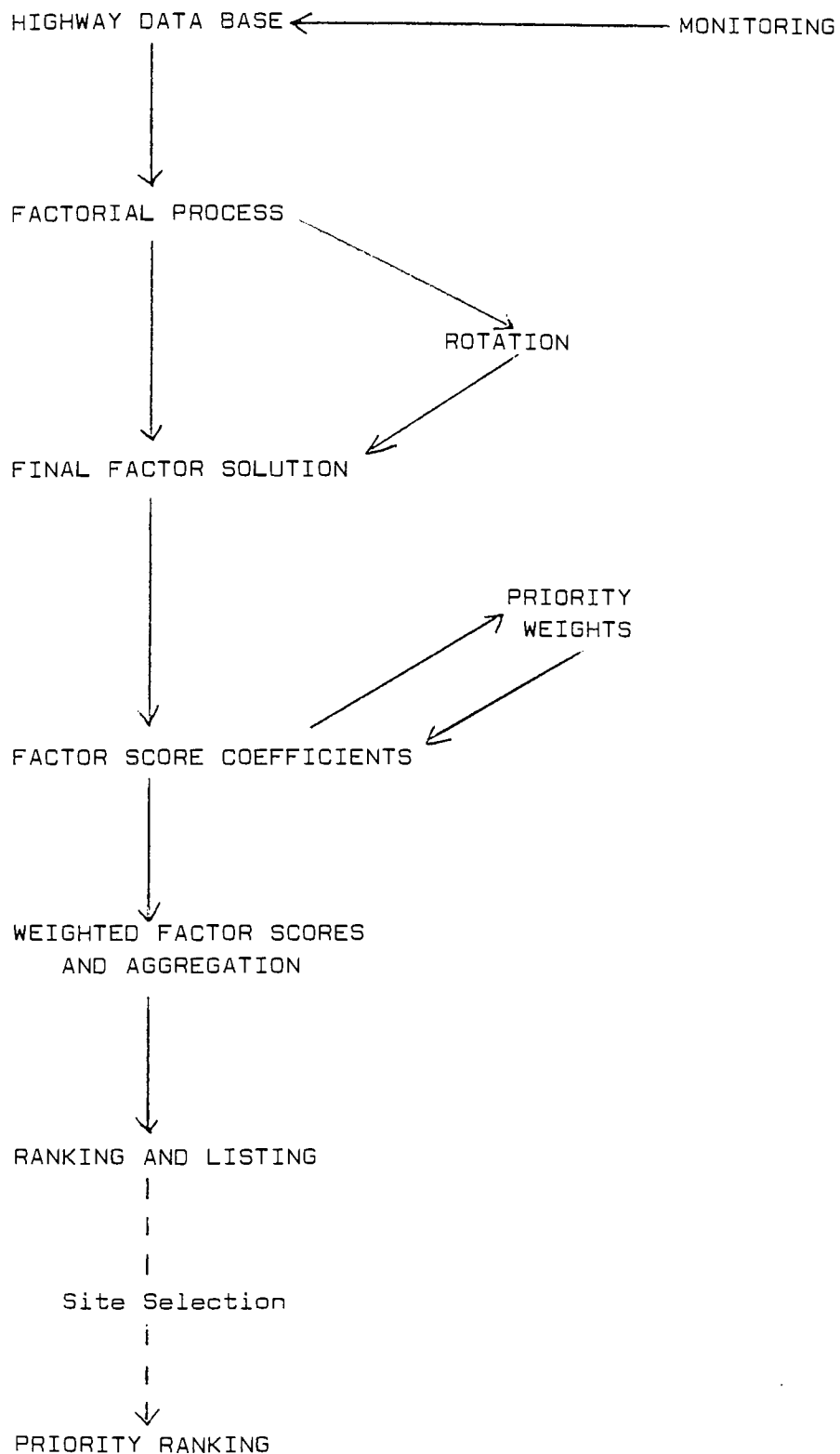
radial, Trunk Roads, etc.), facilitating further assessment within a
varied problem framework.

(ii) Highway data had to be readily available due to the time and re-
source constraints that existed.   This limited choice of areas within
the West Midlands to where an existing and reliable source of inform-
ation was available.

(iii) The area should be self contained, although as part of the West
Midlands agglomeration this could not be entirely possible.   However,
by selecting an area constrained by the County boundary, an area of
little development or a railway line or canal, it proved possible to
achieve considerable independence.   The advantages in this were that
certain information sources, particularly those associated with the
County traffic model were adversely affected if boundaries were drawn
crossing numerous highway links.

(iv) West Midlands County Council (W.M.C.C.) were interested in the
effect of problems generated outside the West Midlands, upon conditions
within the County.   Thus an area bordering other counties was preferred.

(v)   The area chosen was selected with regard to its political
sensitivity.

(vi) The precise boundary was dictated by a combination of computer
requirements and data form.   In particular, the local traffic model
(T.R.A.M.P.) and the use of it in compressed form, whereby it can be
run for a restricted highway network to reduce resource costs, requires
definition of an area which avoids cutting across centroid connectors.
This constrained the specification of precise boundaries, but had little
effect upon the ability of the case study to assess the application of
the methodology.   Figure 3.2 shows the area chosen and Figure 3.3 the

N

WOLVERHAMPTON

WALSALL

DUDLEY

SANDWELL

BIRMINGHAM

SOLIHULL

COVENTRY
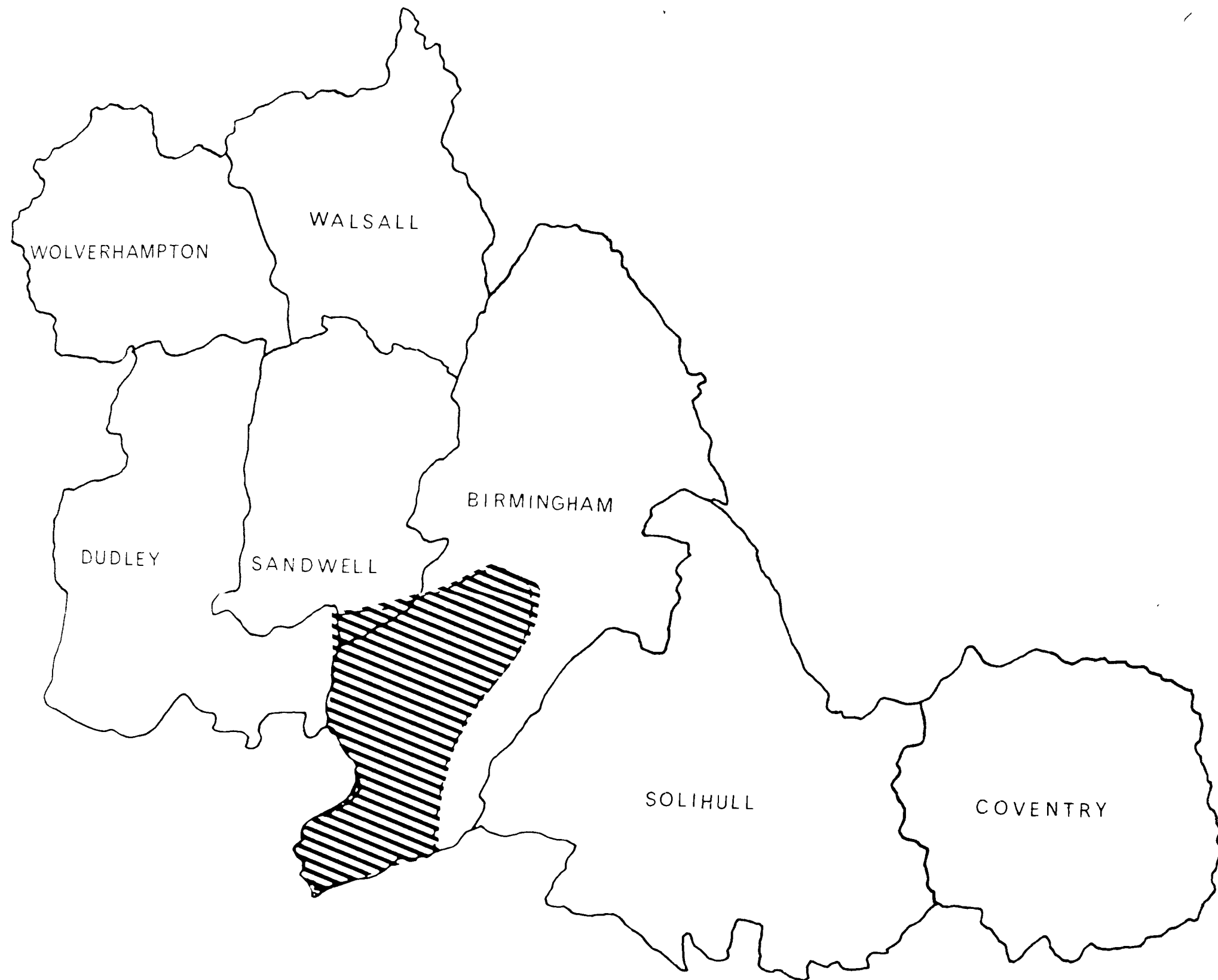
FIGURE 3.2

CASE STUDY AREA
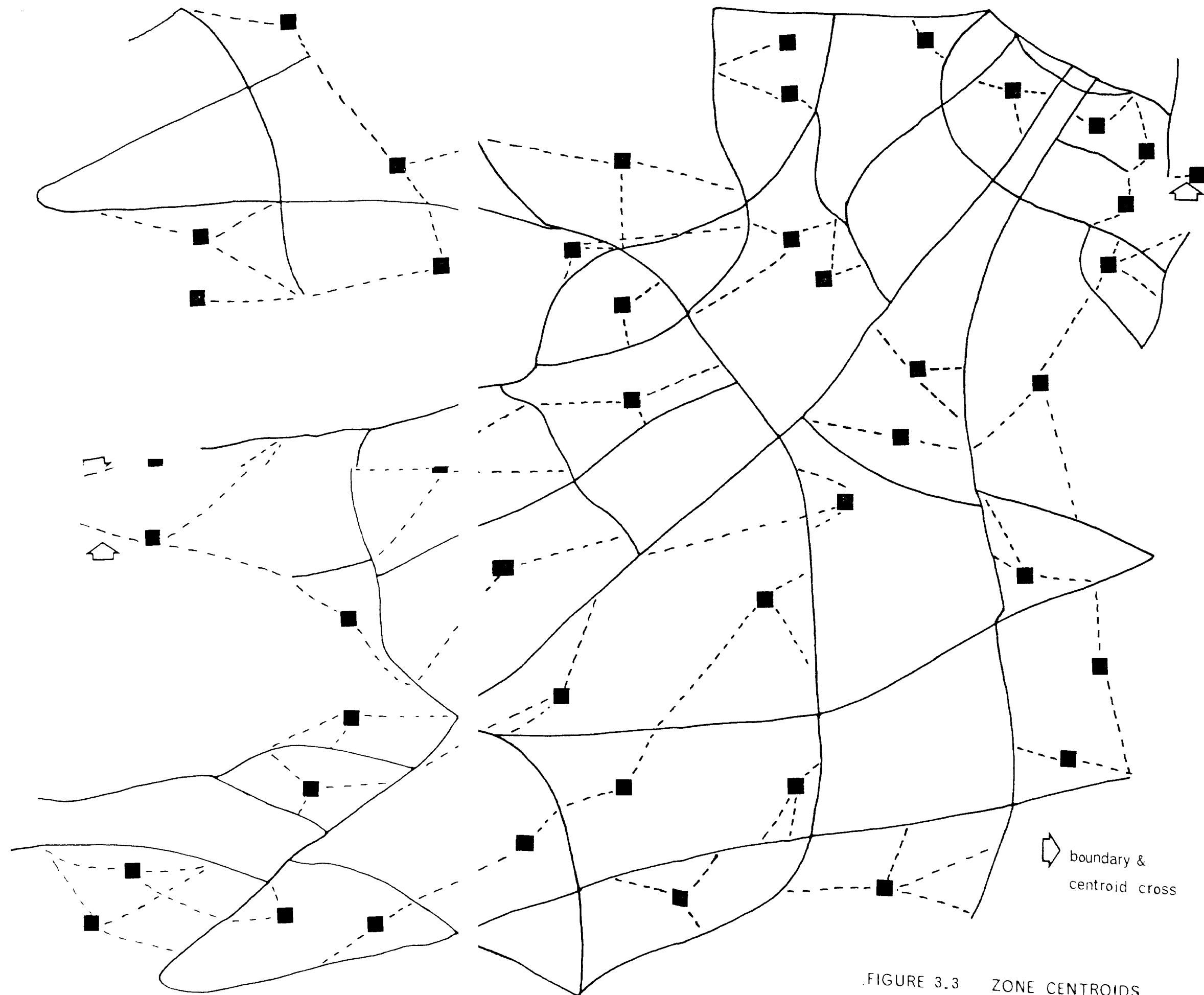
FIGURE 3.3 ZONE CENTROIDS AND CONNECTORS

boundary &
centroid cross

effect of centroid connectors upon the choice of boundary.

The case study area covered a large part (approximately 50 square miles) of south and west Birmingham. It lay wholly within the City of Birmingham apart from a limited area within Sandwell M.B.C. and included city centre, inner city and suburban areas within its boundaries. Crossed by the middle and outer Ring Roads and dissected by the A38(T) and A450(T) roads, it also included substantial areas characterised by minor roads, limited in traffic flow. In general, it was continuously built up with only limited open areas.

The Data Base

The choice of criteria used to measure the existence of highway problems was dictated by the range of highway policies that emerged from the 1979 T.P.P. and Structure Plan (W.M.C.C., 1979, 1980). However, at the same time, choice was constrained by the availability and reliability of data sources - resource constraints precluded further data collection. Consequently, the selection of data sources represents a combination of idealism tempered by feasibility.

Although highway policies regularly change, the majority of highway criteria are liable to remain the same, changes in preferences being reflected in changes in objective weights. Thus, it was possible to derive a set of criteria from the policies expressed for 1979 (the latest available) which were pertinent for a number of subsequent years. As political administrations change, so could policy weights, but criteria would normally remain the same as they would still be relevant. The issue of weights is discussed later in this chapter. An outline of the process of deriving problem criteria from policies was discussed in Chapter 2 and is summarised for 1979 in Figure 2.1. As a result of this process, criteria, and therefore data sources, were needed to measure the achievement of the following categories of objective.

(i)   The provision of access to development.

(ii)   Promotion of the efficient operation of private transport.

(iii) Promotion of the efficient operation of public transport.

(iv)   Reduction of accidents.

(v)   Reduction of the impact of transport on the environment.

The role of maintenance conditions in problem definition was also noted and a measure of condition included so that maintenance needs could be coordinated with attempts to improve the highway network. Although they could be linked only indirectly with policies, it made obvious economic and administrative sense to coordinate investment. A variety of other pieces of information were available within the West Midlands and were assessed for inclusion in the set of problem criteria. They included bridge and level crossing conditions and problems assoc- iated with new developments. Each might contribute to the measurement of certain objectives. Finally, a sizeable quantity of other data was available upon such diverse issues as road geometry, road class and index, and land use. Some of this information would contribute directly to the assessment of problems, others might be included as of general use in transport planning.

Each source of data with potential to describe the achievement or otherwise of transport policies and objectives was assessed against a series of requirements that included:

(i)   As far as possible, each data source should provide information over the complete West Midlands highway network. Without comprehen- sive coverage, it is possible that problems would be missed and that the picture of highway condition that emerged would be inadequate.

(ii)   Data needed to be available immediately, and readily updated, preferably in a format suitable for problem identification. Some data

transformation would be possible, but inevitably it would require

scarce resources.

(iii) Data needed to be accurate and specific. Inaccurate or spurious

data would lead to inaccurate problem location definition.

(iv) It was important that double counting of problems should be

avoided whenever possible and, therefore, problem indicators should not

overlap in coverage.

(v) The indicators had to be capable of reflecting changing political

priorities both quickly and sensitively.

Clearly, where choice was constrained, some of these requirements

could not be met and use had to be made of information that was avail-

able. Elsewhere, they formed the basis for selection.

The Data Options

The following sections describe and assess the data that was avail-

able in the West Midlands which had clear relevance for problem ident-

ification. Indication is given of the objectives towards which each

variable might be directed - this varied according to data type and

some were pertinent for more than one.

(i) Traffic Flow and Congestion Data

A number of sources of congestion and traffic flow data were

available within the West Midlands. Some, including data collected by

the City of Birmingham, local police and the Civil Engineering Depart-

ment of the University of Birmingham, were excluded at an early stage

due to limitations in scope, coverage and accessibility.

Traffic flow and congestion data is fundamental to many criteria

used in problem identification, acting as a basis for calculating

environmental impacts, the levels of traffic congestion and as an

indicator of road safety and public transport conditions.

West Midlands Monitoring Data consists of two types (a map of site
locations can be found in Figure 3.4). The first is data collected
from permanent automatic counters. Only 8 sites exist, located on
the M5 and M6 motorways, maintained by the Department of Transport.
Counts are coarsely disaggregated into vehicle type and are adequate in
terms of time coverage operating continuously throughout the year. This
obviates the need for periodic updating of data. However, they are un-
suitable for problem identification in that the information is highly
site specific and limited in geographical coverage. Extrapolation to
other sites would be impossible. These problems are compounded by the
inaccuracies of automatic counters that remain and the inherent diffi-
culties in their calibration (Roe, 1978A).

The second type of data is collected on a regular but not per-
manent basis. This data exists in a number of forms, including 100
point census data, hand counted 1 week in every 4 at 24 sites through-
out the County; cordon and screenline counts, including central
Birmingham (annually), central Coventry (2 yearly), an external cordon
(annually) and the Coventry/mid Warwickshire screenline (3 sites
annually); and programme counts, automatic counts at 350 sites over
the whole of the county for one week at the same time each year. Over-
all coverage compares well with other local authorities, but is both
inadequate and unsuitable for problem identification, which needs
temporally and geographically comprehensive data. Despite the large
number of sites, only an impression of traffic flow is available,
insufficient for the level of detail required. The reliability of
automatic counters is also doubtful. Studies by the Transport and Road
Research Laboratory (Philips, 1979) suggest that the frequency of
sampling is inadequate and that the minimum should be six months at
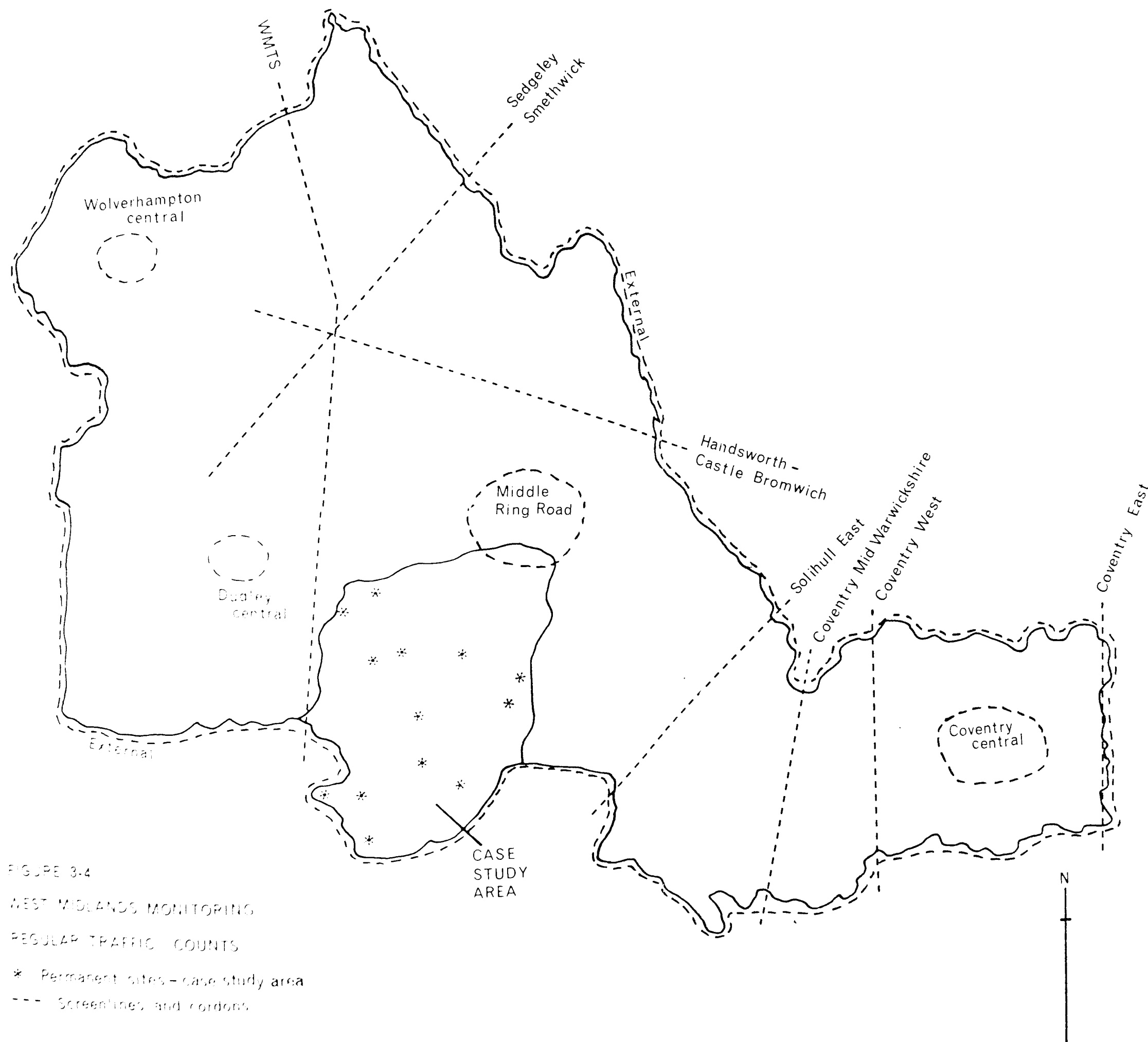
FIGURE 3.4

WEST MIDLANDS MONITORING

REGULAR TRAFFIC COUNTS

∗ Permanent sites – case study area

- - - Screenlines and cordons

Labels on figure: WMTS, Sedgeley – Smethwick, External, Wolverhampton central, Handsworth – Castle Bromwich, Middle Ring Road, Dudley central, Solihull East, Coventry Mid Warwickshire, Coventry West, Coventry East, Coventry central, External, CASE STUDY AREA, N

any one site in a year.   Current maintenance and calibration schedules

in the West Midlands are unable to meet this requirement.

Specific site surveys are undertaken whenever a particular traffic

management or highway scheme proposal requires additional flow/congestion

detail.   A record is kept of each traffic count and factors are avail-

able which can be used to update counts.   Each factor is specific to

an area of the West Midlands (south, west, etc.), but even so lacks the

detail necessary for problem identification.   Some examples of the

results of factoring are given in Figure 3.5.   The level of accuracy

is clearly inadequate.   Specific site surveys, despite location

accuracy at the time of the count, are inappropriate for problem iden-

tification unless they are regularly updated (e.g. annually) and under-

taken over a comprehensive range of the highway network.

Urban Traffic Control (U.T.C.) automatically counted data pro-

vides a partial answer to the data needs of problem identification in

that it is counted continuously and provides detail of traffic flow and

the existence of queues.   However, it is inadequate for problem ident-

ification because it is highly site specific and the sites that do

exist are poorly distributed.   Detectors exist only in association

with traffic signal installations and in areas where U.T.C. is in

operation - currently Wolverhampton, Walsall and Coventry, although

proposals do exist to extend this coverage to Birmingham and the Black

Country.   Even within U.T.C. areas, there are only 88 one way flow and

occupancy detectors providing minimal network coverage.   A problem

associated with automatic flow and queue detection is the inaccuracy of

loop detectors, particularly under congested conditions.

Urban Congestion Study data - covers Birmingham alone whilst that

of the Network Performance Study covers areas within the West Midlands

outside Birmingham.   Survey techniques are of the moving car observer

The following 'predicted' traffic flows were calculated using traffic flow   factors r the appropriate area, calculated from past trends, and compared with actual flow.

A34   STRATFORD ROAD (Traffic Flow 8 - 9 a.m.)

	HAMLET ROAD/FOX HOLLIES ROAD		MARSHA LAKE ROAD		HIGH STREET, DIGBETH		CAMP HILL	
	In	Out	In	Out	In	Out	In	Out
1976 Actual v.p.h.	1540	560	741	541	n/a	n/a	n/a	n/a
Predicted v.p.h.	1291	472	734	724	n/a	n/a	n/a	n/a
1977 Actual v.p.h.	1489	438	842	733	1876	1354	n/a	n/a
Predicted v.p.h.	1291	472	808	797	1594	1000	n/a	n/a
1978 Actual v.p.h.	1553	583	831	586	n/a	n/a	1368	718
Predicted v.p.h.	1488	545	545	829	n/a	n/a	1195	628

A38   BRISTOL ROAD (Traffic flow 8 - 9 a.m.)

	Bristol Street		Licke Road		Weoley Park Road	
1978 Actual v.p.h.	1635	873	1927	1583	1856	1458
Predicted v.p.h.	1811	826	2089	1744	1573	1572

MIDDLE RING ROAD (Traffic flow 8 - 9 a.m.)

	Curzon Street		Jenner Road		Lister Street	
1976 Actual v.p.h.	252	295	1005	566	177	n/a
Predicted v.p.h.	475	251	1260	495	212	n/a
1977 Actual v.p.h.	312	299	1040	505	190	181
Predicted v.p.h.	446	235	1181	464	199	119
1978 Actual v.p.h.	n/a	143	1387	575	169	221
Predicted v.p.h.	n/a	287	1444	568	243	145

n/a = not available.

Factors and traffic flow were made available by West Midlands County Council Monitoring Team.

and anual traffic count types and the data collected consists of
journey times, running times, flows and parking conditions. Despite
relatively good coverage of the day (hourly runs, peak and off peak),
this data is collected only once in every five years, requiring the
use of factors to update information with the problems this involves
(see Figure 3.5). Highway coverage is limited but the data that is
available is accurate for that time at that site.

County Transportation Model. West Midlands County Council use
a package transport model - T.R.A.M.P. (Wooton Jeffreys, 1979) which
consists of a suite of programs designed for the analysis of traffic
surveys and Land Use/Transport Studies. It comprises programs to
analyse survey data, to produce trip end forecasts by category analysis,
to construct computerised route and road networks, to assess shortest
paths and to build multi-path trees of routes, to distribute trips
through a gravity model including modal split, calibrating the model
using maximum likelihood techniques, to assign trips to routes accord-
ing to specified criteria (time, cost, distance), and to produce a range
of ancillary information to be used in evaluation and assessment.

The major advantage it possesses is that the data it produces is
relatively comprehensive, covering the entire strategic highway network
and a number of other roads; it provides estimates of average speeds
which are unavailable from other sources; information is disaggregated
by vehicle type, and it can be produced for any year. It is also an
advantage that much of the other information in the West Midlands is
model based. Compatibility is consequently rarely a problem.

However, there are drawbacks. Mackinder (1979) and Mackinder
and Evans (1981) studied the predictive accuracy of a number of British
transport studies from 1962 to 1971, including work carried out in the

West Midlands. The conclusions are of interest, indicating the level of accuracy which has been and is likely to be achieved in the near future. Every study forecast an increase in total trips (on average 32%), whilst in the West Midlands, the actual situation was that no change occurred. Almost every element of the forecasting process - including population size, household data trip time, etc., was over-estimated. Errors were larger for individual links than for the area as a whole.

Similar conclusions were reached by Robinson (1978), who assessed the accuracy of the West Midlands Transportation Study by comparing observed and assigned flows for a sample of highways. The results from these comparisons are given in Figure 3.6. It is apparent that the model overestimated many flows, especially those of cars and motor-cycles, whilst the predictions for Heavy and Light Goods vehicles were more accurate. This corresponds with the conclusions of Mackinder and Evans. Robinson suggests that these inaccuracies would not have significant implications for noise and air pollution predictions, with the maximum error for noise level on any one link ranging between 3 and 4 dBA. The effect upon accident rates and congestion measures is more significant, although accuracy improves as flow increases and thus as the likelihood of problems occurring. The impact of the inaccuracies is lessened as a result.

Inevitably, the use of model predicted data will lead to impre-cisions in the assessment of highway problems. However, the altern-atives are poor due to the existence of technical and human error coupled with the general unavailability of information for many sites.

The case study required running the traffic model for only part of the West Midlands highway network. This was carried out using 'model compression', requiring specification of a limited number of input and

FIGURE 3.6 - W.M.T.S. COMPARISON OF FLOWS

(after Robinson, 1978)

FLOW	(Observed - Assigned)		$\dfrac{(Observed - Assigned)}{(Observed/100)}$	
	MEAN	SD	MEAN	SD
Cars & Motor Cycles				
0 - 749	- 244	466	- 56 %	106 %
750 - 999	- 107	424	- 12 %	49 %
1000 - 1499	- 153	552	- 13 %	46 %
1500 +	- 321	790	- 19 %	41 %
L.G.V.				
0 - 69	- 27	48	- 58 %	110 %
70 - 139	- 5	81	- 6 %	85 %
140 +	4	92	+ 2 %	56 %
H.G.V.				
0 - 69	- 2	37	- 11 %	83 %
70 - 129	7	60	7 %	70 %
130 +	12	109	2 %	53 %

output nodes through which all trips into and out of the area must pass. The predictive accuracy of the model is reduced marginally by compression since trip assignment is further constrained.

Although the traffic model fails to produce results which are necessarily as accurate as manual or automatic counts, two other factors need to be considered. Firstly, the model itself is based upon actual traffic counts and calibrated against them. Its predictive accuracy is not perfect but remains the best option available. Secondly, since many of the monitoring and site surveys use automatic traffic counters, the data they produce is questionable due to technical inadequacies. An additional attraction is that the majority of local authorities possess a traffic model enabling model based problem identification to be applied elsewhere. The choice of traffic flow information was constrained by a wide selection of practical needs and the model data was the only information available that matched the demands of the study. Extensive use of factors and extrapolatory techniques might have made it possible to combine a variety of data sources - but a number of pilot studies, using data from the A34, A38 and A41 Trunk Roads revealed intractible difficulties (Roe, 1979).

(ii) Parking

Details of on-street parking conditions for the West Midlands provides additional information for the assessment of congestion and traffic flow, although current local policies do not emphasise parking as an issue of any significance in itself. It is also useful for general highway and planning purposes, and as a consequence it was included in the database. Only limited information was available from the W.M.C.C. Traffic Management section. The rest came from personal surveys. A comprehensive survey of all highways in the study area collected details of parking facilities (meters, carparks, yellow lines) and parking

problems (restriction violated commonly, under provision, etc.). The

major problem with this data is that it requires constant updating,

particularly the assessment of problems. This was precluded by the

resource constraint that exist.

(iii) Accident Data

Two forms of accident data were available - accident numbers and

accident rates. The latter were selected for problem identification as

they reflected more accurately, and sensitively, the existence of safety

conditions allowing comparison of sites unaffected by link length. It

is also the method preferred by the Department of Transport

.   The only source of accident information in the West Midlands

is the Traffic Accident Analysis System operated by the Accident

Analysis Unit of W.M.C.C. in collaboration with West Midlands Police.

This system is based upon police records of notified road accidents of

all types - including damage only, personal injury and fatalities.

Each record of an accident is coded and entered onto a police database,

a restricted copy of which is available to the Accident Analysis Unit.

The system is continuously updated and contains extensive details of

incident type, location, causation factors and characteristics of all

incidents from 1974 to date. An example of this information is shown

in Figure 3.7. Data used in problem identification is taken for the

last 3 years, continually rolled forward, ensuring a reasonably repre-

sentative sample of highway conditions (Singleton, 1981).

Two types of referencing are used - network and non network.

Network accidents are located upon a limited range of specified main

routes and the location of each incident is recorded in detail. Non

network accidents cover all other locations and are noted using Grid

References. The locational references are only accurate to the nearest

100 metres.

FIGURE 3.7 : AN EXAMPLE OF ACCIDENT ANALYSIS DATA

ENGLISH ACCIDENT SUMMARY

ACCIDENT NUMBER	DATE	TIME	CLASS	WEATHER	ROAD SURFACE	LIGHT CONDITION	DAMAGE TO PROPERTY	ROAD NAME OR NUMBER	KMEAGE	JUNCTION OR PEDX	COLLISION TYPE
D1288	110677	1730	MIN DAM				YES	LICHFIELD RD BIRM	1040	D6	SINGLE VEHICLE GOES OUT OF CONTROL

ENGLISH ACCIDENT SUMMARY

ACCIDENT NUMBER	DATE	TIME	CLASS	WEATHER	ROAD SURFACE	LIGHT CONDITION	DAMAGE TO PROPERTY	ROAD NAME OR NUMBER	KMEAGE	JUNCTION OR PEDX	COLLISION TYPE
D1319	140677	0600	SLIGHT	FINE	WET	DAYLIGHT	YES	LICHFIELD RD BIRM	1040	1	HEAD-ON COLLISION NOT AT A JUNCTION

VEHICLE DETAILS

TYPE	MANOEUVRE	DIRECTION AND ROAD
GDS 3 & 11/2	GOING AHEAD	TO CITY MAJOR TOW

CASUALTY DETAILS

OTHER FACTORS I	CLASS	SEVERITY	AGE	POSITION
1	DRIVER VEH 1	SLIGHT	46	

Despite its accuracy, and the fact that it is continuously updated, this system is not without its drawbacks, particularly in network description. Locations on the network are referenced from a point in central Birmingham. Nodes are not used and consequently the system is incompatible with other data sources. At the same time, unreported accidents are excluded, particularly affecting damage only incidents. Near misses are not assessed and consequently potential and perceived conflicts are excluded from the assessment. Meanwhile, the police continue to argue for further constraints to be placed upon the release of information.

A more significant issue is that basing the prediction of accident conditions upon data from the last three years assumes that future problem conditions can be assessed adequately through the extrapolation of past trends. There is no attempt to examine the cause of accidents which, in turn, makes design recommendations difficult to formulate. The analysis of the relationships of traffic, personal and highway factors, with actual and potential conflict is only in its infancy. Examples of some recent investigative studies can be found in Older and Shippey (1980), but the findings of much of this work remain untested and only in the earliest developmental stages. Consequently, extrapolatory methods had to suffice for this study.

A final problem arises from the calculation of accident rates based upon traffic model data. Inaccuracies in model prediction can lead to inaccurate accident rate definition.

Despite these problems, accident analysis information is detailed, comprehensive, relatively accurate and technical problems associated with referencing can be overcome with the development of interface programs. It was selected as the source of road safety information as a result.

(iv) Bus Problem Data

An important issue in highway development relates to public transport operation and the identification of specific bus problems. Recently, priority in the West Midlands has been given to improving highway conditions for buses to achieve greater reliability at a lower cost to the travelling public. Thus an indicator of bus problems was needed which would emphasise operating difficulties. West Midlands C.C. have developed a technique specifically for bus problem assessment. Although far from ideal in either assumptions or application, the alternative was data collected by the P.T.E., much of which is already used as input to the bus problem ranking technique.

Output from the technique is a list of problem sites along existing routes. The technique categorises trouble spots, identified through knowledge of the operating system, into a limited number of problem types (e.g. parking problems, turning facilities, width restrictions, and so on). Each site is scored using points, in terms of delay to travellers, importance of the site, operational criteria, safety and the existence of a T.P.P. scheme. Points scores are used to rank sites and weights to allocate priorities between criteria. The details of the method are given in Appendix 5.

Clearly, there are drawbacks and the earlier discussion of points rating techniques is pertinent here. Sites are chosen prior to problem identification; those not already on routes are unassessed (inhibiting development of the network and measurement of accessibility); criteria are selected intuitively rather than in relationship to policies; scores are allocated haphazardly and without objective basis. However, a more adequate source of data is not available. To avoid some of these deficiencies, only the information upon bus operating problems and safety were included. The latter tends to double count the accident information used in problem identification which includes details

of bus incidents but was retained following requests from the County
Council. Weights for criteria were excluded altogether, since
priorities between issues could be accommodated at the problem identifi-
cation weighting stage.

(v) Bus Flow

        Information upon bus flow used in the bus problem ranking process
was derived from the local P.T.E. and published timetables for the P.T.E.,
National Bus Company subsidiary and local independent operators. These
sources were reasonably accurate, despite the fact that they reflected
planned rather than operated mileage. A map of bus routes in the
study area is given in Figure 3.8. Patronage details were not avail-
able in a form sufficiently comprehensive or accurate for problem
identification purposes.

(vi) Noise Level

        A measure of highway associated noise levels was required to pro-
vide detail of environmental conditions. Three sources were
available:

        (i)   specific site surveys (W.M.C.C.);

        (ii)   Environmental Protection Unit (City of Birmingham);

        (iii)   noise prediction models (W.M.C.C.).

        Specific site surveys of noise level are conducted for every major
highway project and traffic management scheme for the purposes of com-
pensation assessment. The result is a collection of noise readings
scattered throughout the county relating to a wide variety of traffic
conditions and dates. The requirements of problem identification
makes use of this data very difficult for reasons similar to those
applying to 'ad hoc' traffic flow counts. Consequently, it was
discounted.

        The City of Birmingham Environmental Protection Unit carries out

N

QUINTON

FIVE WAYS

HARBORNE

EDGBASTON

WOODGATE

SELLY
OAK

NORTHFIELD

KINGS
NORTON

LONGBRIDGE

FIGURE 3.8

frequent but irregular studies of traffic noise condition throughout the Birmingham area. However, no information is collected for areas outside the City boundaries and for this reason, and due to its irregular characteristics, it was of limited use. The predictive noise level models derived by J.U.R.U.E. (1975, 1976) and adopted for the West Midlands, provide the only source of comprehensive data which is both in a useful format (L_{10}dBA) and which is predictable for any given date, given appropriate traffic flow information. It was selected for those reasons. The West Midlands model is based upon an empirical regression model relating noise and traffic flow, derived in the London Borough of Hammersmith, and Kensington and Chelsea (J.U.R.U.E., 1975, 1976) and recalibrated for use in the West Midlands, using information from 20 minute observations at 39 sites. It produces estimates of mid link noise levels. The observations of traffic flow consisted of a two-way classified count and simultaneous recording of traffic noise. A dependence relationship was derived from comparisons between noise levels, traffic flow and site characteristics. The resultant noise models are shown in Figure 3.9.

They utilise output from the West Midlands traffic model and consequently suffer from the inaccuracies that bedevil traffic modelling and prediction. They are also much more adaptable to reproducing mean noise level than specific site conditions. At 75 dBA, the 95% confidence interval in the prediction of mean noise level using the 5% significance level model was 0.4 dBA. For point estimation (at a specific site), the confidence levels are much larger (+ 2.5 dBA [at 75 dBA]), although obviously still well within acceptable limits. Clearly, the model provides geographically and temporally comprehensive results; however, they are only applicable within the range of validity of the model, as determined by the range of conditions included in the sample from which they were derived (J.U.R.U.E., 1977). However,

FIGURE 3.9 - W.M.C.C. NOISE MODELS - WEST MIDLANDS

(Source, J.U.R.U.E., 1977)

Aston University

Content has been removed for copyright reasons

overall the predictions of the models are sufficiently adequate for problem identification.

(vii) Air Pollution

No assessment is made of air pollution levels over the whole of the county.   The only source of data is a set of environmental models developed by J.U.R.U.E. (1975, 1976) to estimate pollution levels from traffic flow data using a similar approach as for noise conditions. Models were developed to assess carbon monoxide and smoke, variables selected because of their relevance to environmental condition, ease of prediction and distinct dissimilarity to each other in characteristics or effects.   Other variables might have been used (e.g. No) but data is not readily available.   At the same time, other indicators are closely related to the two selected and would add little to the detail of air conditions in general.

In the case of carbon monoxide, only the nearside flow of cars, the car velocity and wind speed are needed to derive the regression model giving carbon monoxide estimates in parts per million.   Wind speed was found to be insignificant at the 5% level.   In the case of smoke, the independent variables are total nearside flow of H.G.V's, L.G.V's and buses (a single variable), the nearside flow of cars and windspeed (w).   The resulting model gave smoke levels in micrograms/m^3. Both models of CO and smoke are shown in Figure 3.10.

The problems associated with using data generated from traffic models have already been outlined.   They are relevant to environmental models of this type when traffic flow sources are traffic model outputs. An alternative approach to environmental assessment was not available without the collection of substantial quantities of data or the derivation of new environmental models and relationships - both precluded by the research constraints.   The overall accuracy and convenience of the

Aston University

Content has been removed for copyright reasons

Aston University

Content has been removed for copyright reasons

J.U.R.U.E. models made the design of alternative sources unnecessary.

(viii) Traffic Signal Data

This section considers information upon the time settings, geometry and location of traffic signals, information needed in the calculation of junction capacity, and for design of solutions to problems at these sites. A discussion of detector flow and occupancy data can be found in the section upon flow and congestion data. The location of traffic signal installations was obtained from the U.T.C. section of W.M.C.C. Unfortunately, data was available of timings for only the most recently installed sites. Consequently, a survey of most sites had to be carried out. Due to the use of vehicle-actuated variable time signals for most areas in the case study, peak hour average values of green times, lost times, cycle times and split times had to be calculated. To be compatible with traffic model data and to reflect problem conditions at their worst, morning peak data was used. Surveys over the whole of the morning peak were necessary at many sites, to obtain average values which were representative. The full range of information collected was:

site location,

traffic signal installation number,

pelican or road junction,

number of arms,

cycle time,

green time,

lost time,

lane widths,

turning movements.

Much of this information was used in the calculation of junction capacity, itself used as an indicator of congestion and delay.

(ix) Node Type and Geometry

This information was for those junctions that were unsignalled.
A survey of junction sites was carried out for roundabouts, priority
junctions and mini-roundabouts forming the basis of capacity calcul-
ations.   Entry and exit widths, link lengths, weaving widths, island
dimensions and other relevant data was collected specifically for prob-
lem identification, as this data was not held by W.M.C.C.   The need to
update this information will arise in the future, but should not prove
prohibitive as all changes in junction characteristics are now noted
by the County Council.

(x) Land Use

The inclusion of land use data was to provide additional inform-
ation upon the implications of a particular highway problem.   In itself,
it did not provide evidence of problem conditions.   The source of data
was the environmental computer model package which provided information
for noise and air pollution conditions.   The original source was a
series of development plan review maps and a more recent series of
large scale maps.   The age of these sources ranged from 1965 to 1976.

The classification of land uses was a simplified version of the
national land use system.   The following categories were derived:

> residential,
>
> industrial and manufacturing,
>
> retailing,
>
> countryside and open space,
>
> offices and public buildings,
>
> others.

The age of the data and the rather coarse nature of its categor-
isation has meant that the use to which it can be put is limited.   Con-
tinuous updating is necessary but unavailable, and as a consequence its

use is restricted to providing an impression of the characteristics of

an area. It was not used directly in the problem assessment process.

Alternative information was not available.

(xi) Road Class and Index

Information upon road type and geometric characteristics is used

in the assessment of highway capacity and to provide other ancillary

detail. It is held in the traffic model in digitised form as road

class and index. The classification used is shown in Figure 3.11 and

is based upon the Department of Transport highway speed/flow curves,

used to determine free flow speeds and capacities for the West Midlands

traffic model.

(xii) Maintenance conditions

Two types of maintenance information were valuable as indicators

of highway problems:

      (a) structural condition;

      (b) problems associated with undertaking maintenance work.

Within the West Midlands, one source of data was available for

each. The assessment of structural condition is assessed using the

Maintenance, Assessment, Rating and Costing of Highways (M.A.R.C.H.)

system. It comprises

> 'the collection of data relating to the con-
> dition of the highway based against objective
> standards and subsequent processing of data,
> with further technical and financial data
> input, carried out by a series of computer
> programs to produce a list of remedial high-
> way works in a priority or 'needs' order.'

(M.A.R.C.H., 1977)

A detailed description of the methodology is given in Appendix 6

and an outline below. It begins by deriving a highway network for the

county, divided into short maintenance lengths. Each length is reason-

ably uniform and has attached to it a substantial quantity of ancillary

FIGURE 3.11 - DEFINITION OF ROAD CLASS AND INDEX WITH

ASSOCIATED CAPACITIES AND SPEEDS

Class	Index	Description	Free Flow Speed (km/hr)	Free Flow Limit (p.c.u./hr.) one dir.	Limiting Capacity (p.c.u./hr.) one dir.	Speed at Limiting Capacity (km/hr.)
0	0	Urban Dual 3 Motorway	80	5100	7200	66
0	1	Urban Dual 2 Motorway	80	3400	4800	66
1	0	Urban Dual 3, All Purpose, 80 km/hr. Speed Limit	65	4200	6600	56
1	1	Urban Dual 2, All Purpose, 80 km/hr. Speed Limit	65	2800	4400	56
1	2	Urban Dual 3, All Purpose, 65 km/hr. Speed Limit	50	1800	3300	30
1	3	Urban Dual 2, All Purpose, 65 km/hr. Speed Limit	50	1200	2200	30
2	0	Urban Single 2, Outer Area	45	500	1000	25
2	1	Urban Single 3, Outer Area	45	650	1300	25
2	2	Urban Single 2, Intermediate Area	35	350	600	25
2	3	Urban Single 3, Intermediate Area	35	450	800	25
3	0	Urban Single 2, Central Area	25	250	500	15
3	1	Urban Single 3, Central Area	25	330	650	15
3	2	Narrow Single 4	40	400	2000	22
4	0	No Major Intersection	–	–	2000	47
4	1	Less than 1 Major Intersection per km.	–	–	1700	27
4	2	1-2 Major Intersections per km.	–	–	1200	20

information (road geometry, layout, pedestrian and traffic flow, etc.). Data upon structural condition is collected manually at regular intervals and standards used as a basis against which conditions are assessed. Priorities for expenditure are based upon usage and condition. The final output is a points scored ranked listing - the M.A.R.C.H. rating.

M.A.R.C.H. has a number of advantages for problem identification and, in particular, it provides a constantly updated, fully comprehensive review of structural conditions. There is no rival in the West Midlands for this information, although similar techniques exist elsewhere (e.g. CHART). However, its limitations need to be recognised. It uses a valuation and weighting mechanism to reflect priorities without reference to local political preferences. Computer referencing is through a system incompatible with other sources of data without redefining the system of links and nodes, whilst the results of M.A.R.C.H. ratings tend to be accepted unquestioningly due to their computerised and objective appearance. Despite all this, it remains a useful tool if treated with caution.

A different view of maintenance problems is one based upon difficulties of undertaking regular maintenance work. A technique to identify problems of this type has been devised by the West Midlands Minor Works Team (1980). It rests on the belief that improvements to highways can relieve maintenance conditions in one or more of the following ways:

(a)   reduce the requirement for diversions, lane closures, traffic control, Sunday or night work;

(b)   reduce disruption caused by statutory undertakers' work by road widening;

(c)   reduce requirement for temporary patching by provision

110

of footway kerbs, drainage, etc.;

(d)   reduce the requirement for handlaying or difficult work.

Scores within the range of 0 - 4 are allocated to sites according to traffic f ow and road characteristics (width and carriageways) with additional points if there is a significant mains presence or absence of kerbs or drainage facilities (see Figure 3.12).

It was considered important that this type of maintenance problem should be reflected in the generation of schemes since regular maintenance needs can be predicted and problems of this type foreseen.   The technique developed by minor works reflects a simple approach to problem identification but which exhibits many of the deficiencies typical of points rating techniques.   In particular, scores and scales ignore issues of measurement and valuation.   Despite this, it provides an indication of regular and predictable maintenance problems as long as the inadequacies outlined above are noted.

(xiii) Bridges

Bridge problems present their own specific difficulties for highways having ramifications for safety, public transport accessibility, development, congestion and the like.   Clearly, many of these problems are already accounted for by other criteria (e.g. road safety, congestion and delay, etc.), but the existence of a substantial number of poor bridges in the West Midlands, a local political desire to improve them and the existence of a technique to assess their condition led to the inclusion of a bridge problem criterion in the problem identification methodology.

The Bridge Problem Ranking technique is described in Appendix 7. It covers all bridges in the county using a points based approach to score problem conditions - including weight and height limitations,

FIGURE 3.12 - MINOR WORKS MAINTENANCE CONDITION ASSESSMENT

Traffic Flow and carriageway characteristics are used as a surrogate
for difficulties in maintenance and as an indicator of maintenance cost

SINGLE CARRIAGEWAY SCORES

Road Width (metres)	2 way peak hour flow veh/hour				
	200	200-600	600-1200	1200-2000	2000
5	0	1	2	2	2
5 - 7	0	0	1	2	2
7 - 9	0	0	0	1	1
9	0	0	0	0	1

DUAL CARRIAGEWAY SCORES

Width of single c/way.	1 way peak hour flow veh/hour				
	500	500-1100	1100-1800	1800-2600	2600
6	0	1	2	2	2
6 - 7	0	0	1	2	2
7 - 8	0	0	0	1	1
8	0	0	0	0	1

Add to score   1   for significant mains presence
                1   for lack of kerbs or drainage

P.T.E. problems, maintenance and road safety deficiencies, etc. Weights are used to reflect priorities between issues, but are not derived from current policies and do not necessarily adapt to changes that occur in them.

Clearly, it has drawbacks, particularly because of its use of varying scales, subjective ratings, implicit valuation and double counting. However, three reasons lay behind its use for problem identification. Firstly, bridges are numerous in the West Midlands and their condition is generally poor - they thus represent an important highway problem which needs to be recognised. Secondly, this system provided the only source of bridge information. Thirdly, West Midlands engineers were very keen to use the information it provided and thus integrate bridge problems and their solution into the T.P.P. process. Consequently, data from the Bridge Ranking technique was used to help indicate the existence of development and congestion problems, although the inadequacies it exhibited particularly in terms of data duplication were noted.

(xiv) Other Link Characteristics

A number of other items of data were useful for problem identification and highway planning purposes.

road name - derived from large scale local maps

road classification - A, B, M, unclassified, etc

priority area - indication was given when a link passed through

a conservation, priority, inner city or development area

1 or 2 way - derived from a personal survey

district - the district authority in which the highway lies

level crossings - derived from large scale maps

There is little doubt that some of the problem criteria described here and used for problem identification exhibit deficiencies. Where

112

data of this sort has been used, three factors need to be noted:

(a)   In many cases there was no alternative.   Omission of, say, the
       bridge problem ranking information would have meant that an issue
       of local importance would have received inadequate consideration.

(b)   Through a process of discussion, many areas where data sources
       could be improved have emerged.   These improvements have been
       implemented wherever possible.

(c)   Problem identification as a methodology is far from invalidated
       by the use of suboptimal data.   The initial objective is to
       develop the method and assess its application in a practical con-
       text.   Given the existence of a number of local practical con-
       straints, problem identification represents the best possible
       reflection of highway conditions.   Improvements in data sources
       can be incorporated in time.

     Despite inadequacies in data, problem identification should still
produce a substantially clearer picture of the existence of highway
deficiencies and the need for more accurate and consistent approaches
to assessment and monitoring.   For the moment, it is enough to recog-
nise the existence of deficiencies in data and to be aware of their
ramifications.

     Figure 3.13 shows the objectives derived from county transport
policies for 1979 and the criteria used to measure their achievement
(or otherwise), the sources of data for each and method of assessment.
In most cases, the criteria measure achievement directly - for example,
accident rate is a straightforward indication of road safety conditions.
However, delay and congestion is measured rather less easily and in-
volves assessing the capacity of highways and their relationship to
traffic flow, producing a measure of highway loading.   Appendix 8
describes the capacity calculations and the derivation of load values
for each link and node.

FIGURE 3.13 - THE MOVEMENT FROM POLICIES TO CRITERIA

IN PROBLEM IDENTIFICATION - 1979

POLICY	OBJECTIVES TO MEET POLICIES	CRITERION TO MEASURE OBJECTIVE ACHIEVEMENT
(1) To ensure that roads, etc., are maintained in a safe, serviceable condition.	(A) Provision of access to development (2).	(i) Overload (flow/capacity) bridge problem score (A).
(2) To provide for transport infrastructure to developments, etc., that will provide employment and homes.	(B) Promotion of the efficient operation of private transport (1), (3), (5), (7).	(ii) Overload (flow/capacity) MARCH rating maintenance (minor works) score (B).
(3) To continue to develop the strategic highway network.		
(4) To reduce road accidents.	(C) Promotion of the efficient operation of public transport (1), (3), (5), (6), (7).	(iii) Bus problem score (operational and safety) (C).
(5) To increase the capacity of transport facilities, both public and private.		
(6) To give priority to public transport.	(D) Reduction of accidents (1), (3), (4).	(iv) Accident rate (no./per km.) (D).
(7) To restrain the use of private cars in the peak period, and where congestion is a problem.	(E) Reduction of the impact of transport on the environment (8).	(v) B(A) level. CO level smoke level (E)
(8) To ensure that both the social and physical environment are assessed in transport developments.		

The factorial process takes each of the problem criteria and provides the mechanism to aggregate this information and compare it in a meaningful way.

The Network Options

The process of problem identification cannot end with the derivation of a set of highway problem criteria. Problems have a spatial dimension and they need to be defined in locational terms so that reference can be made to them and so that different problem types at differing locations can be compared. Clearly, the choice of referencing method is important, a fact emphasised by Bohn (1972). Two possible methods exist - site specifically; or in more general areal terms. The former is closely associated with accident sites, bridge problems and bus operational problems, the latter to inadequate accessibility, or urban blight.

In many ways, the latter areal type of problem is a direct function of the former site specific ones. Poor accessibility is caused by a combination of traffic congestion and inadequate public transport; generally poor environmental conditions are the consequence of specific site traffic operation conditions. Site specific referencing requires a technique based upon highway links and nodes (junctions) in a way similar to that used by traffic models. Areal descriptions are often based upon grid squares. The latter approach is more difficult to design and implement and has been used rarely. The former was selected for its familiarity, experience with networks of this type and because much of the problem information was already in this form.

The following requirements for a referencing system for problem location were derived. It should provide:

(i) a clear and precise means for problem referencing;

(ii) a framework for problem identification facilitating the

114

aggregation of highway problems in locational terms;

(iii) a framework for the digitisation of problem information through the definition of links and nodes suitable for computer storage and processing;

(iv) comprehensive coverage of highways in the county to facilitate comprehensive problem identification.

Achievement of this last requirement was important, yet difficult. It was essential that problems should not be overlooked solely because the highway network was inadequate. Ideally, every highway in the county would be included, but this would require extensive additional data collection and the design of a new network upon which it could be located. Intuitively, it was felt that the majority of highway problems relevant to the T.P.P. process would be located upon a limited part of the highway network consisting in the main of the major highways. This feeling was reinforced by the knowledge that only schemes valued at over £50,000 are subjected to the Priority Ranking process - and for schemes of this cost to have any possibility of being considered worthwhile, they would need to generate net benefits substantially in excess of cost - that is greater than £50,000. This is unlikely for any site unless it lies in the Strategic Highway network. Consequently, derivation of a comprehensive network for the whole of the West Midlands was unnecessary, although ideal if it was an easy option. To test this assumption, an assessment of the allocation of resources was made for the 1979 - 1980 T.P.P. The results, summarised in Figure 3.14, indicate a concentration of expenditure upon the Strategic network beyond expectation. The predominance of strategic expenditure was given added significance by a fact not revealed in these figures, that all proposals not located on the Strategic network were bridge problems, identified through the Bridge Problem Ranking technique and which, as a result, would not be missed if only

FIGURE 3.14 - T.P.P. SCHEMES : COMMITTED AND PROPOSED

STRATEGIC NETWORK

COMMITTED EXPENDITURE	SCHEMES ON STRATEGIC NETWORK	TOTAL SCHEMES	% ON STRATEGIC NETWORK
Needs of Industry	21	27	78
Needs of Housing	10	11	91
Highway Network	30	32	94
	61	70	88

PROPOSED EXPENDITURE			
Needs of Industry	6	12	50
Needs of Housing	7	10	70
Highway Network	40	40	100
	53	62	85

TOTAL COMMITTED AND PROPOSED	114	132	86

COMMITTED EXPENDITURE	Strategic £(000)	Total £(000)	%
Needs of Industry	4981	5624	89
Needs of Housing	2389	2582	95
Highway Network	58440	62407	94
	65810	70613	93

PROPOSED EXPENDITURE			
Needs of Industry	5115	6037	79
Needs of Housing	2330	4142	56
Highway Network	57454	57454	100
	64899	67633	96

TOTAL COMMITTED AND PROPOSED	130709	138246	95

a Strategic network were used.   It also suggests that bridge problems

are the only ones likely to be located off this network.   Although

the introduction of problem identification could lead to a redistribution

of investment proposals as problems are clarified and redefined, its

likely effect is more in terms of readjusting priorities between the

types of problems known to exist and in providing information upon

their structure than exposing new problems upon less used highways.

With this discussion in mind, 5 highway networks were identified

in the West Midlands:

(i)   TRAMS - Transport Referencing and Mapping System;

(ii)   Accident Analysis Network;

(iii)   UTC network;

(iv)   MARCH network;

(v)   TRAMP - the traffic model network.

(i)   TRAMS

The Transport Referencing and Mapping System (TRAMS) consists of

a set of computer programs held by W.M.C.C. which contain data upon

highways, land use and property.   It was developed by T.R.R.L. follow-

ing an extensive review of the land use and planning needs of local

authorities (Williams, 1977; Perrett, 1977).   TRAMS represents the

highway network as a series of segments, each of which has data

attached including road classification, street name, house number and

the Ordnance Survey grid reference of each end of the segment.

Segments are strung together to form numbered routes which re-

present the structure of the highway network.   Data for the segments

are held in a number of computer files, each organised on the basis

of an identifier (for example, grid reference) and linked to the

other files.   Thus, data can be retrieved in a number of ways - by

address, street, area, road type, etc.   Segments are defined by the

116

nodes located at the end of cul-de-sacs, at all junctions, at E.D.,

county and district council boundaries, where road classes change.

TRAMS is intended to be a general referencing system facilitating data

processing and is separate from any data with which it might be used.

The programs produce computer files, the layout of which is shown in

Figure 3.15. The TRAMS system includes routines enabling the user to

produce maps based upon the information held in the network files.

These maps can be produced to any scale, showing all or part of an

area. Figure 3.16 shows a sample plot.

TRAMS is designed to produce a framework whereby data can be

referenced in various ways for use in different applications - for

example problem identification. Although the data files are maintained

centrally within the West Midlands, programs for different applications

could be written by various departments to suit their own requirements.

The system is still under development in the West Midlands. It

possesses a number of advantages over other network approaches. These

include comprehensive geographical coverage, graphical facilities and

a number of ways of referencing information. However, there are a

number of disadvantages. In particular, the methods used to reference

information are unique and as a result some form of interface programs

are needed to facilitate data transfer from information source to net-

work. This particularly affects traffic model data, which forms a

significant input to the problem identification process. The system

is not yet fully operational and insufficient computer hardware or

software exists for adequate implementation. This situation is un-

likely to improve for some years. These problems make the use of

TRAMS for problem identification difficult at present. However, with

further development, it is likely to become a significant aid to the

synthesis and interpretation of highway data.

FIGURE 3.15 - T.R.A.M.S. FILE SYSTEM

STREET FILE ROUTE FILE NODE FILE

```
STREET FILE                    ROUTE FILE                     NODE FILE

┌─────────────────┐            ┌─────────────────┐            ┌──────────────────┐
│ Street code     │            │ Route number    │            │ Node number      │
│                 │   Route    │                 │   Node     │                  │
│ Settlement      │ ─────────► │ Road class & No.│ ────────►  │ Grid reference   │
│   code          │    No.     │                 │    No.     │                  │
│                 │            │ Street code     │            │ Connected nodes  │
│ Street name     │            │                 │  Route     │ and associated   │
│                 │   Street   │ Node Numbers    │ ◄──────    │ routes           │
│ Routes con-     │ ◄───────── │                 │    No.     │                  │
│ taining this    │    Code    │ Property        │            └──────────────────┘
│ street          │            │ numbers         │
└─────────────────┘            │                 │
                               │ Area codes      │
                               └─────────────────┘
```

SPECIAL
ADDRESS
FILE

GRID REFERENCE
FILE

```
                    ┌──────────────────────┐
                    │ Property number      │
                    │                      │        Grid        ┌───────────────────┐
                    │ Street code          │      reference     │ Grid reference    │
                    │                      │ ─────────────────► │                   │
                    │ Route number         │                    │ Node number       │
                    │                      │                    └───────────────────┘
                    │ Node number          │
                    │                      │
                    │ Grid reference       │
                    │                      │
                    │ Property descrip-    │
                    │ tion Land use        │
                    │ code                 │
                    └──────────────────────┘
```

Street code

Route number

Property number

Node number

Node number

117(ii)

FIGURE 3.16

EXAMPLE OF A TRAMS PLOT

(ii)   Accident Analysis System

The method of referencing accident data originated in the City of Birmingham before local government reorganisation.   Major roads (motorway, A, B and certain other roads) are divided into 100 metre lengths, the starting point being the centre of the city.   Each accident is coded and allocated to a 100 metre length on a route (e.g. A45, between 1600 and 1700 metres from Birmingham), if it lies on the main network.   Non-network accidents are referenced by grid square. It is currently used to store accident data alone.

Overall, it possesses few advantages.   In particular, it is simple to use and understand.   There are considerable practical difficulties.

(a)   Not all the network is referenced directly.   This makes comparison and interpretation difficult.

(b)   The method of referencing is unique and it would be difficult to make other sources of data compatible with it.

(c)   It is limited in ability to produce a range of accident inform- ation.   Accident rates, for example, are not available and further programs are needed to calculate this information.

Current attempts to restructure the accident analysis system are only in their earliest stages and will not be completed in time for their integration in problem identification.

(iii)   UTC

The UTC traffic signal computer network is incomplete in coverage since it provides a referencing system only for those highways and junctions where there are computer controlled signals.   This includes Wolverhampton, Walsall and Coventry.   Even after extension to the Black Country and Birmingham, it will provide only sparse coverage of junctions and highways, wholly inadequate for problem identification

purposes. The extension of the UTC network has now been postponed until at least 1984, further precluding its use.

(iv) MARCH

The MARCH referencing network identifies a series of routes, using the centre of Birmingham as a starting point. These routes are then divided into suitable maintenance lengths (based upon carriage-way changes or major junctions) and referenced, for example, as A45, maintenance length 5, with a more recognisable title usually based upon house numbers (e.g. Coventry Road between numbers 132 and 387). It possesses a number of advantages, since it covers all adopted high-ways in the county, it already acts as a register of highways and it could be made compatible with the TRAMS network relatively easily. However, it is not without disadvantages. The method of referencing is not compatible with many other data sources, in particular traffic model data, and although it contains a considerable body of ancillary information, much is irrelevant and often limited in range. There is no doubt that the MARCH network could provide a suitable basis for highway problem identification. However, it was rejected for two reasons. Firstly, its unique referencing system, and secondly the particular incompatibilities with the traffic model data. Although future developments might see the combination of TRAMS with MARCH and the traffic model through a series of interface programs, this is not possible at the moment and the temporal requirements of the research preclude its development.

(v) TRAMP

TRAMP is the computer traffic model used by W.M.C.C. to assess, evaluate, predict and describe the consequences of alternative trans-port policies and plans. Its network consists of a series of high-way links and junction nodes. Attached to this skeletal structure

119

is a substantial quantity of observed highway and traffic information used to predict future conditions. The network itself is not comprehensive and only the Strategic Highways in the county (including all motorway, A, B, and a number of other important minor roads) are modelled. TRAMP, as a framework for problem identification, possesses a number of advantages:

(a) It is computer based, defined in a way eminently suited for highway problem identification;

(b) Much of the data needed for problem identification is already attached to it;

(c) The only source of environmental and land use data in the county is produced using model flow output;

(d) Prediction of future highway conditions is possible using the model. In theory, any future year can be simulated given assumptions about car ownership levels, economic development, etc. This information is the best available in the West Midlands.

Although a number of disadvantages in its use clearly exist - particularly its lack of comprehensive coverage, the inability to produce data for highway nodes rather than links, and the inaccuracies inherent in traffic modelling at this scale - it was chosen as a basis for network construction for problem identification. Coverage of extra links would always be possible by adapting the network and collecting additional data, and improved calibration techniques would help to overcome some of the inadequacies of accuracy. The traffic model network is reasonably compatible with many other data sources, although clearly adaption of accident and maintenance data will be necessary. As noted earlier, it forms the basis for the calculation of environmental information which constitutes a significant input to the problem identification process. It also possesses a facility for compressed application for a limited area of the county, reducing

the demands upon computer time and storage whilst still providing a full range of information. The exact choice of network is indicated in Figure 3.17 and a summary of the characteristics of each option is given in Figure 3.18.

Site Definition

The definition of highway sites for problem identification is an important issue, since it affects the type and priorities of problems that will emerge. The use of sites which are clearly over long will tend to conceal small scale but possibly significant problems as their effects can be diluted by stretches of highway exhibiting adequate conditions contained within the same link storage space. Too small sites might divide a problem, lessening its overall impact and encouraging solutions which are inappropriate or ineffective.

The majority of highway problems can be allocated to one of two groups:-

(i) link problems - environmental conditions, severance, traffic queues, accident conditions, etc.;

(ii) nodal problems - other aspects of accidents, over-load, etc.

However, the distinction between the two is unclear in many circumstances. Nodal problems of congestion can cause queues to form along adjoining highways - the cause therefore may be nodal whilst its effects are along the link. In defining problem conditions the ideal methodology would allocate problems to the type of site associated with their cause rather than their effect, but this is difficult if only because it is sometimes difficult to separate the two. It would also lead to problems in comparing sites defined in a different way. Spatially continuous data would be ideal, but this
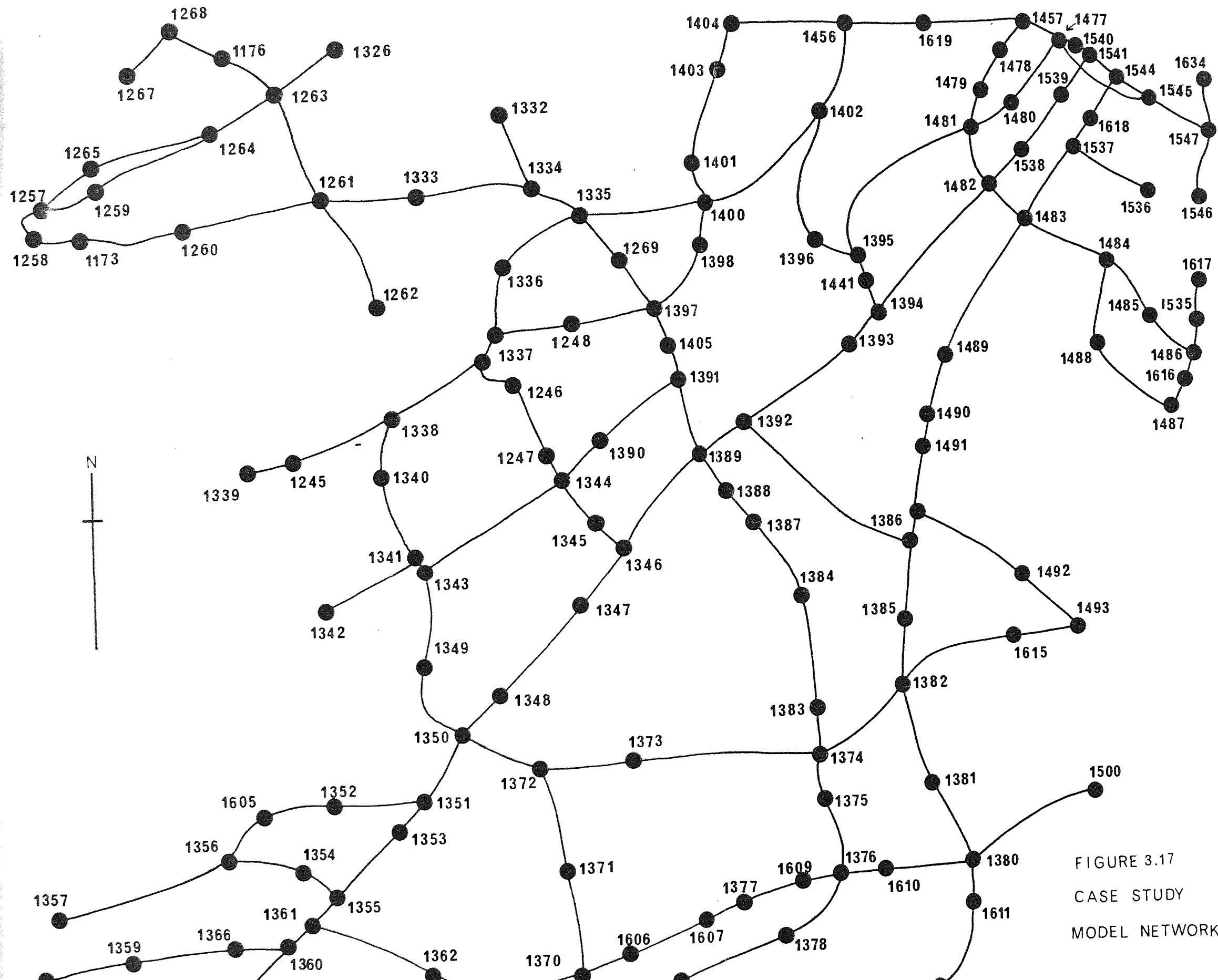
FIGURE 3.17

CASE STUDY
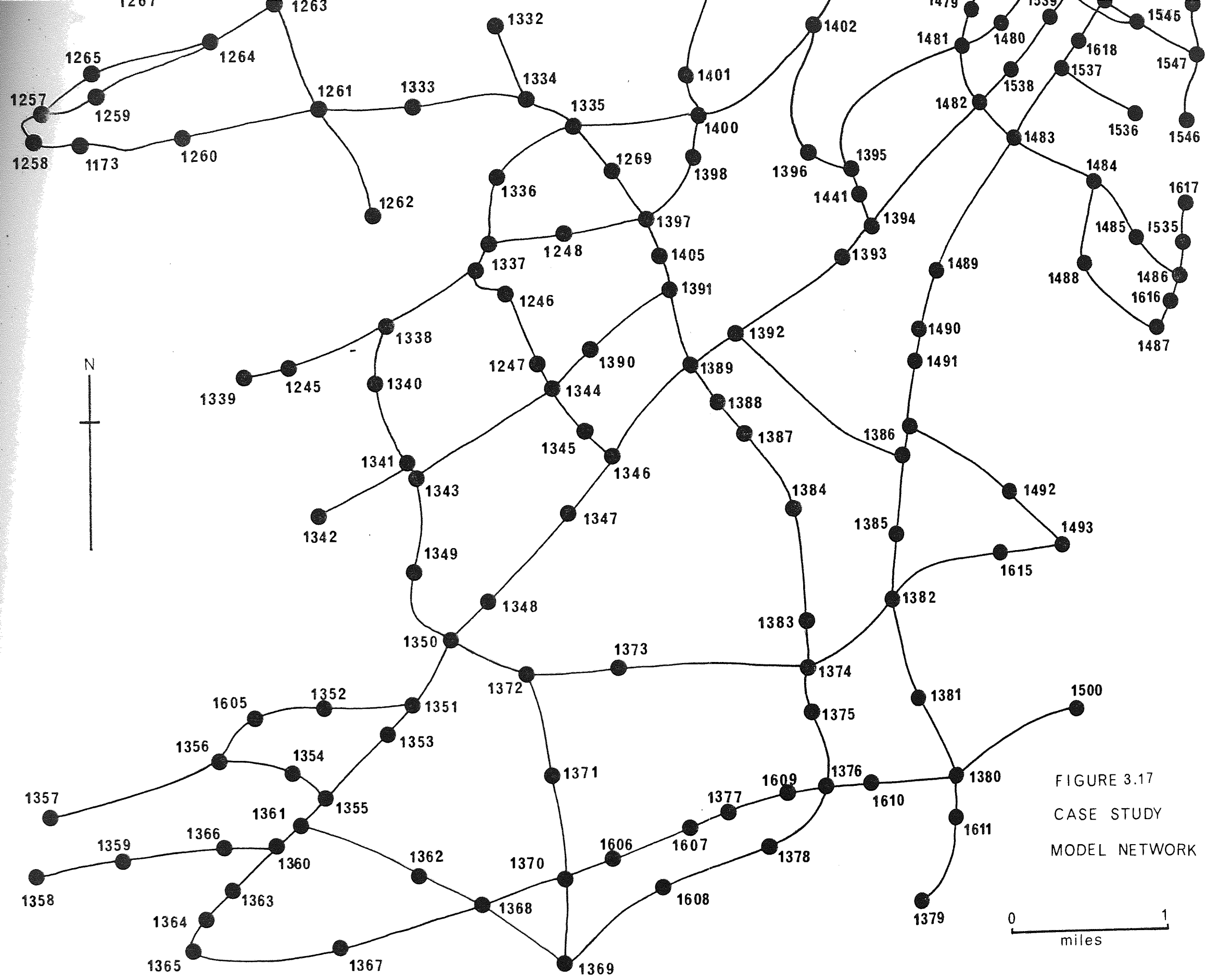
MODEL NETWORK

FIGURE 3.17

CASE STUDY

MODEL NETWORK

FIGURE 3.18 - NETWORK OPTIONS

NETWORK	CHARACTERISTICS	DEFICIENCIES	ADVANTAGES
TRAMP - TRAFFIC MODEL	Strategic traffic model. Used for prediction and evaluation purposes.	Not comprehensive. Limited detail.	Computer based. Predictions available for any year. Environmental models and land use data. Considerable additional data available.
TRAMS	Data network referencing system. Under development.	Not yet complete. No data attached. Serious delays before available.	Computerised. Comprehensive. Purpose built.
ACCIDENT ANALYSIS	Accident location network. Referenced from Central Birmingham.	Not comprehensive. Incompatible referencing system. Limited data. Under review. No environmental data available.	Computer based.
MARCH MAINTENANCE RATING	Maintenance assessment network.	Limited useful data. No environmental models available.	Comprehensive. Computerised. Additional data.
U.T.C.	Traffic signals network.	Very limited coverage.	Computerised.

is currently not a possibility, and as a result, the definition of

sites prior to problem definition has to be made.   A second choice

is to divide the network into links and nodal areas (see Figure 3.19)

so that node and link problems can be defined separately.   Nodal

areas would include short lengths of highway links leading away from

each junction.   The difficulty is that data is in general not defined

in this way nor networks in common use designed to accept information

of this sort.

The final alternative is to use link information for the defin-

ition of highway problems.   This is far from the ideal suggested by

Massam (1980), but given the discussion above, reflects the con-

straints imposed by data sources and existing network characteristics.

Figure 3.20 shows a typical arrangement.   Problems with cause and

effect lying wholly within the same single link present no difficulties.

Where the problem effects spread over a number of links, the situation

is less satisfactory, but given common sense and a little foresight,

the spatial nature and extent of the problem condition should soon be

apparent.   Wholly nodal problems cause the greatest difficulties and

it is hoped that problems allocated to links for the sake of organis-

ational, administrative or technical reasons will draw the attention

of the user to examine the nodal conditions at either end.   To

encourage and help in this process, a separate file of nodal inform-

ation has been created including details of junction type, geometry,

capacity and specific conditions.   It is not directly comparable

with the link data which continues to form the basis of the problem

identification methodology, but acts as a reminder to the user that

site definition is more a function of data availability than problem

characteristics.

Given the decision to use the traffic model network, the
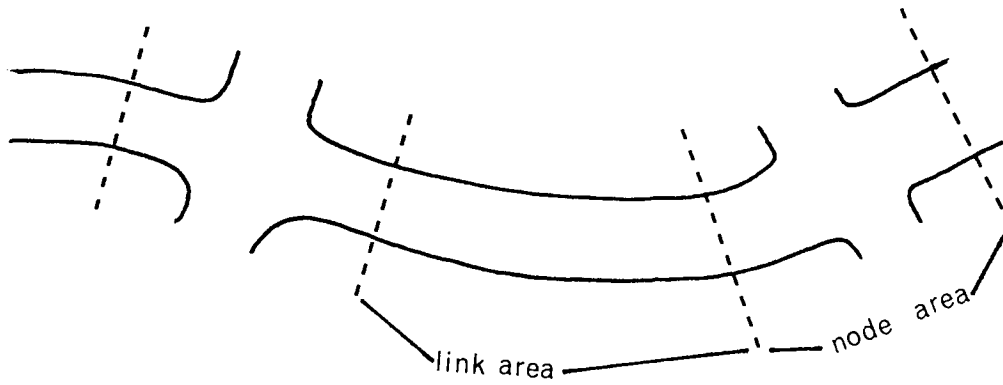
FIGURE 3-19   LINK AND NODAL AREAS
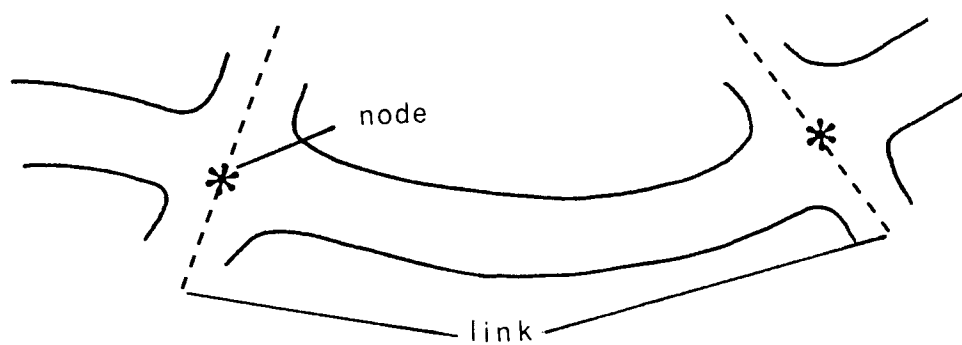
FIGURE 3-20   TYPICAL SITE DEFINITION

specification of sites was determined by the location of nodes upon
this network. The links between nodes varied in length up to a
maximum of 2 km but the majority were less than this and relatively
consistent in size, making comparisons between them more meaningful.
Undoubtedly, the question of site definition affects the subsequent
identification of problems. After carrying out the case study, it
may be necessary to redefine highway sites - and certainly, the effect
of definition will be noted as the development of problem identific-
ation continues.

Priority Weights

Priority weights form an important part of problem identific-
ation. They reflect the priorities between problem types which are
he d by the political decision-makers and without explicit weights
these priorities cannot be incorpora ed in a systematic and consistent
way and the allocation of resources to highway investment will fail to
reflect local preferences.

The use of priority weights in evaluation is common and not con-
fined to the West Midlands. However, they are not universally
welcomed and dissenting views are typified by the recent discussion
from Mishan (1982). He suggests that there are two main types of
weight applied within evaluation by what he terms the 'revisionists'.
They are 'ethico' weights, aimed at reflecting issues such as
priorities for income redistribution and the need to achieve a realloc-
ation of resources through public investment; and 'politico' weights,
which aim to reflect current policies but which do not necessarily
reflect ethical ideals. Neither, in his opinion, are a valid element
of the evaluation process, for they lack consistency in application
over time particularly as political administrations change. Compari-
sons between the merits of projects or the severity of problems are

123

meaningless as a result.   Each administration is presented with a different set of priorities for investment, which simply aims to reflect the views held by decision-makers.   The 'true' value of a project or a problem is lost, and the evaluation process simply becomes a tool to back up the policies of the current decision-makers.

There is certainly some validity in this argument.   Mishan stresses that political ideals and ambitions are inextricably entwined with evaluation and decision-making, but that economic evaluation (and by implication, other forms) should aim to leave the political element alone and present traditional economic assessments which are comparable over time and between different political administrations.   The political decision-making process can then use this information and introduce its own values and bias as it wishes.

Despite this argument, the need for a weighting process for problem identification remains.   Traditional economic evaluation, without the application of ethical or political priorities, still contains an implicit weighting mechanism.   Each individual and societal group and the effects of highway problems are still given a weighting - in this case of unity.   The exclusion of weights does not mean that the results of evaluation are unbiased, but that the weights used are largely unrecognised.

In terms of problem identification, the use of weights also helps to ensure that current priority issues emerge with force and before those issues of lower priority.   The whole concept of a highway problem is a relative one, and consequently can only be defined in ethical or political terms.   There can be no single set of standards which do not change against which highway conditions can be measured.   Consequently, it is preferable to be explicit about the values which must be used.   Mishan suggests that a result of

124

using political weights is that:

> '... the statement that a policy or project is
> economically more efficient than another is no
> longer admissible for what is presented as an
> economic calculation has, in fact, no meaning
> or sanction independent of the will of the
> relevant political authority'.

But the use of weights does allow appraisal to give quantitative

expression to legitimate concerns of income distribution, quality of

life, economic growth, etc.   Mishan's view that the evaluation process

acts as no more than a contribution to a political decision would be

laudable and credible if an unbiased and consistent method of assess-

ment existed.   This is not so.   Mishan concludes:

> 'The economist can indeed remain neutral with respect
> to the political power game - to the extent that is,
> of refusing to have any truck with political weights
> which, in the last resort, serve only to confer
> quantitative rationalisation on schemes desired by
> decision-makers.'

However, the use of political and ethical weights helps to

ensure that local democratic ideals are reflected in evaluation and

not ignored or accidently overlooked through the assumption of objec-

tivity characterising traditional assessment techniques.

Priority weights were thus seen as an essential element of

problem identification.   An attractive approach was to use the same

arrangement as adopted for Priority Ranking.   This takes the form out-

lined below:

(a)   Using policy statements as a starting point, as expressed in the

current T.P.P. and Structure Plan, objectives are specified to indic-

ate more accurately the purpose and aims of these policies and they in

turn generate a series of problem criteria indicating how achievement

of the objectives can be measured.

(b)   Policies are weighted to reflect priorities between them.

Objectives are scored by considering the number of county policies

towards which each is specifically directed.   In some cases, the link

is strong, in others quite weak.   Policy weights and objective scores

are then multiplied together to produce objective weights, those

objectives serving two or more policies tending to gain more points

than those serving only one.   Figure 3.21 shows the objective weight-

ing process using a form specially designed for weighting policies and

objectives.

(c)   Criteria are used to measure achievement of objectives (e.g.

number of accident fatalities;   traffic delay, etc.).   Irrespective

of the number of criteria associated with each objective, the same

number of points are allocated to be divided between them.   This is

carried out by a panel of officers from the Transportation and

Engineering Department of the county council and the P.T.E.

(d)   When a particular criterion has been quantified, it is then

allocated a score from within a range -4 to +4.

(e)   For each scheme, a weighted score is obtained by multiplying

objective weight by criterion weight by score, and then summing.   An

unweighted score is also calculated.   Schemes can then be ranked by

total score.

It was decided to adopt a similar approach for problem identif-

ication.   The methodology is sensitive to political requirements,

easily changed to reflect changing priorities and well tested and

familiar in the West Midlands.   Consequently, weights were allocated

to policies taken from the T.P.P. and Structure Plan and objectives

derived from these policies scored to reflect the relationships

between them and the policies themselves.   Policy weights and

FIGURE 3.21 - RELATIONSHIP OF POLICIES AND OBJECTIVES - 1979 POLICIES (USED IN PROBLEM IDENTIFICATION)

POLICIES	POLICY WEIGHT	Provision of access to development	Promotion of the efficient operation of private transport	Promotion of the efficient operation of public transport	Reduction of accidents	Reduction of the impact of transport on the environment	Unweighted total
Maintenance	5	-	7	2	1	-	10
Access to development	5	10	-	-	-	-	10
Development of strategic network	3	-	6	2	1	1	10
Accident reduction	3	-	-	-	10	-	10
Improved use of network	2	-	6	2	-	2	10
Public transport	2	-	-	10	-	-	10
Restraint	1	-	3	7	-	-	10
Environment	1	-	-	-	-	10	10
OBJECTIVE WEIGHT (Policy weight × Obj. Score)		50	68	47	38	17	220
1.0		0.227	0.309	0.213	0.172	0.077	1.0

objective scores are multiplied together to produce objective weights in the same way as Priority Ranking (Figure 3.21). Problem criteria - formed by the data variables outlined earlier in this chapter - were weighted according to their contribution towards measuring objective achievement (or failure). Thus, the objective to reduce the impact of traffic on the environment, with an objective weight of 0.087 for 1979, was measured using three criteria - noise, CO and smoke level - and the contribution made by each of these towards assessing objective achievement was reflected in the criteria weights allocated to them - 50.0, 25.0 and 25.0 respectively (summing to 100). These criteria weights were allocated by a panel of officers and in the case of each objective, totalled 100.0 points to avoid unintentional bias.

The entire weighting process is shown in Figure 3.22 and the weights adopted for problem identification for 1979 are shown in Figure 3.21. The weighting process is identical to that used for Priority Ranking except that different criteria (and therefore differ- ent criteria weights) are used to measure problem condition rather than scheme value. Thus, the accident rate at a site is used rather than the change in accident rate attributable to a highway scheme.

Additional weights are also incorporated into the problem ident- ification process reflecting spatial priorities and those associated with differing land uses. Thus, the user can specify weights to give preference to Conservation, Inner City, Industrial Areas, etc., and to certain land uses if desired. These weights are allocated by a panel of officers from the Planning and Transportation Departments of the county council and reflect their interpretation of current political preferences.

The final decision which had to be made regarding the application of priority weights was how and when to introduce them to the problem

127 ( )

FIGURE 3.22 - THE WEIGHTING PROCESS AS PART OF PROBLEM IDENTIFICATION

MONITORING → DATA MATRIX (CASE STUDY) → DATA CORRELATION MATRIX → COMPOSITE PROBLEM FACTORS → GEOMETRIC ROTATION → FACTOR SCORE COEFFICIENTS → WEIGHTED FACTOR SCORES → AGGREGATION OF WEIGHTED FACTOR SCORES

COUNTY TRANSPORT POLICIES FROM STRUCTURE PLAN AND T.P.P. → OBJECTIVES → CRITERIA

POLICY WEIGHTS

OBJECTIVE WEIGHTS

CRITERIA WEIGHTS → STANDARDIZED DATA → WEIGHTED AND STANDARDIZED DATA MATRIX

RANKING BY INDIVIDUAL FACTOR

RANKING BY TOTAL FACTOR

PRIORITY RANKING

IMPLEMENTATION

127 (ii)

identification process. Should it be before factorial analysis and applied to the raw data, or following standardisation, immediately prior to the derivation of factor scores and the ranking of sites? There was little to guide this decision from past experience or theoretical principle. The choice was made eventually of weighting standardised data. This ensured that the weights had the same effect upon all data variables and obviated the need to derive a factorial solution using data which was deliberately biased. Consequently, the factorial solution was statistically 'correct', used to derive composite factors from the raw data correlation matrix but factor scores derived from the composite factors were applied following standardisation and weighting of variables at each site. The weights for 1979 shown in Figure 3.21 reflect the priorities between policies that existed at that time. Also shown is a set of weights for 1981, following a change in political administration. These were used later in computer runs for comparative purposes and sensitivity testing.

Summary of the Case Study

The ultimate choice of study area, the use of the TRAMP traffic model network and site definition by link and node format resulted in 164 highway sites defined for problem identification. These sites, the network, zone centroids and connectors and their boundary implications and associated nodal information are displayed in Figures 3.2, 3.3 and 3.17. The density of the network clearly decreases as one moves from the City centre, but this is to be expected as urban development and the highway fabric become less complex. Clearly, some further definition of highways as part of the problem network would be preferable, but the design of problem identification does not preclude extension to other areas given sufficient data resources. However, until the results of the trials of the methodology are available, its extension would appear to be unjustified. In the next chapter, we shall turn to the results produced from the case study.

CHAPTER 4 - RESULTS FROM THE CASE STUDY

The Characteristics of the Chosen Technique

Earlier review of methodologies which were suitable for highway problem identification indicated that factorial analysis offered the best available approach in the light of a number of objectives and the existence of a series of constraints, and the previous chapter outlined the characteristics of the case study which would apply factorial analysis to the needs of T.P.P. problem identification. However, factorial analysis is not a single approach but a range of methods with differing characteristics appropriate in different circumstances. Techniques subsumed within its terms and which have application in an evaluation contex include classical factor analysis, principal components analysis, cluster analysis, discriminant analysis and correspondence analysis.

With due regard to the nature of the problem and the availability and characteristics of information upon highway problems, classical factor analysis was chosen. Its application is described in detail in Appendix 3. Its advantages over other factorial approaches were clear, and those that contributed most to its choice are summarised below:

(i)   It is the only established factorial approach which allows for the existence of both common and unique variance within the data set. Common variance reflects the co-relationship of data variables - clearly in the context of highway variables this is likely to be substantial. Unique variance reflects all other variance, which in this case is unique to each variable and reflects no form of inter-relationship. It is of no use in the factoring process, which relies upon common variance to derive a solution, and thus needs to be excluded. However, this presents

129

technical difficulties and classical factor analysis provides
one of the few methods available to estimate and exclude unique
variance from further analysis.

(ii) Assumption that both common and unique variance exists appears
to conform with the known characteristics and structure of high-
way problems.   It is widely recognised, for example, that road
safety conditions are correlated (share common variance) with
maintenance conditions; environmental conditions with conges-
tion conditions - whilst at the same time, each has its own
characteristics which are shared with no others (unique variance).
This closely resembles the assumptions of classical factor
analysis, but not those of, say, principal components analysis,
where unique variance is assumed not to exist.

(iii) Classical factor analysis allows the composite factors derived
from the original data to become correlated following their
extraction.   Principal components analysis, its main rival in
the evaluation context, does not encourage correlation.   Con-
sequently classical factor analysis possesses considerably more
flexibility in modelling the inter-correlated nature of problem
patterns that are likely to exist.

(iv) Unlike principal components analysis, classical factor analysis
has an experimental basis looking for patterns and relationships
within the body of data.   Principal components analysis remains
'merely a transformation rather than the result of a fundamental
model for ...... structure',   (Morrison, 1967) and has the
objective solely of transforming orthogonally the coordinate
axes of a multivariate system to new orientations.

Classical factor analysis also has two main disadvantages.

Firstly, it is a complex and unfamiliar technique to practising transport planners more used to cost benefit analysis and points appraisal. This may have ramifications at the stage of application, but does not affect its ability as an evaluation tool. Secondly, it is a highly flexible technique, like all multivariate methods, adaptable to a variety of problems and consequently capable of producing a wide range of results. Although this may be beneficial, in that it meets the flexible and changing needs of transport evaluation and, in particular, the characteristics of political decision-making and local government financial arrangements, it also leads to difficulties in selecting an optimal solution, and consequently to problems in comparison and justification. This flexibility has been the cause of much criticism of factorial techniques in general as it is seen as a deficiency by users who desire a simple and single solution to the problem of appraisal. The need to be sure of applying classical factor analysis in the most suitable way was emphasised by this, and to ensure that the ramifications of varying inputs and techniques employed within the method were fully understood, a number of sensitivity tests were carried out. The details and results of these tests can be found in Appendix 9. They centred around choices which meed to be made in four areas - data distribution and its effects, choice of rotation method, level of solution iteration, and the selection of a cut-off point in the derivation of factors. The choices made and the reasons for them are outlined below:

(i) Data Distribution. All methods of factorial analysis assume that input data, in this case the traffic and highway problem data, are normally distributed. Although this requirement has been relaxed a little in recent years (Clark, 1973; Roff, 1977), it remains the case that highly skewed or peaked data distributions will invalidate the factor solution. Classical factor analysis is no exception.

131

In general, there is little disagreement that normalisation (for instance by taking the $\log_{10}$ value of each variable) will either improve data distribution or leave it largely unaffected. There are a few rare occasions where it can worsen distributions. Since normally distributed input data is important, and since transformation is nearly always beneficial, it was incorporated into the process of factorisation. The results of transformation, using $\log_{10}$ values, are described in Appendix 9, and are summarised in Figures A.15 and A.16., and they reflect largely improved distributions. Rummel (1970) has suggested that there may be occasions where partial transformation, involving only some data variables, would be preferential and, indeed, this may prove to be the best option for future problem identification runs. However, evidence of the benefits from partial transformation remain scanty.

(ii) Rotation method. Discussion of factorial methods in an earlier chapter and in Appendix 3 noted the use of geometric rotation to move the initial factor solution to alternative positions in search of an improved description of the data, and in particular to assess whether clearer patterns could be derived. Four methods of rotation were described - three orthogonal (keeping factors uncorrelated) and one oblique (allowing factors to become correlated if conditions dictate). Different factorial solutions and consequently different problem scores and ranks would emerge if different rotations were used. The choice of rotation technique was made on the basis of past practice and the desire to produce the simplest and most easily interpreted solution. Consequently, an orthogonal 'equimax' solution was chosen, which aims to balance loadings on both rows and columns of the factor matrix. Other rotations were also tested and comparisons made between the problem scores and ranks which resulted. The results from this can be found in Appendix 9 and are summarised in Figures A.17 and A.18.

Clearly, the choice of rotation is significant, particularly between an orthogonal and oblique method. However, this was less important than the need to retain consistency between factor runs to allow comparisons to be made. Hence, the choice of a single and simple rotational method.

(iii) Iteration. Classical factor analysis relies upon an iterative process to assess communalities in the data matrix, taking a set of initial estimates as a starting point. The choice of iteration level affects the ultimate derivation of communalities which in turn is important in deriving a factorial solution. Appendix 9 describes sensitivity tests carried out to assess the impact of varying iteration levels and Figure A.19 summarises the results. The traditional value - ceasing iteration when successive communalities are within a value of 0,001 - was found to be satisfactorily sensitive and was retained.

(iv) Cut off point. Eigenvalues are used to decide whether a factor should be retained or discarded as contributing little to the explanation of variance in the data matrix. Clearly, changing the eigenvalue cut off point will affect the number of factors retained and used to describe the original problem matrix. Problem scores and ranks will change as a result. Appendix 9 and Figure A.20 contain details of the sensitivity tests varying the eigenvalue cut-off, the results of which suggested that a value of 1.0 marked a significant point whereby raising it resulted in removal of valuable factors and lowering it resulted in inclusion of factors worth little. Some theoretical support for this choice of eigenvalue comes from the knowledge that a factor possessing an eigenvalue of less than 1.0 explains less than the equivalent of one problem data variable (Rummel, 1970). It thus represents a backward step in reducing the original data

133

matrix, as more factors (of this quality) than variables would be needed to explain the variance present. For these reasons, a value of 1.0 was retained.

In summary, the classical factor approach to highway problem identification was characterised by the following choice of parameters:

data normalised	-	all variables ($\log_{10}$)
correlation measure	-	Pearson Product Moment Correlation coefficients
rotation	-	equimax
iteration level	-	successive values different by less than 0.001 (maximum 25 iterations)
eigenvalue cut off point	-	1.0

Application

The classical factor analysis approach to highway problem identification was applied to the matrix of problem information for 1979, described in the last chapter, using the TRAMP (traffic model) highway network of 164 links and 131 nodes, for an area of south-west Birmingham. Weights were derived to give priority to certain geographical areas and to reflect the relationship of problem criteria to transport objectives (and, therefore, policies) for that year, using a process derived from Priority Ranking and described earlier. The following sections describe the computer output from the factoring process as it would be received by the user, and go on to discuss the emergence of the characteristics and distribution of highway problems in the case study area.

Output

The computing arrangements for highway problem identification

can be divided into four stages.

(i) Database creation and updating. Two distinct databases have
     been created, specifically for problem identification, but with
     application as a source of information for engineers and planners.
     Two files - one containing nodal and the other link information -
     are necessary because of the difficulties in structuring a
     single file for both types of data. Each will need frequent
     access to update and revise information. They replace a large
     number (8) of existing transport databases.

(ii) Data manipulation. A small amount of the input data needs to
     be recalculated prior to use in problem identification. This
     includes bus flow and accident rate data, neither of which is
     directly available in the West Midlands.

(iii) The factoring programs. This suite of programs forms the major
     part of the computer process, taking information from datafiles
     and transforming it into a factor solution. They have been
     adapted from the SPSS8 computer package and thus form a set of
     generalised programs which are easy to operate but tend to lack
     flexibility in specific circumstances. They contain all that
     is necessary to calculate correlations, derive and rotate factor
     solutions, and to calculate factor score coefficients.

(iv) Output programs. A series of programs have been written to
     calculate factor scores, rank and tabulate them. This includes
     the introduction of weights to reflect geographical priority and
     to allow for the relationship of criteria and objectives. A
     series of weights can be used to assess sensitivity. The
     information from this stage is used as the basis for selecting
     sites to be assessed at the coarse sieve stage of Priority
     Ranking.

135

Examples from these programs are given in Appendix 10.

The following sections describe the output from the computer process, using as an example an equimax run, giving details of problem conditions and their relative priorities. This information is not input directly to Priority Ranking, as this might encourage acceptance of results from problem identification without sufficient discussion and interpretation. It forms the basis for the selection of highway sites for further consideration.

Output from problem identification is in the form of a series of tables and maps, which describe the movement from the original data matrix, through the derivation of problem factors, to the calculation of problem scores and ranks. The following tabular information, derived from the case study runs, is of direct interest to the highway planner:

(i)   The Correlation Matrix

The correlation matrix, showing association between highway problem variables, forms the basis of the classical factor analysis calculations. It is shown in Figure 4.1 for the case study area. It performs two functions. Firstly, it provides the basic information for the factoring process. Secondly, it provides information for the user upon the detail of highway problem structure and the inter-relationship of problems that exist. This information may lead to design of more cost effective solutions to highway problems, particularly where problem conditions are found to be highly inter-related and the possibility exists of alleviating a number of problems through a single design type. The correlation matrix may also suggest where data is duplicated or where one piece of information might act as a surrogate for others - thus helping to rationalise the information process.

FIGURE 4.1 - CORRELATION MATRIX FOR THE CASE STUDY

	CONGESTION	ACC. RATE FATAL	ACC. RATE SERIOUS	ACC. RATE SLIGHT	NOISE LEVEL	CO. LEVEL	SMOKE LEVEL	PUBLIC TRANSPORT OPERATIONAL	PUBLIC TRANSPORT SAFETY	MAINTENANCE (MARCH)	MAINTENANCE (OPERATIONAL)	BRIDGE PROBLEMS
CONGESTION	–	-0.13424	0.00722	0.06252	0.27549	0.33084	0.30629	0.08096	0.18496	-0.12952	0.30670	0.16761
ACC. RATE – FATAL	-0.13424	–	0.05237	0.22310	-0.06944	-0.00376	-0.04526	0.01956	-0.04035	-0.10850	0.03015	-0.04453
– SERIOUS	0.00722	0.05237	–	0.11259	-0.28692	-0.21478	-0.19294	-0.01707	-0.01456	-0.02419	-0.11833	-0.03535
– SLIGHT	0.06252	0.22310	0.11259	–	0.12257	0.18883	0.21406	0.08796	-0.03927	-0.02186	0.27507	-0.02403
NOISE LEVEL	0.27549	-0.06944	-0.28692	0.12257	–	0.71655	0.74171	0.08054	0.03487	-0.18661	0.53798	-0.01733
CO. LEVEL	0.33084	-0.00376	-0.21478	0.18883	0.71655	–	0.78739	0.07513	0.03245	-0.18792	0.75484	-0.02689
SMOKE LEVEL	0.30629	-0.04526	-0.19294	0.21406	0.74171	0.78739	–	0.04998	-0.00779	-0.23707	0.73244	-0.05203
OPL. PUBLIC TRANSPORT	0.08096	0.01956	-0.01707	0.08796	0.08054	0.07513	0.04998	–	0.50750	-0.04228	0.09567	0.13999
SAFETY PUBLIC TRANSPORT	0.18496	-0.04035	-0.01456	-0.03927	0.03487	0.03245	-0.00779	0.50750	–	0.03610	0.01503	0.21449
MAINTENANCE (MARCH)	-0.12952	-0.10850	-0.02419	-0.02186	-0.18661	-0.18792	-0.23707	-0.04228	0.03610	–	-0.18258	0.12135
MAINTENANCE (OPL)	0.30670	0.03015	-0.11833	0.27507	0.53798	0.75484	0.73244	0.09567	0.01503	-0.18258	–	-0.07017
BRIDGE PROBLEMS	0.16761	-0.04453	-0.03535	-0.02403	-0.01733	-0.02689	-0.05203	0.13999	0.21449	0.12135	-0.07017	–

<u>(ii)   The Rotated Factor Matrix</u>

Figure 4.2 shows the factor matrix following an equimax rotation. The figures (loadings) in the table are a measure of how much each variable is involved with each of the factors and can be interpreted as correlation coefficients.   Only 5 factors are displayed as the remaining 7, which together originally described the problem data, have been discarded following examination of the variance each explained, (i.e. only 5 had eigenvalues greater than 1.0).   Each factor can be interpreted in terms of the loadings of variables upon it, as each is a composite made up of pieces of information from each of those variables.   A high loading represents a strong relationship between factor and variable; a low loading the converse.

For example, factor 1 is closely correlated with a set of environmental variables (noise, CO and smoke) and factor 2 with public transport variables.   Each factor is poorly correlated with all other variables, suggesting that there remains some relationship between them, but very little compared with the dominant relationship.   This information provides a means of classifying factors by problem type. Thus:

factor 1   ......   environmental conditions

2   ......   public transport conditions

3   ......   congestion conditions

4   ......   road safety conditions

5   ......   maintenance conditions

Due to the orthogonal nature of the equimax rotation, the definition of factor loadings shown here may not be optimal and it may be possible to derive stronger, clearer relationships.   Only an oblique (correlated) solution could show this.   However, the advantages of orthogonality in simplifying further interpretation over-ride the benefits in accuracy which obliqueness would bring.

FIGURE 4.2 - EQUIMAX ROTATED FACTOR MATRIX - CASE STUDY

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
CONGESTION	0.15263	0.11380	0.73902	-0.02783	0.09000
ACC. RATE - FATAL	-0.05094	0.00636	-0.16840	0.34405	0.12800
- SERIOUS	-0.32823	-0.03509	0.09249	0.24073	0.04946
- SLIGHT	0.14990	0.01044	0.06500	0.63627	-0.02059
NOISE LEVEL	0.77597	0.04167	0.16588	-0.06112	0.16525
CO LEVEL	0.84080	0.01899	0.25612	0.11466	0.16450
SMOKE LEVEL	0.83711	-0.02708	0.24043	0.11024	0.22655
PUBLIC TRANSPORT (OPL)	0.06291	0.70188	-0.00520	0.10057	0.04434
PUBLIC TRANSPORT (SAFETY)	-0.01023	0.73503	0.14514	-0.06556	-0.05370
MAINTENANCE (MARCH)	-0.07131	0.00030	-0.06704	-0.04161	-0.67384
MAINTENANCE (OPL)	0.69741	0.01026	0.25848	0.27861	0.17129
BRIDGE PROBLEMS	-0.05208	0.23405	0.19489	-0.07339	-0.18909

Two conclusions can be drawn from this data upon factor loadings:

(a)   The categories of factors reflect the original categories of

        problem indicators derived from West Midland policies and

        objectives.   It suggests that the factoring process has des-

        cribed problem conditions in policy terms in an adequate way.

(b)   Since problem types can be associated with each factor, if a

        relationship between factors and individual sites could be

        established, then sites could be ranked in terms of each prob-

        lem condition.   More significantly, if these factors could be

        combined into a single factor of total problems, and this ranked,

        then we would possess a means of comparing overall problem con-

        ditions at each highway site.

(iii) Factor Score Coefficients

        Factor score Coefficients provide this link between rotated

factor loadings, the original data variables and highway sites by

reflecting the relationship between the original problem data variables

and the derived composite factors.   They are shown in Figure 4.3.

As explained earlier, they are used in conjunction with the standard-

ised raw data to produce problem scores for each site on each factor.

Consequently, each site can be scored and ranked in terms of factor 1

(environment), factor 2 (public transport) and so on.   A comprehen-

sive problem score for each site is produced by summing these factor

scores after allowing for the variance explained by each factor.

Thus, since f ctor 1 explained 53.7% of the variance in the problem

matrix, factor 2 19.4% and so on (summing to 100.0% for all 5 factors)

the individual factor scores are adjusted to allow for this and a

total factor score reached for each site in the following way:

$$\sum \begin{array}{l} [[\quad \text{Factor 1 score} \; * \; \text{variance explained} \;) \\ [[\qquad \text{site A} \qquad\qquad \text{by Factor 1} \qquad) \end{array} \quad + $$

$$\begin{array}{l} (\quad \text{Factor 2 score} \; * \; \text{variance explained} \;) \\ (\qquad \text{Site A} \qquad\qquad \text{by Factor 2} \qquad) \end{array} \quad \cdots\cdots$$

$$\begin{array}{l} (\quad \text{factor n score} \qquad \text{Site A} \; * \\ (\end{array}$$

$$\begin{array}{l} \text{variance explained} \quad)] \\ \qquad \text{by factor n} \qquad)] \end{array}$$

Comparison and ranking of sites can then proceed using the 5 individual factor scores, and the comprehensive factor score.

It is at this stage of the factoring process that the weights that reflect distributional priority and which allow for the relation-ship between problem criteria and objectives are introduced. These weights, described in Chapter 3, are used to adjust the factor scores after rotation but prior to the derivation of a total factor score. The user is able to extract final problem scores and ranks both before and after the introduction of distributional weights, but only after the involvement of criteria weights. This allows comparison of solutions both with and without introducing priorities between areas, and the sensitivity of these weights can be assessed. Clearly, criteria weights are always needed to ensure that unjustified and unwanted bias is not introduced simply because the achievement of some objectives are measured by more criteria than others (e.g. road safety has 3 criteria; congestion only 1). Both sets of weights would be reviewed each year in the light of changing priorities and policies. Details of all weights used in a factor run are given at the end of the site listings.

Results from the Case Study

Figure 4.4 shows an example of the tabulated weighted and unweighted scores for a selection of highway sites in the case study

FIGURE 4.3 - FACTOR SCORE COEFFICIENTS - CASE STUDY

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
CONGESTION	-0.15681	-0.01224	0.69288	-0.05449	0.01764
ACC. RATE - FATAL	-0.01775	0.01742	-0.08145	0.18572	0.07770
- SERIOUS	-0.09254	-0.02261	0.09015	0.14643	0.05401
- SLIGHT	-0.02724	0.00460	0.02146	0.52392	-0.08813
NOISE LEVEL	0.21662	0.04250	-0.08450	-0.21336	0.00842
CO. LEVEL	0.39205	-0.00206	0.03671	0.02347	-0.03992
SMOKE LEVEL	0.37512	-0.07070	0.04158	0.00416	0.11649
PUBLIC TRANSPORT (OPL)	0.01737	0.43924	-0.10000	0.08287	0.05257
PUBLIC TRANSPORT (SAFETY)	-0.01492	0.49955	0.04881	-0.05963	-0.03592
MAINTENANCE (MARCH)	0.12244	-0.01804	0.01148	0.00605	-0.62400
MAINTENANCE (OPL)	0.07589	-0.00816	0.05750	0.24941	0.00853
BRIDGE PROBLEMS	-0.00546	0.06617	0.08669	-0.02311	-0.10699

FIGURE 4.4 – OUTPUT FROM IDENTIFICATION BY FACTORIAL ANALYSIS
UNWEIGHTED AND WEIGHTED SCORES.   EQUIMAX ROTATION.   AN EXTRACT.

UNWEIGHTED

ROAD NAME	NODES	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	TOTAL
RIDGACRE RD	173258	-0.70369	-0.24019	-0.40939	0.27149	-0.27705	-0.39089
RIDGACRE RD	173260	-0.75283	-0.22434	-0.39691	0.05462	-0.28903	-0.43382
WVHAMPTON RD	176268	0.27545	-0.35535	-0.21953	-0.44576	0.09936	-0.06059
WVHAMPTON RD	176263	0.68882	-0.36202	-0.31227	-0.44793	0.06939	0.09026
CLAPGATE LANE	245339	-0.16713	-0.18073	0.81263	0.65802	1.01704	0.15746
STONEHSE LANE	245338	0.67687	-0.38118	0.14533	-0.15860	-0.11704	0.17548
BOTTETORT RD	246337	0.44519	-0.31024	-0.73704	0.15412	-0.22477	-0.00096
CASTLE ROAD	246247	-0.69059	-0.32424	-0.64323	0.78704	-0.24011	-0.37298
CASTLE ROAD	247344	-0.39510	-0.25010	-0.59733	0.15646	-0.25547	-0.30933
QUINTON ROAD	248337	-0.37764	-0.39349	-0.18043	0.29670	0.24273	-0.30758
QUINTON ROAD	248397	-0.50890	-0.40093	-0.20976	0.33806	00.24063	-0.28061
RIDGACRE RD	257258	0.03086	-0.23809	-0.56587	-0.05566	-0.27034	-0.15608
HAGLEY RD W	257265	-0.27605	-0.25468	-0.54470	-0.19857	-0.32233	-0.30389
HAGLEY RD W	259257	-0.53484	-0.25431	-0.47378	-0.24046	-0.31996	-0.40394
RIDGACRE RD	260261	-0.27452	-0.24936	-0.59285	-0.00832	-0.27680	-0.28185
W BOULEVARD	261262	-0.67015	-0.31712	-0.46241	-0.27722	-0.28248	-0.47548
WVHAMPTON RD	261263	-0.00905	-0.34414	-0.26608	-0.34241	0.11713	-0.16647
COURT OAK RD	261333	0.02823	-0.23271	-0.57371	-0.38089	-0.35564	-0.20422
HAGLEY RD W	263326	3.31819	2.21250	-0.95832	-0.22284	-0.11889	1.72391
HAGLEY RD W	263264	2.21973	-0.85530	3.54737	-0.44438	-0.10148	1.16447
HAGLEY RD W	264259	-0.65579	-0.48331	1.23648	0.25985	0.14338	-0.15879
HAGLEY RD W	265264	-0.17293	-0.48204	1.09135	0.13001	0.12946	-0.00099
BLEAKHSE RD	267268	0.50168	-0.35036	-0.38140	0.07017	0.15910	0.07877

WEIGHTED

ROAD NAME	NODES	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	TOTAL
RIDGACRE RD	173258	134.5848	-71.1430	-1393.9743	80.8972	8.2219	-91.8877
RIDGACRE RD	173260	140.2313	-69.8924	-1398.6232	69.5810	12.8026	-89.7139
WVHAMPTON RD	176268	-316.4210	-124.3122	1627.7889	-229.8936	106.0778	-20.8661
WVHAMPTON RD	176263	-265.5393	-125.9787	1628.2413	-237.7209	109.7254	5.8210
CLAPGATE LANE	245339	-58.7893	489.3782	-178.1996	54.3250	115.6687	56.1928
STONEHSE LA	245338	-7.1202	-103.7322	339.1091	-111.3966	69.3153	10.4779
BOTTETORT RD	246337	292.1586	-70.2528	-1392.9694	58.7019	5.1807	-9.0072
CASTLE ROAD	246247	41.0029	-90.4784	-1346.2247	199.0833	-7.9918	-132.1233
CASTLE ROAD	247344	173.7351	-73.3760	-1381.6563	102.6071	-2.0439	-68.9064
QUINTON ROAD	248337	-543.6712	-125.6676	1644.9408	-153.8734	84.0657	-136.6941
QUINTON ROAD	248397	-534.5810	-127.2557	1648.0304	-148.7939	83.9239	-131.3721
RIDGACRE RD	257258	256.7460	-69.3124	-1393.7870	62.8310	5.9890	-30.9698
HAGLEY RD W	257265	250.8601	-74.1838	-1393.4703	62.0403	15.4981	-30.9698
HAGLEY RD W	259257	211.4122	-73.8864	-1395.4511	63.7708	17.1168	-52.0599
RIDGACRE RD	260261	219.1183	-72.3445	-1388.6345	79.4096	4.7111	-46.5032
W.BOULEVARD	261262	175.5471	-71.9066	-1406.6605	44.6505	23.5388	-73.0942
WVHAMPTON RD	261263	-362.8498	-124.7938	1633.1450	-230.2080	100.0834	-44.1366
COURT OAK RD	261333	326.2172	-70.8901	-1405.8501	22.4239	25.4347	6.2619
HAGLEY RD W	263326	-74.9324	-137.1057	1619.7869	-207.4906	151.5106	110.6037
HAGLEY RD W	263264	-127.6303	-140.0440	1649.4307	-224.4251	130.4721	82.1434
HAGLEY RD W	264259	-506.3096	-131.2289	1659.9520	-138.0424	98.3631	-113.6746
HAGLEY RD W	265264	-421.7334	-130.4223	1655.3956	-138.8728	97.7649	-70.3472
BLEAKHSE RD	267268	-369.7172	-127.1203	1645.8471	-180.1218	89.3658	-45.1956

area. The first column of information refers to the highway site name and is followed by a unique reference number. The following 5 columns give details of the factor scores derived for the sites for each of the 5 individual factors. In both cases, the problem scores are formed of the composite problem units comparable both between sites and between factors and in a form which allows the derivation of a single comprehensive problem score. The higher the score, the more severe the problem condition. In the case of the unweighted solution, a score of zero would represent average conditions at that site for that factor. Positive scores represent increasing problem severity, negative scores the converse. In the weighted case, whereby distributional and geographical priorities have been included, this is still the case but the relationship of site scores has altered, so that ranks have changed.

Taking the weighted scores and looking at the unranked table (Figure 4.4), the first site is Ridgacre Road (nodes 173-258), a fast moving, relatively busy residential dual carriageway. Factor 1, the environmental factor, has a problem score of 134.5848, representing a relatively high positive figure which implies the existence of an environmental problem; factor 2 (public transport) has a relatively high negative figure, suggesting the converse; factor 3 (congestion) a very high negative figure (few problems); factor 4 (road safety) and 5 (maintenance), small positive figures representing close to average conditions. This information allows the user to draw up a picture of site conditions in comparable terms - something which cannot be done using data in its original form on noise levels, traffic speeds, etc. Consequently, it is possible to suggest that if investment to solve problems was proposed at Ridgacre Road, the greatest priority (in 1979 policy terms) would be in the environmental sector, and the least in congestion.

Just as significant is the opportunity that problem scoring in
these terms affords for comparisons between sites. The third site in
Figure 4.4 is Wolverhampton Road (176268), a major Trunk road forming
the principal artery from Birmingham to Wolverhampton. Here, environ-
menta conditions and road safety (factors 1 and 4) present few prob-
lems, public transport (factor 2) is also satisfactory, but congestion
and maintenance conditions (factors 3 and 5) reflect severe problems.
Problem structure at this site is again clearly represented and the
priorities for improvement emerge from the factor scores. They differ
markedly from those at Ridgacre Road and the factorial approach allows
comparison of the two sites as well as between problems at a site.

In this way, a picture of problem structure over all sites can
be drawn up, and ranking can take place both by individual factor
type (and thus by problem type) and by comprehensive problem scores.
Clearly, different scores, ranks and priorities might be produced
using different factors.

The final column of data contains the comprehensive problems
scores. These are made up of the individual values, adjusted for
variance as described earlier, and as a result tend to mask the
extreme individual scores. However, they provide a single measure
of problem condition which can be used to allocate priorities between
sites for investment. They also represent an average of problem con-
ditions and thus act as a standard against which individual scores can
be compared. Thus, Ridgacre Road (173258) displays slightly worse
comprehensive problems than Wolverhampton Road (176268) but signifi-
cantly worse road safety conditions (factor 4). This suggests that
in general terms, Ridgacre Road has more immediate needs for invest-
ment than Wolverhampton Road, and particularly in the road safety
sector. Both total needs, and individual problem structure is avail-
able from the factor scores facilitating the allocation of priorities

and the design of schemes.

However, the sheer wealth of data may inhibit interpretation, and consequently the output from the computer process is used to construct a series of maps which display the distribution and characteristics of problem types. This form of presentation is not only likely to be more acceptable to laymen and politicians alike, but in many ways facilitates interpretation and comparison by the expert user. In conjunction with the tabular data, it provides all that is needed for highway problem identification purposes.

Figure 4.5 showed the case study area, the highway network, nodes and links, and the major centres of activity and land uses. This information forms the basis for the following discussion of the patterns of problems which emerged from application of the equimax solution for highway problems (chosen because it represents the least extreme rotational solution). This discussion is structured around a framework of issues which reflect how this information might be used in practice. Five issues can be distinguished:

(i) the spatial distribution of problems,

(ii) a comparison of comprehensive and individual problems,

(iii) the significance of highway characteristics,

(iv) the characteristics of highway sites,

(v) the inter-relationship of problem conditions.

Each of the factors are discussed in turn.

Comprehensive Factor Scores

Figure 4.6 shows the distribution of weighted comprehensive highway problem scores for the case study area. This information is likely to form the most significant basis for selecting sites to proceed to Priority Ranking. A clear pattern of problems emerges. The most severe problems are found, almost without exception, on the
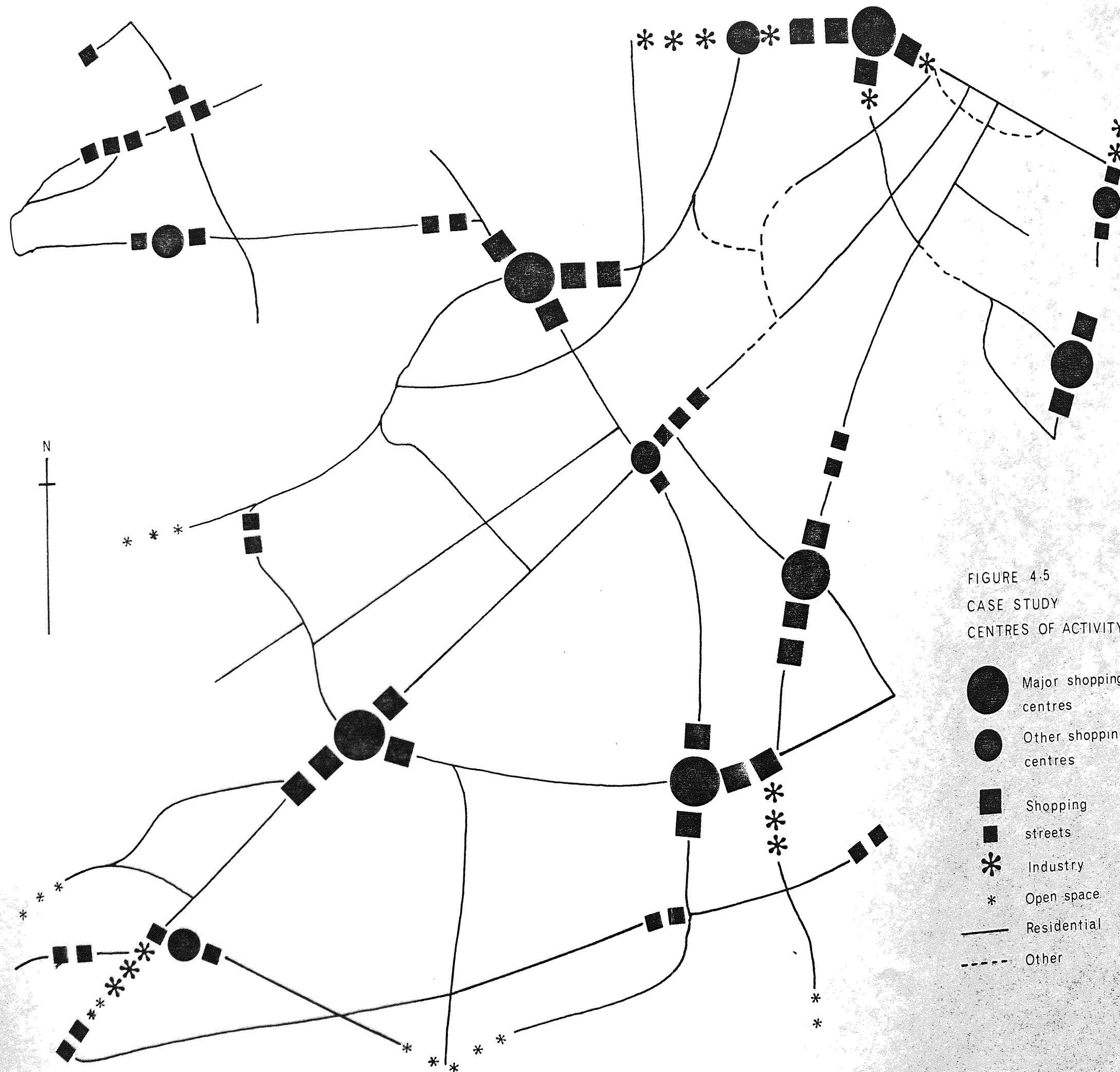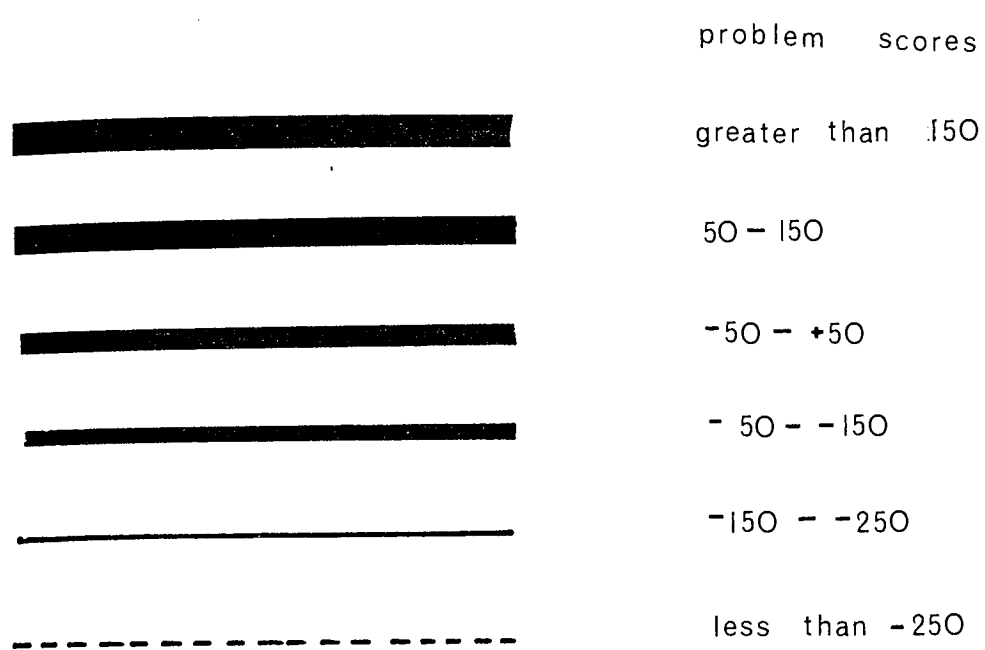
FIGURE 4·5
CASE STUDY
CENTRES OF ACTIVITY

Major shopping
centres

Other shopping
centres

Shopping
streets

Industry

Open space

Residential

Other

problem   scores

▬▬▬▬▬▬▬   greater than 150

▬▬▬▬▬▬▬   50 – 150

▬▬▬▬▬▬▬   ⁻50 – ⁺50

▬▬▬▬▬▬▬   ⁻ 50 – ⁻150

──────────   ⁻150 – ⁻250

– – – – – – – – – – – –   less than –250

C	California
CV	Chad Valley
E	Edgbaston
FW	Five Ways
KH	Kings Heath
KN	Kings Norton
H	Harborne
M	Moseley
N	Northfield
L	Longbridge
SO	Selly Oak
Q	Quinton
St	Stirchley
WH	West Heath
R	Rednal

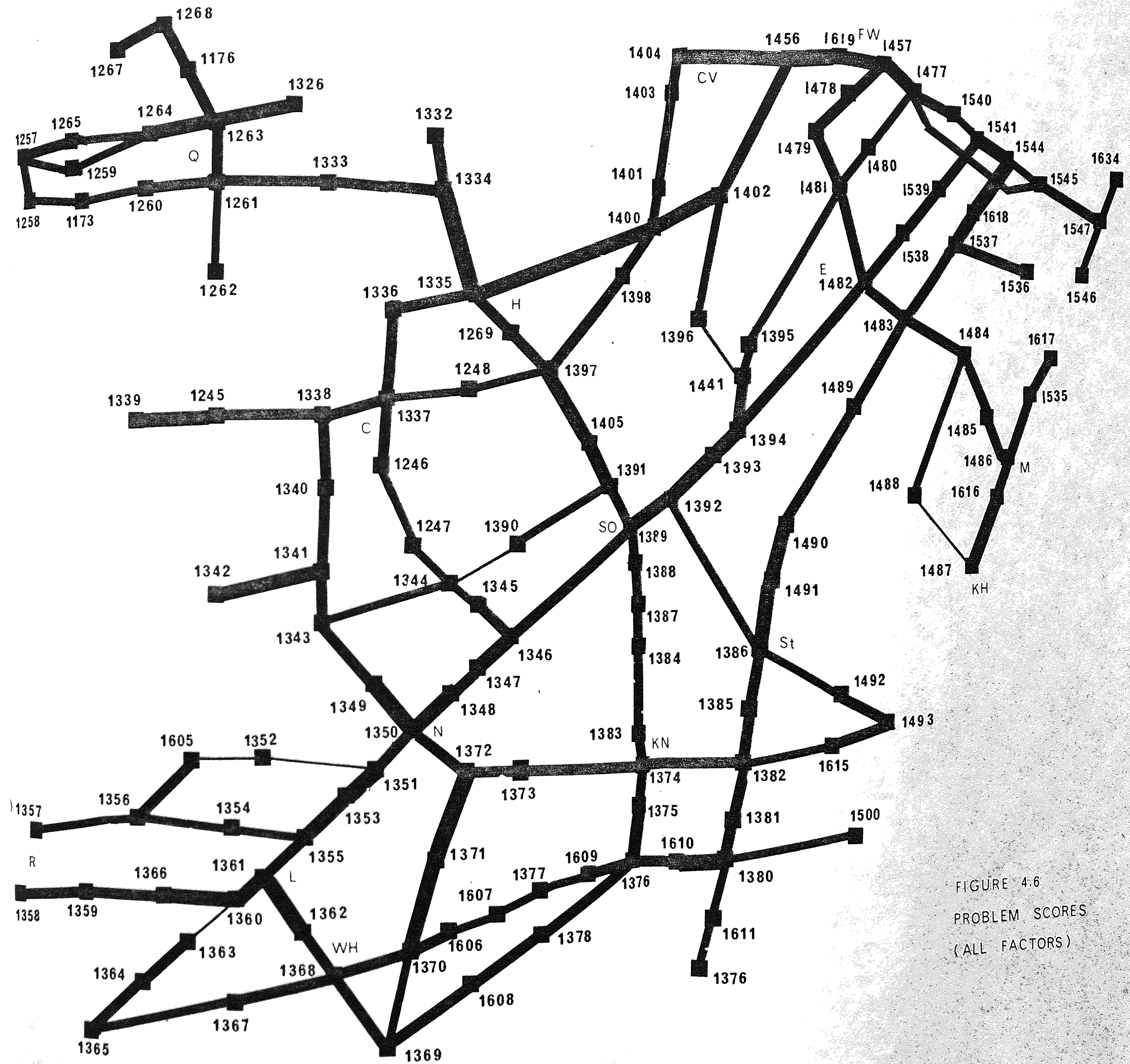FIGURES 4·6 – 4·11   PROBLEM SCORES – KEY

FIGURE 4.6
PROBLEM SCORES
(ALL FACTORS)

busiest highways - Bristol Road (1346-7, 1353-1535, 1389-1393),

Pershore Road (1544-1618), Moseley Road (1616-1487) and Harborne

High Street (1335-1400-1402).   Meanwhile, less busy roads are

characterised by less severe problem conditions.   This is far from

surprising, since intuitively one would expect problem conditions to

deteriorate on highways with higher traffic flows, but it remains of

value since it provides confirmation of a widely held view previously

less easy to substantiate in comprehensive problem terms.   Exceptions

to this are found where highways have been improved recently -

stretches of the Middle Ring Road (1477-1540) and the Pershore/Redditch

Road (1369-1376) stand out in particular, exhibiting few problems

despite intensive use.

A similar pattern of problems can be found in the major shopping

centres, where pedestrian and vehicular activity is at its most com-

plex.   Harborne, Selly Oak, Northfield, Kings Norton and Longbridge

all exhibit relatively severe problems compared with sites between

centres.   A trend in the distribution of problems is apparent.

Severest problems are concentrated upon the most used highways, parti-

cularly at junctions within shopping centres.   Possibly of greater

interest are the occasional poor sites which lie away from concen-

trations of activity - for example Parsons Hill (1380-1610) and Long

Nuke Road (1341-1342).   In each case a more detailed examination is

needed to establish the cause of problems, necessitating the use of

individual problem scores.   In the first case, the problem is caused

largely by a poorly designed junction at node 1380 characterised by

severe road safety and congestion problems.   This emerges from the

individual road safety (factor 4) and congestion (factor 3) scores.

In the case of Long Nuke Road, a road of this importance would not

normally be expected to present severe problems.   It is small, with

a low traffic flow, but maintenance conditions are poor (factor 5)

and the design characteristics of the highway are low.   This latter
data would only emerge from site visits and reference to the original
data bases, but the problem identification technique has drawn
attention to its presence.

This discussion suggests three conclusions:

(i)   The pattern of problems that emerges are intuitively correct.
        They match knowledge of the area and the data upon problem con-
        ditions and consequently act largely to justify and support pre-
        conceived notions of highway problems.

(ii)   Sites exhibiting severe and few problems emerge with clarity as
        do the priorities for further assessment.   However, the detail
        of problem structure can be established by examining individual
        problem scores.

iii)   However, despite this, the comprehensive scores perform a valu-
        able task in the interpretation of problem conditions and
        facilitating compa ison of sites in 'general' problem terms.
        They act as a standard against which the individual conditions
        can be measured.   Clearly a site exhibiting severe comprehen-
        sive problems needs attention;   one with few problems needs
        little;   whilst the mass of sites within the middle range of
        scores need further investigation to establish any individual
        problems that might exist and the priorities that there are for
        investment.

Problem scores - factor 1 (Environment)

Figure 4.7 shows the distribution of weighted problem scores for
factor 1 - which is closely associated with environmental problems.
The distribution of problems is clearly different from that found in
Figure 4.6 showing the total problem conditions, although environ-
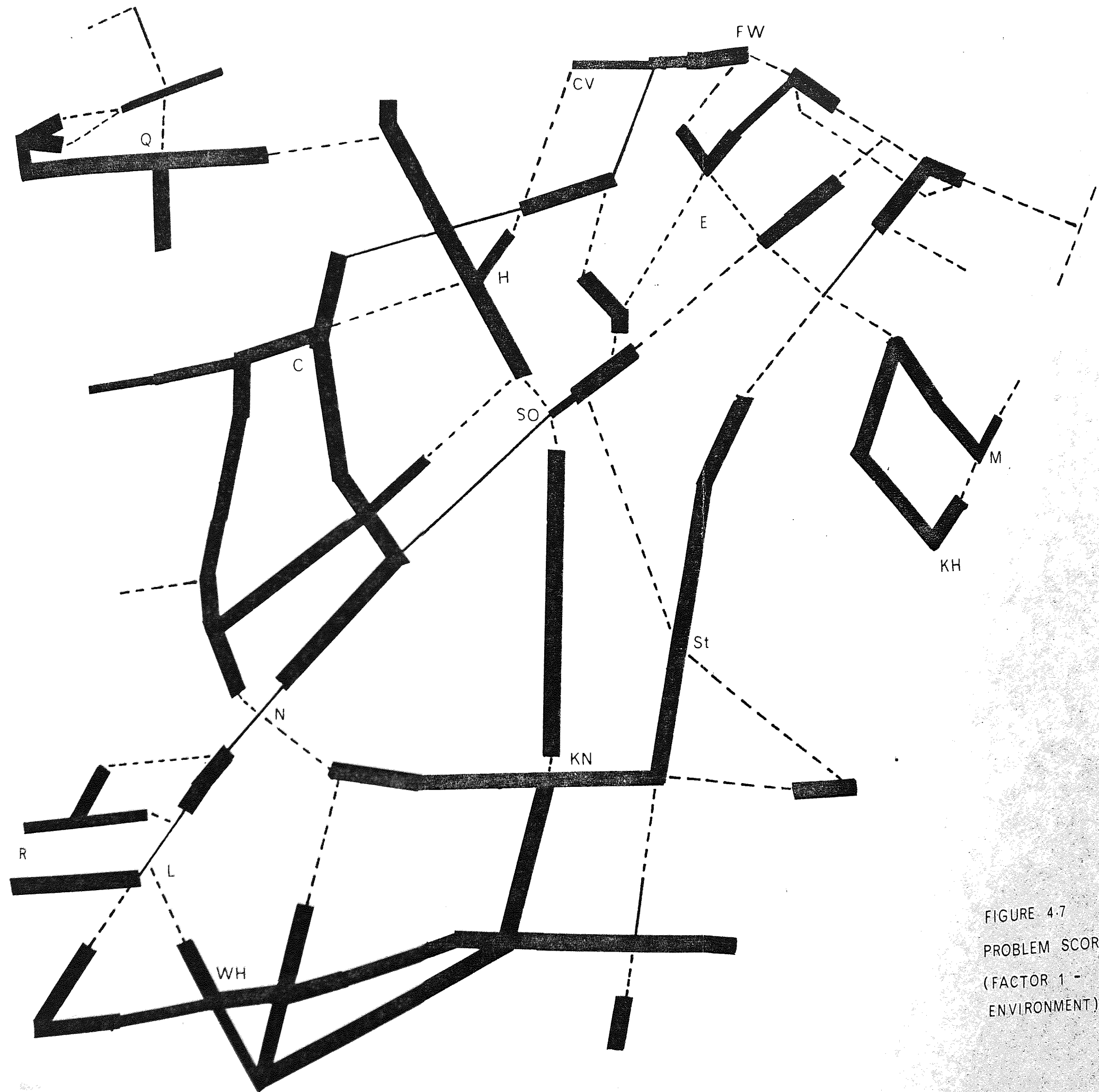mental problems are once again concentrated upon the busier highways.

144 (i)

FIGURE 4.7
PROBLEM SCORES
(FACTOR 1 -
ENVIRONMENT)

Noticeably, severe conditions are found on the Bristol Road South

(1358-1360), Bristol Road (1348-1346, 1392-1394 and 1482-1539) and

the Middle Ring Road (1477-1540), each of which are major radial or

orbital routes.   However, the precise location of the poorest

environmental sites does not correspond well with the comprehensive

problems.   A number of minor roads also exhibit severe problems on

factor 1, including Salisbury Road and Ridgacre Road (1484-1486 and

1258-1173).   The distribution of problems is less easy to interpret

or categorise than in the case of comprehensive problems.   Environ-

mental conditions are markedly affected by non transport factors -

such as land use and building configuration - and to gain a better

understanding of the reasons for the distribution of problems using

factor 1, reference might need to be made to the original data

matrices.   The absence of close correlation with comprehensive

problem scores implies that the user needs to refer to both to gain

an understanding of the complete situation.   If investment were pro-

posed on environmental grounds, sites exhibiting worst conditions -

for example Bristol Road South, Hagley Road West (1619-1457) or the

Outer Ring Road (1391-1394) - would be selected first.   None of

these sites would be selected on comprehensive problem scores.   Far

from invalidating the use of either total or individual factor scores,

it simply suggests that both must be taken into account to ensure an

understanding of detailed individual problems and the generalisation

inherent in the comprehensive scores.

Problem scores - Factor 2 (Public transport)

        Figure 4.8 shows the weighted scores achieved for factor 2,

which is closely allied to public transport conditions.   The general

level of problem conditions is not poor compared with other individual

factors and, consequently, priority for investment would be low.   A

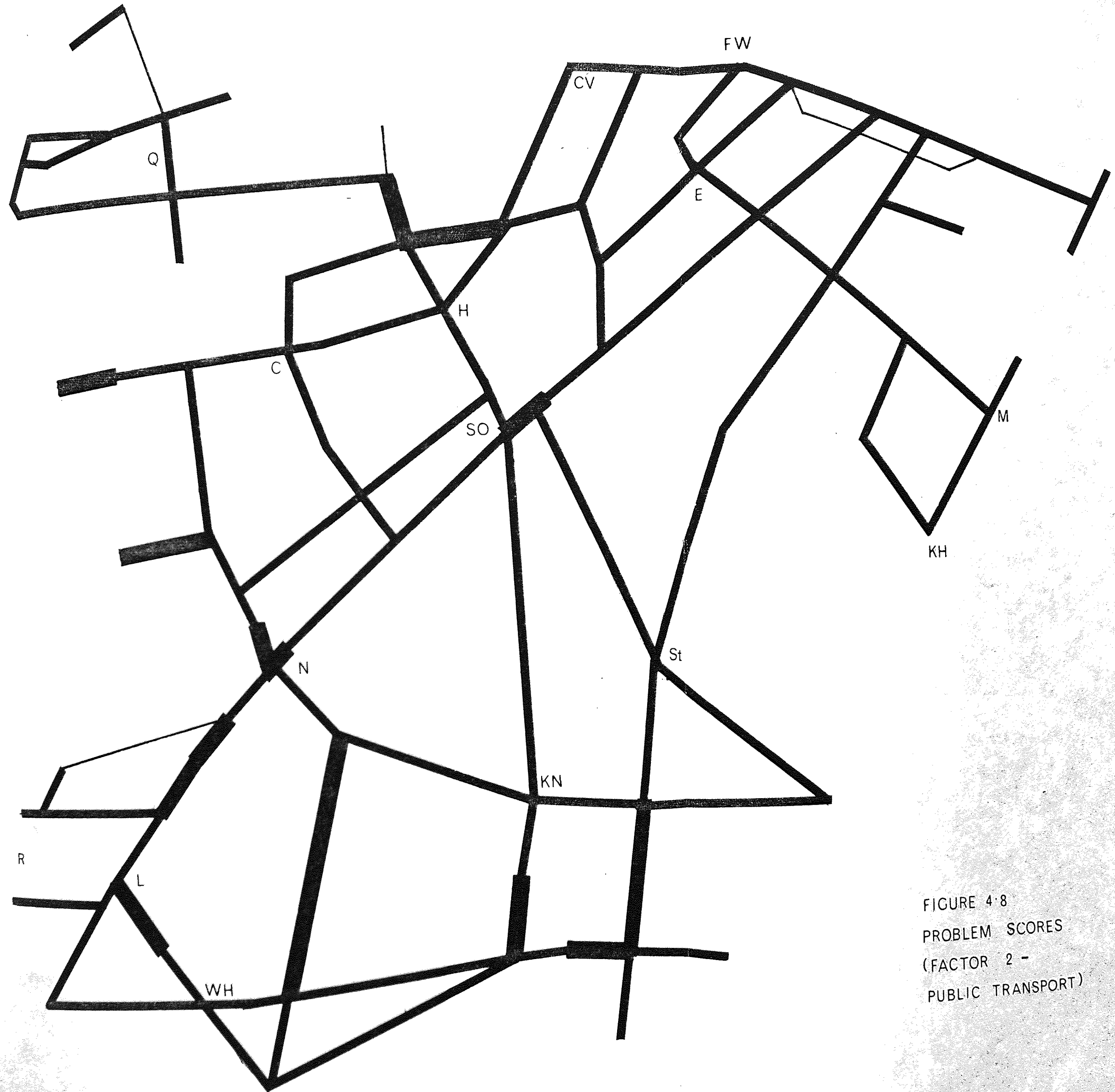small number of significant problem sites can be identified - in

FIGURE 4·8
PROBLEM SCORES
(FACTOR 2 –
PUBLIC TRANSPORT)

particular those at Harborne (1334-1335), Northfield (1345-1350,

1348-1350 and 1351-1355), Kings Norton (1375-1376) and Selly Oak

(1389-1392), and elsewhere at Long Nuke Road (1341-1342), Clapgate

Lane (1339-1245), Longbridge Lane (1361-1362) and Lifford Lane

(1380-1382).   They fall into two categories of public transport prob-

lem.   The former group can be associated with major shopping centres

where congestion may be causing operational problems (difficulties of

pulling out, queuing, etc.), and safety problems are also likely to

exist.   The second group is associated with specific highway sites

where operational problems exist - including narrow roads and bridges,

confined turning circles and the like.   The impression given from

the display of factor 2 is that few public transport problems exist

and compared with others (including comprehensive problems), the

position is satisfactory.   Investment at the majority of sites is

unnecessary, although the existence of problems in stopping centres

could be used as a basis for influencing the design of other highway

investment proposals (say road safety) at those locations.

Problem Scores - factor 3 (Congestion)

     The distribution of problems displayed using factor 3 - the

congestion factor - is shown in Figure 4.9 and is markedly different

from any other.   It represents an example of the need to assess

individual problem scores as well as the comprehensive picture.

Geographical distribution of congestion problems is closely associated

with the main shopping centres and busiest highways.   Harborne,

Northfield, Selly Oak, Longbridge and Kings Norton each display severe

problems both compared with other sites and other problem types.

Other locations characterised by problems of congestion can be assoc-

iated with poor junctions (1380, 1537), or simply a low standard of

road compared with its use (1537-1483-1489; 1386-1392 and 1371-1372).

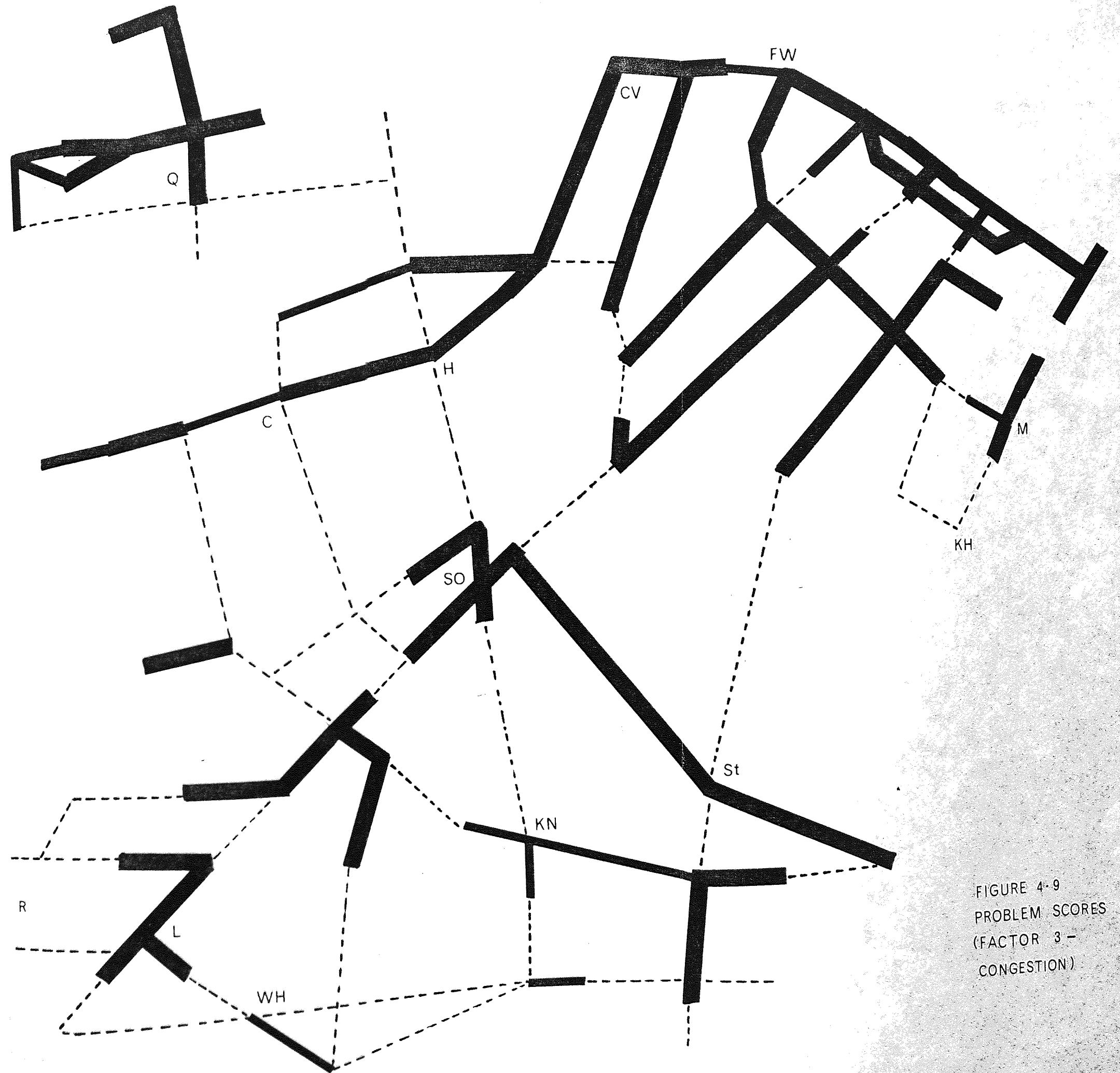This latter category includes the newly constructed Middle Ring Road

FIGURE 4·9
PROBLEM SCORES
(FACTOR 3 —
CONGESTION)

(1457-1547) which despite a high standard, is markedly overloaded in the morning peak period. Hagley Road (1265-1326 and 1404-1457), although to a lower standard, displays many of the same characteristics. One interesting point to note is the obvious concentration of problems as one moves towards the city centre - a well known morning peak phenomenon which has been reflected in the problem assessment.

This information would indicate to the user where to concentrate activity to alleviate traffic congestion. It would also indicate that many sites need no investment at all, whilst many others are comparatively poor when set against other problem conditions. Congestion appears to be a highly varied but relatively significant problem in the study area, necessitating closer examination at certain sites. One other issue to emerge is the existence of many poor highway sites which are known to be minor roads with average to low traffic flow. They are typified by 1352-1351 (Frankley Beeches Road), 1354-1355 (Tessall Lane) and 1267-1268 (Bleakhouse Road). However, each have in common the fact that they lead onto a major highway, (e.g. Bristol Road, Pershore Road and Wolverhampton Road) with consequential problems at their intersection. This suggests that the nodal file of information would be important in this context in providing both background and detail.

Problem Scores - Factor 4 (Road Safety)

The distribution of problem scores for factor 4, associated with road safety conditions, suggests yet another pattern of problem conditions (Figure 4.10). Particularly noticeable is its sporadic nature with little definite association with road status, centres of activity or geographical location. In fact, close examination suggests that the most severe sites are found on the less significant highways, where traffic flow is average, but design standards are low
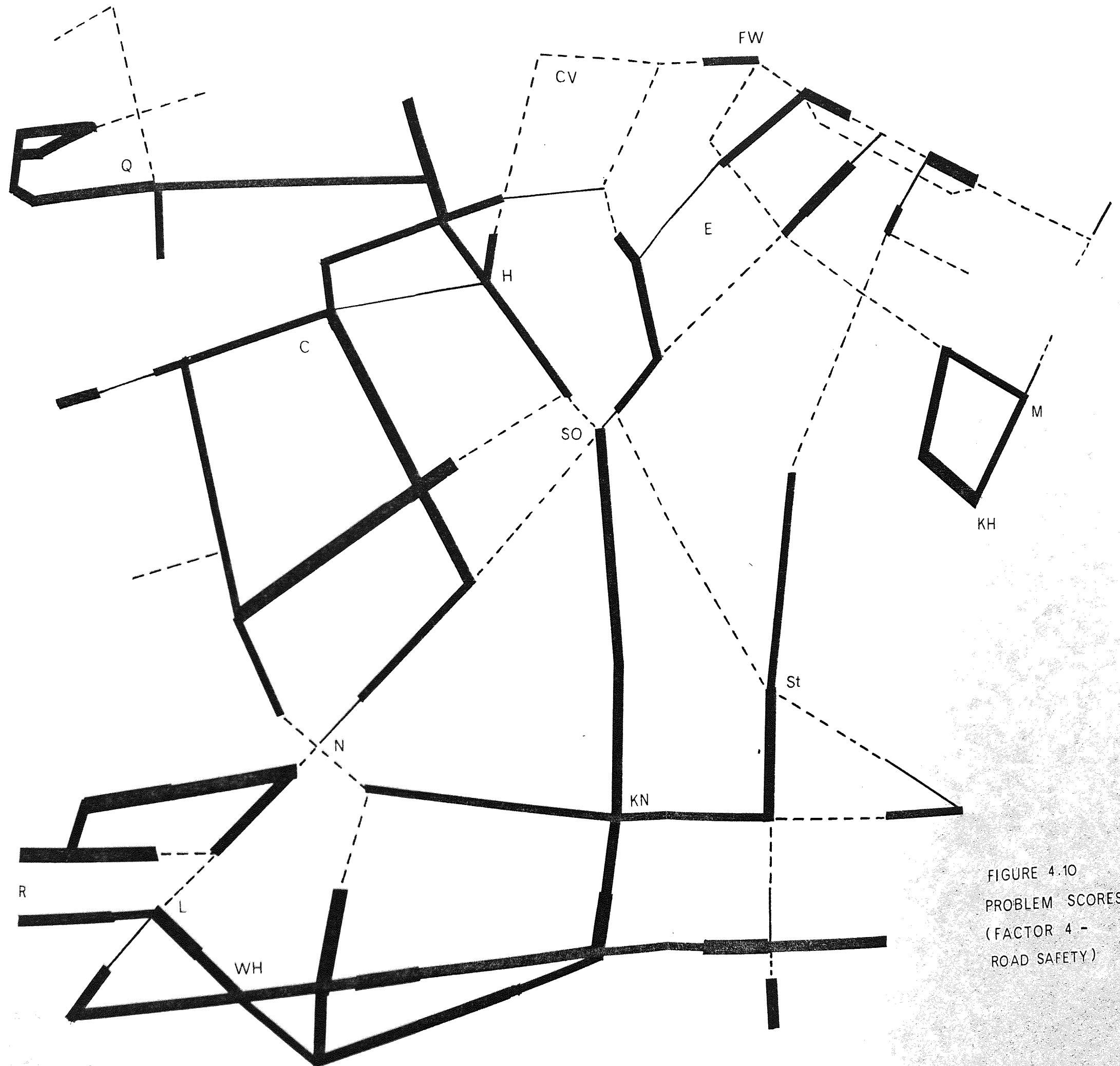
147 (₁)

FIGURE 4.10
PROBLEM SCORES
(FACTOR 4 –
ROAD SAFETY)

(e.g. Rednal Road, 1365-1376;   Monyhull Hall Road, 1380-1500 and Ridgacre Road, 1334-1257).   This clearly could be a contributary factor.

Perhaps more surprising is the relative absence of problems at centres of activity, which are characterised by congestion and public transport problems.   Generally, conditions are good at these sites, possibly reflecting the presence of congestion and the effect it has in slowing traffic and thus reducing accident severity.

The distribution of road safety problems tends to become more dense as one moves away from the city centre - possibly reflecting the distribution of congestion once again.   It is also a response to the presence of new highways, built to higher standards on the Middle Ring Road (1457-1547) and Hagley Road (1619-1404).   One site stands out which would be investigated by the user.   It is Shenley Fields Road (1343-1390), which is a poorly used, residential road not characterised by problems in other sectors.   Original site data might need to be examined before remedial action could be proposed and priorities determined.   In fact, this would reveal a particularly poor junction layout at site 1344, which has led to a poor accident record despite low usage.   This has affected problem scores for the approach links.   This type of site would not materialise high up the comprehensive problem list, since it is a problem only from one view-point.   However, its solution may be reasonably inexpensive, compared with sites exhibiting widespread problems, and it qualifies as a result for further investigation.   This clearly reveals the value of both individual and comprehensive problem scores.

Overall, road safety conditions are not poor, but a small number of sites need attention.   This is a function of the site specific

nature of road accidents which tend not to group together over a series
of connected links, but remain distinctly separate.

Problem Scores - factor 5 (maintenance)

The final map (Figure 4.11) shows problem scores associated
with maintenance conditions.   The distribution of these problems
displays the greatest consistency of all factors - generally poor con-
ditions.   Although few immediate priorities emerge, exceptions are
Oak Tree Lane (1387-1392), and Frankley Beeches Road (1351-1352).
There are also few sites exhibiting good conditions.   This includes
the relatively new roads at the Middle Ring Road (1457-1547) and
improved sections at Harborne Lane (1391-1389) and Bristol Road South
(1358-1360).

The information in this map is more difficult to interpret than
for other factors simply because significant priorities do not emerge.
In general, poor conditions are found over most of the case study
area, and compared with other problems (e.g. public transport), the
need for investment is clear.   However, the picture that does emerge
reflects the well documented shortage of investment in maintenance
in recent years which has led to general decline in standards.   Use
could be made of the data from factor 5 to justify highway improve-
ments in other sections (road safety or the environment) by suggest-
ing that maintenance improvements could be incorporated at the same
time with obvious benefits.   Detail of factor scores for maintenance
conditions provides information upon priorities which can help in
deciding resource allocation which is not available from the problem
maps.

Individual and Comprehensive Problem Scores

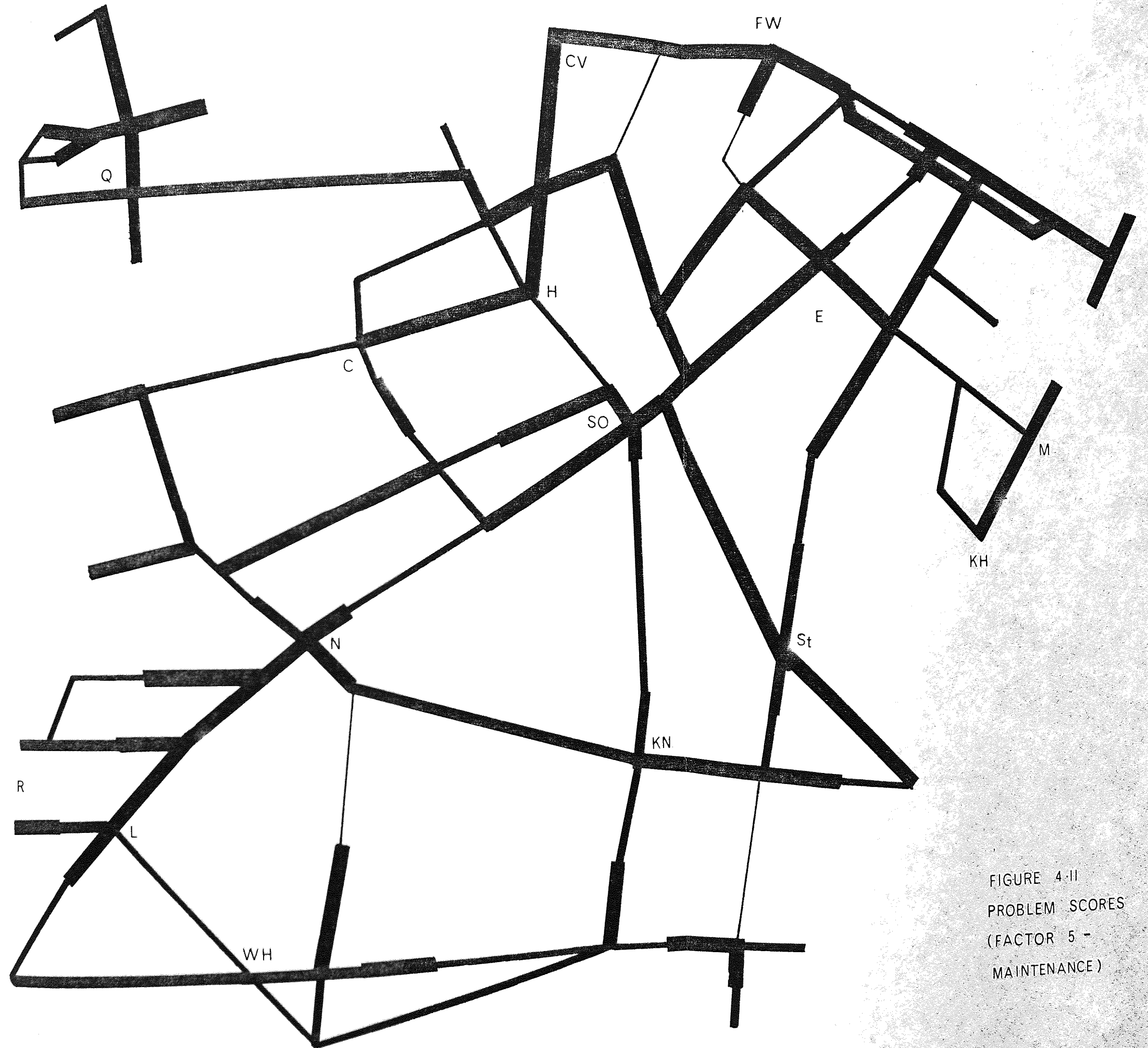One of the more important functions of the problem identification

FIGURE 4·11
PROBLEM SCORES
(FACTOR 5 -
MAINTENANCE)

process, is to facilitate the comparison of problem types - enabling assessment of priorities between maintenance, public transport, etc., and also providing for the calculation of a total problem score for each site. Of interest to the user is the difference between scores, using each individual factor and the comprehensive factor, each representing different facets of highway conditions. Figure 4.12 shows the co-relationships of the various equimax factor solutions. Clear differences in the scores and ranks are apparent from the low Pearson Product and Spearman Rank coefficients. The highest positive correlation is between total problem rank and factor 2 (public trans-port), suggesting that the distribution of public transport problems is similar to overall problems for the area (P.P.M.C. = 0.4659, Spearman = 0.6871). The highest negative correlation is between factors 1 and 3 - representing a strongly contrasting pattern for environmental and congestion conditions. Poorest Spearman correla-tions are for factors 3 and 5 (congestion and maintenance) (0.0881) and total problems and factor 1 (congestion) (- 0.0544). Other correlations range between these figures.

Figure 5.7 shows the sites exhibiting the worst conditions for each factor. It is notable that different sites emerge for each of the factors reflecting the need to assess each to gain an impression of problem distribution. Particularly interesting is the contrast between the comprehensive problem sites and those of the individual factors. Some sites (notably Frankley Beeches Road, 1351-1352, Bell Hill, 1349-1350, and West Heath Road 1371-1372 amongst others) feature on more than one list, and these are the sites exhibit-ing all round poor conditions. They tend to rank highly in the com-prehensive list as well. It is also notable how some stretches of highway, covering a number of sites, appear on a number of lists -

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR TOTAL
FACTOR 1	-	-0.1641	-0.8836	0.0724	-0.0273	0.1712
FACTOR 2		-	0.2081	0.0931	-0.0319	0.4659
FACTOR 3			-	-0.1595	-0.0603	0.0346
FACTOR 4				-	0.7476	0.7271
FACTOR 5					-	0.5219
FACTOR TOTAL						-

PEARSON PRODUCT MOMENT CORRELATION COEFFICIENTS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR TOTAL
FACTOR 1	-	0.2475	-0.8639	0.2810	-0.2419	0.1448
FACTOR 2		-	-0.3108	0.5481	0.2804	0.6871
FACTOR 3			-	-0.5194	0.0881	-0.0544
FACTOR 4				-	0.5367	0.4763
FACTOR 5					-	0.5930
FACTOR TOTAL						-

SPEARMAN RANK CORRELATION COEFFICIENTS

(All significant at 0.001 % level)

Bristol Road and Bristol Road South (1360-1366, 1393-1394, 1346-1347, 1353-1355 on factor 1 (congestion); 1348-1350 on factor 2 (public transport); 1360-1361, 1539-1541 and 1389-1392 on factor 5 (maintenance) and 1351-1353 and 1389-1392 on the comprehensive factor) are a good example. This suggests that problems along stretches of highway of this type are extensive and that single site definition is insufficient. However, in many cases, sites differ completely. Consequently, site definition by each problem factor would produce differing priorities. The implications of this for resource allocation and decision-making are clear.

The Interpretation of Problem Scores

Use of the factor solutions to analyse highway problem conditions has a number of advantages. Firstly, it enables the user to compare conditions by problem type and location without the need for the introduction of a common metric such as points or money, with all the value implications this brings. It far from eliminates subjective or value choice, but ensures that comparisons are consistent and, consequently, meaningful. Thus, it is possible to recommend priorities for investment between problem types and sites. These priorities clearly emerge from the display of tables and maps which are produced by the problem identification process. Secondly, the availa ility of both individual and total problem scores enables the user to examine the structure of problem conditions, how they interrelate at each location and generally over an area, and thus provides detail of design requirements. It also indicates the existence of individual problems which might otherwise be overlooked. Thirdly, it is comprehensive, ensuring that problem sites are not excluded solely due to the absence of appropriate information. The user is presented with details of highway conditions over the whole case study

area, allowing him to select sites in the knowledge that he has data for all locations. Fourthly, even if no different sites or priorities emerged from the review of problem conditions, the information and its characteristics provide justification for resource allocation which previously did not exist. Evidence of problems and their measurement and comparison against local objectives ensures that contentious decisions to invest at sites can be justified more clearly and firmly in the eyes of the public and central government. Fifthly, by measuring problems strictly in local objective terms, and in the same manner as scheme evaluation is carried out, the user is sure that the process of highway appraisal is consistent, and does not lead to the derivation of schemes which solve unimportant or conflicting problems. Finally, it provides a method of producing a set of sites for the Coarse Sieve stage of Priority Ranking, which is manageable in size, related to local objectives and yet not solely based upon political pressure, local knowledge or officer expertise. The user can have confidence in the results in the knowledge that it reflects highway conditions. The role of political intervention, expert interpretation, and public pressure can then be incorporated either to adapt the pool of sites to meet their requirements, or to act as a filter to adjust these sites that proceed to the Fine Sieve stage of Priority Ranking.

There are a number of disadvantages. Firstly, the method of factor analysis is complex and unfamiliar to practising transport planners. It might prove difficult to gain acceptance and thus to be used successfully as a method of site selection and resource allocation. Secondly, each of the problem factors is a representation of a number of transport and highway items (e.g. maintenance, public transport, etc.), albeit dominated very largely by one. Consequently, scoring

and ranking in terms of that dominant item, and implying that it is representative solely of that item, is not exactly the same as actually using that item. Other elements of other problems are also present. This affects the representation of problems by individual factors, although less so as the dominance of the major one increases. The user of the system needs to keep in mind the relationship of factor to dominant item and the need to select the number of factors retained by the analysis to ensure the closest and clearest description of conditions. An additional deficiency in the case study is the absence of a number of highways from the network which might generate significant problems. Although the network used is sufficient for T.P.P. preparation purposes, ideally it would be comprehensive, to ensure that sites were not excluded from consideration; and so that it could be used as a means for reviewing conditions in general. Fourthly, problems of site definition clearly exist. Arbitrary boundaries placed around sites, and the existence of 'point' problems (e.g. junction congestion, accident black spots) are not accommodated adequately in the network structure. Further effort is needed to make referencing more flexible and to accommodate problem distributions, rather than impose a structure upon them. Fifthly, the difficulties of translating detailed factor scores into a map form need to be noted. This is important because the map information is likely to form a major means of communicating problem information to decision-makers. Categorisation of problem scores results in an immediate loss of information, and the choice of category clearly affects the distribution of priorities. Thus, selection of a finer score range for factor 5 (maintenance) would probably produce a different set of priorities. Although not central to the development of problem identification, the effect of mapping needs to be noted. Finally, the problem data used in the case study refers to the morning peak

period only.   Although this is commonly taken to represent worst con-

ditions, it is not as accurate as using data for the whole day, and

its weaknesses also need to be kept in mind.

T.P.P. Preparation and the Use of Problem Scores

This information on problems enables the user to compare highway

conditions both between sites for an individual problem type and bet-

ween problem types at a site.   This is possible for two reasons.

Firstly, the problem scores are composite values, standardised through

the factoring process and thus comparable upon the same terms.

Secondly, the problem criteria, scores and ranks are all derived from

the set of objectives and priorities selected by the County Council.

Given these priorities as a framework for standards, against which con-

ditions can be compared, the individual problem scores reflect any

deviation from idealised conditions and the priorities that exist

between them.   These scores are thus not only in common units, but

also units derived from a common set of standards.

This enables both overall and individual problem scores to be

used to derive priorities for highway sites prior to design and

evaluation through Priority Evaluation.   Overall scores can be used

to indicate problem conditions in general and facilitate comparison

between sites;   the individual scores enable comparison between prob-

lem types at any site and the user to establish the structure of

problems that exist.   The individual scores also provide an opport-

unity to identify sites which exhibit, in general, few problems, but

which in detail may have one severe problem which merits further con-

sideration.   Details of this single problem may be lost in the pro-

cess of constructing the overall problem score.

In summary, a typical pattern for the use of output from the

problem identification process in the preparation of a T.P.P. might

be as follows:

(i)   take the overall problem map and scores and extract the sites

         exhibiting severe problems;

(ii)   take the individual problem maps and scores and extract those

         sites which exhibit severe problems which do not feature from

         the overall problem analysis.   This includes comparisons bet-

         ween problem types to assess relative needs in each sector.

         The structure of the overall problem sites, extracted at stage

         (i) can also be derived;

(iii)   use the problem scores to assess the detail of highway condition,

         and to compare priorities between marginal sites;

(iv)   rationalise the selection of sites to form a manageable bundle

         which moves forward to the Coarse Sieve stage of Priority

         Ranking.

Conclusions

       This chapter has described the output from the problem identifi-

cation process applied to the case study area.   It has shown how both

the detailed scores for highway condition and the use of mapped scores

can help to indicate sites for priority investigation, and the

structure and nature of conditions that exist.   The next chapter will

look at the implications of the technique for the T.P.P. preparation

process, for the derivation of priorities and for the highway evalua-

tion process as a whole.

CHAPTER 5 - IMPLICATIONS

The main implications of introducing factorial problem identification are two-fold. Firstly, its effect upon the process of T.P.P. preparation. This in turn has two main aspects:

- the direct effect upon the method and approach to highway evaluation;

- the relationship of problem identification to the existing scheme evaluation methodology;

secondly, does it have implications for the results that emerge from that process?

Implications for T.P.P. Preparation

The development of problem identification introduces a new stage into the established process of T.P.P. preparation in the West Midlands, and at the same time replaces a number of procedures which were characterised by many of the deficiencies in evaluation that problem identification was designed to overcome.

The existing process of T.P.P. preparation in the West Midlands has the following stages:

(i) Scheme generation - a process characterised by discussion between local authorities, the P.T.E., British Rail and other interested groups, political and public pressure, and the input of a considerable amount of officer expertise providing local knowledge of highway conditions which is used to justify site selection. Highway data for monitoring purposes is used selectively to establish the level of problem conditions at sites previously selected.

(ii) These sites then proceed to coarse scheme evaluation in Priority Ranking, and if they survive, to fine sieve and subsequently detailed scheme design. Those which are found to be best 'value for money' in

meeting local objectives, proceed to be inserted into the programme

of schemes for the T.P.P. at the earliest possible date.

Problem identification has ramifications for the early stages

of this process. The stage of discussion, public and political

pressure and expertise is supplemented, and in part replaced by a

formal stage of continuous monitoring of all highway sites in the

county on the Strategic Network. Highway data, the range of which is

determined by current county policies and objectives, is assembled

through the year (as now), but used during the annual T.P.P. prepara-

tion period as the main basis for problem identification and scheme

generation. The factorial analysis programs are applied using this

data and current objective/criteria weights to determine the location,

severity and structure of problems at each site. Clearly, the

majority of sites will display few problems, but those appearing

highly ranked in the overall problem list would then be selected for

further assessment and would enter the coarse sieve stage of Priority

Ranking. Those sites highly ranked on individual problem scores also,

in the main, would be ranked highly overall. However, any sites appear-

ing highly ranked only in one or two individual lists would be further

scrutinised to analyse t e type of problem that existed, and might

proceed subsequently to Priority Ranking.

Problem scores also could be used to compare sites that exhibit

significant but not exceptional problems. These sites are likely to

lie at the margin of highway priorities and will be competing with a

considerable number of other sites which exhibit similar levels of

problem condition, for a diminishing supply of financial resources.

The problem scores enable comparisons to be made between these sites

in terms which allow priorities to be allocated.

Once this pool of sites has been derived from the problem scores,

it then proceeds as before to the latter stages of scheme evaluation. Discussion and political and public pressure remain valid elements of scheme generation, but would not form the sole basis, acting as a supplement to the formal stages of problem identification.

However, the use of problem scores would not end there. Detail of the structure of problems from the individual scores would be of use at the design stage of appraisal, facilitating and guiding the development of schemes to alleviate these problems. Since problems are derived from current county policies and objectives, scheme designs could be directed towards their alleviation. Individual problem scores also would provide information for the allocation of funds between sectors (for example, road safety, environment, public transport issues, and so on), since the identification and comparison of problems facilitated by this method provides detail of needs and priorities between elements which constitute highway conditions. Consequently, if the highway authority wished to give priority to environmental or public transport biased schemes, it could deliberately select those sites which exhibited those problems, over and above other sites exhibiting (say) road safety, maintenance or even overall problems. This, of course, could also be achieved by using selective objective weights. Through both methods, the distribution of financial support could be adjusted to match local priorities.

The general structure of T.P.P. preparation remains largely unaltered, but the detail of scheme generation and particularly its emphasis alters, placing greater priority upon regular data collection, up to date local objectives, elements of problem structure, and comparisons between site needs. As a consequence, the selection of sites for Priority Ranking, and subsequent scheme design, would become more consistent with local requirements and more sensitive to local

needs whilst increasing in consistency and reliability.

Factorial problem identification also has implications for the use of data in highway evaluation. One consequence of running a factorial solution is that correlations between highway data variables are calculated and set out prior to factoring and ranking. We have already seen how this matrix of association provides considerable information for the user, describing the relationships between variables, including close relationships between, for example, the environmental variables, or public transport and congestion, and those with little in common - for example, maintenance and road safety. Surprisingly little previous work has been carried out to establish the pattern of inter-relationships of highway characteristics - a function of the eparate funding and pla ning processes that exist for each. Publication of information upon inter-correlation between transport elements can only help to improve appreciation of their inter-related nature and the possibilities that exist to design for corresponding solutions.

Problem identification also provides information upon the value and importance that can be attached to each individual data variable. Firstly, the data upon variable inter-correlation provides information upon the duplication of information - where one variable might act as surrogate for others. Secondly, information from later in the factorial process, upon the contribution made by each variable towards the total variance (information) in the matrix, enables the user to distinguish those which contribute little to the description of problem conditions. An example from the case study is the bridge problem variable, explaining only 1.5% of the variance. It could have been excluded with little loss of information, helping to reduce data requirements, rationalise processing and save on scarce resources.

Finally, the information upon correlation provides a basis for interpreting problem structure and the need to design solutions to meet those structures. It thus forms a significant input to the design stage for without detail of inter-correlations, the structure of highway problems would remain largely indistinguishable from the mass of highway data.

The relationship of problem identification to Priority Ranking

It was an objective from the outset that any developments should be designed to meet requirements of current scheme evaluation methods and the Priority Ranking technique in particular. Consequently, it is important to assess how well the two processes work together and whether problem identification has any ramifications for the subsequent stages of scheme evaluation and implementation. Three issues will be considered.

(a)   How well do the two processes work together?

(b)   Has the development and introduction of problem identification
       any ramifications for techniques used by Priority Ranking?

(c)   The relationship of problem identification to the assessment
       of problems and the selection of proposals.

(a)   How well do the two processes work together?

The evaluation process, from problem identification through to scheme appraisal is shown in Figure 2.2. Clearly, the interface between these two elements needs to be considered carefully. Highway problem priorities for further assessment are taken from the results of the problem identification technique and used to derive the pool of sites for the Coarse Sieve stage of Priority Ranking. However, although this ensures that significant problems are not missed and that they are considered in comprehensive and policy terms, a major issue remains in ensuring that value for money proposals emerge from

160

the list of problems ranked by severity. Problem size is not neces-

sarily related to cost effective proposals. This is discussed more

fully in the following chapter. Of more concern here are the organi-

sational and management complexities which the introduction of problem

identification involves. Two issues can be identified - practical

and methodological.

From a practical viewpoint, it is particularly important that

the results from problem identification are in a form that provides

information and gives direction to Priority Ranking. This necessi-

tates providing detail of problem conditions which facilitates com-

parisons between problem types and sites, and retains the original

highway data. The latter provides practical information against

which Priority Ranking compares proposals. It thus forms a major in-

put to the scheme assessment stage. Problem identification, as out-

lined here, enables both types of information to be used - the stand-

ardised factor scores to indicate severity of conditions, and the raw

data to evaluate schemes.

Another issue of practical significance has been mentioned

already. No formal computer link exists between the two stages and

it is the responsibility of the user to obtain the output from problem

identification and to proceed to scheme evaluation. The value of a

formal link is doubted, since it could encourage acceptance of results

from problem identification without consideration of their implic-

ations, or detail.

Finally, in practical terms, it is important that problem

identification does not use up time, financial or technical resources

needed for Priority Ranking. Problem identification requires

relatively few extra resources beyond those to update the files of

highway data. This could be met from the savings made from

161

rationalising datafiles and monitoring services.

From a methodological viewpoint, it is essential that evaluation of problems is carried out in the same terms as that of solutions, if the process as a whole is to produce consistent and meaningful results - and that current County policies and objectives are used as a common basis. This ensures consistency both for the identification of problem sites and the design of schemes to alleviate them, avoiding the possibility that insignificant or inappropriate developments will emerge. This is helped through the use of a single and consistent set of (objective) weights which are flexible to change where needed. At the same time, the conflicts in policy which frequently emerge must be recognised and accepted as part of the normal decision-making process. This is encouraged by use of a single set of objective weights which reflect these conflicts. Use of common data sources also helps to achieve a consistent approach.

Overall consistency has the additional advantage that it meets the objectives of central government as expressed by the Department of Transport (1977, 1978A, 1979). Thus, the formulation of a set of proposals for the T.P.P. can be seen to have derived directly from the identification of problem conditions in policy and objective terms using locally assembled data and monitoring systems. This data in turn is used to assess scheme achievement. This process compares favourably with the widely held model of the idealised planning and evaluation process shown in Figure 1.16.

(b)   Has the development and introduction of problem identification any ramifications for the techniques employed by Priority Ranking?

Although the research has dwelt upon the needs of highway problem identification in the West Midlands, the case study results and the discussion of evaluation issues in general are useful in terms of how

the process of Priority Ranking might develop.   Scheme evaluation

faces many of the same problems that are faced by problem identification.

The major difference is that it has to consider only a limited number of

highway sites and is not faced with the difficulties presented by com-

prehensive problem identification.

In particular, Priority Ranking has yet to overcome some of the

difficulties associated with the aggregation and valuation of highway

conditions.   In this case, the difficulties arise in calculating a

single index of condition both before and after the implementation of

a highway proposal.   Essentially the difficulties are the same as in

problem assessment - how to bring together a disparate set of variables

which defy conventional approaches of summation.

Clearly the methods used for problem identification could help.

There is no methodological or theoretical reason why a factorial com-

posite measure of highway conditions before and after scheme imple-

mentation should not be used.   It would be statistically reliable,

eliminate subjectivity inherent in the Priority Ranking points alloc-

ation method, allow current weighting methods to remain in use and

permit the derivation of preferred sites in terms of local objectives.

Experience of its use for problem identification has shown it needs

few resources and produces clear results.   Consistency in identify-

ing problems and assessing solutions would be facilitated by using a

common evaluation method.

A number of secondary benefits have also emerged.   In particular

these fo us upon data evaluation.   Clear indications of the contri-

bution made by each data variable are derived through factor analysis

and this could be extended to data used to assess highway projects.

Those pieces of information which contribute little might be excluded

or replaced by others, thus helping to rationalise and improve data

use and efficiency.

A third area where the results of problem identification could be useful to Priority Ranking is in the assessment of site conditions. Simply by maintaining a single up to date inventory of highway conditions, the assessment of schemes becomes more accurate and consistent. Highway site conditions need to be k own prior to problem and scheme assessment and the same database of information is used. This again facilitates consistency throughout the highway evaluation process.

Finally, problem identification plays a significant role in filtering out those sites most in need of attention prior to scheme design and assessment. By so doing, it reduces the time and resource costs of Priority Ranking which currently necessitates assessment of some schemes which are unlikely to prove profitable. Simply by ensuring that o ly valid problems, in local terms, proceed to evaluation, then the number involved will be reduced. This gain offsets many of the resources needed to develop and maintain highway problem identification. It also achieves this in a simple and objective way, long noted as a desirable aim for planning evaluation (see, for example, Kitchen [1972]), but one which has been found difficult to achieve.

(c)   The relationship of problem identification to the assessment of
        problems and the selection of proposals.

        Two closely related issues are relevant here. Firstly, the
implications of problem identification in providing a basis for the justification of site and, therefore, scheme selection, and secondly the use of problem identification to allocate priorities between sites which exhibit similar problem conditions.

Justification: Expenditure upon severe highway problems is easy to

justify, as is the converse of not investing at sites with few problems, but rather more difficulties emerge when expenditure is proposed for sites exhibiting lesser problems. Although the majority of expenditure will take place at sites which face severe difficulties, inevitably the balance will be made up of a series of sites from the confused 'middle ground' - an area where there are a number of average problems which are difficult to distinguish and to which priorities are difficult to allocate. Problem identification involves careful consideration of highway conditions in local objective terms. Even though it is far from value free, it represents a significant advance in formal and structured decision-making compared with existing 'ad hoc' procedures which rely upon a combination of intuition, experience and political pressure. Consequently, the decision to go ahead with designs for a site identified through formal problem identification, almost regardless of problem severity and competing options, can be more easily justified than one based upon current approaches. This has an effect upon the attitudes of four groups who take a close interest in the choice of proposals, and who need to be convinced of the merits of each - the Department of Transport, the elected local authority members, the general public and other interest groups (for example, British Rail, P.T.E., etc.). The D.T.P. welcomes an approach to highway evaluation which involves a formal problem identification stage. It is something that they have recommended for many years. Consequently, local authorities who can point to highway schemes justified in terms of problems identified against local objectives will find themselves in a strongly favoured position. The elected local authority members view similarly the introduction of a process which ensures that sites presented to them have been derived on the basis of their own policy preferences. Clearly, in these circumstances, they are less likely to reject officer advice and thus more likely to be presented with a relevant set of highway problems and proposals. Problem identification

also provides evidence for the justification of site selection and scheme design when presented in public. Finally, the same can be said for other organisations - British Rail, the P.T.E., etc., who can see that sites have been selected based upon their known characteristics and local priorities.

Problem identification eases the path of highway evaluation so that disputes over the need for investment are minimised and effort can be concentrated upon the detailed design of highway schemes. Consequently, it quickens and simplifies the process of evaluation and scheme implementation by placing it upon a firmer footing.

Priorities: Problem identification distinguishes detailed priorities between highway problem conditions even when the characteristics and degree of severity is similar. Normally, in this situation, the allocation of priorities would be difficult. Severe and relatively small problems present few difficulties, but sites which exhibit marginal roblems are more difficult to choose between. These marginal problems in fact form the mass of sites, and with constraints on resources, expenditure is unable to be spread sufficiently to meet all of them. Consequently, decisions have to be made as to which should proceed to scheme design and which not. Problem identification helps by revealing detailed problem structure (and thus possibilities and priorities for solution) and providing a comprehensive problem score which indicates priorities directly. Although the use of scores at this detailed level may be open to question, it represents a significant advance over current resource allocation methods.

The introduction of a formal problem identification process clearly could have ramifications for many stages of the highway evaluation process - from assembly and use of highway data, description of problem structure and evidence for design of proposals, through

providing techniques adaptable to Priority Ranking, to the justification

of expenditure, and distinguishing priorities for further investigation.

Implications for the Results of Highway Evaluation

Given that problem identification will have inevitable implica-

tions for the West Midlands highway evaluation process, it is clear that

its effects on the results of that process ought to be notable. Even

though its effects in site and scheme justification, in providing

methods appropriate for Priority Ranking and improved knowledge of

highway problem structure will take time to have noticeable influence,

the simple process of reviewing conditions and assessing them in terms

of local priorities ought to produce some immediate changes in the sites

which reach Priority Ranking. Such changes will show its immediate

value. Comparisons were carried out of the sites which have recently

reached Priority Ranking with those that emerged as priorities from the

case study. The results from this comparison are discussed in the

following section.

(i)   Comparison of Sites

Comparison of sites exhibiting problem conditions from the exist-

ing methods of site generation and from factorial problem identification

would give a clear indication of the effect of introducing the new

methodology. However, for a number of reasons comparisons are not

easy to carry out, presenting a series of difficulties.

(a)   The case study covered only a limited area of Birmingham

and thus far from included all sites within the West Midlands.   The

only information available from Priority Ranking was for the whole

county.   This presented obvious problems in comparing priorities.

(b)   Problem sites tend to emerge over a number of years from

the existing approach to scheme generation in the West Midlands.   The

selection of sites considered by Priority Ranking is not generated in

response to immediate problem conditions but results from a lengthy process of discussion. The new problem identification methodology responds much more to the immediate nature of problem conditions and do s not rely so much upon a discussion process and the delays that this inevitably brings about. As a result, problems identified through the factorial method for 1979 might not be directly comparable with problems identified by the existing method and a wider perspective is needed to ensure that a complete picture is obtained.

(c) Difficulties exist because no formal and consistent approach to problem identification existed in the West Midlands before the development of the factorial technique. This makes comparison between existing and proposed methods very difficult to carry out. Instead of there being a set of ranked problems derived by each approach, the existing technique produces a pool of sites without specific priorities.

(d) A major difficulty is that the selection of sites that makes up the problem pool is always affected by a number of extraneous factors. These include the availability of land at a site; the state of preparation of ancillary activities such as access roads, site development and property acquisition; the availability of resources, particularly for major problems; and political consider-ations which may result in sites moving forward to preparation and design even though problems are relatively unimportant. Each of these factors intervenes in the process of problem identification and scheme evaluation to a degree which is highly variable and difficult to assess. Clearly, they may upset ranking of problems by highway conditions by over-riding such technical considerations. It is often the most convenient sites (albeit still with problems) which proceed to Priority Ranking, rather than necessarily those which

exhibit the most pressing needs.   Consequently, comparisons between

a highway approach to problem identification and one which has already

seen the intervention of factors of this type, is difficult.

However, given that these difficulties exist, it is still pos-

sible to reach conclusions about the impact of factorial problem

identification and whether its introduction will result in changes

in the priorities for sites and the derivation of a different set of

highway proposals.   To overcome difficulties associated with differ-

ing timescales, all sites which were assessed by Priority Ranking for

the years 1978 - 1980 were taken and compared with those emerging

from problem identification for the year of 1979.   This ensured a

broad comparison between the results of the two methods although

inevitabl it meant that some problem sites were included derived

from data for years other than simply 1979.   However, transport

policies in the T.P.P. remained constant over this period and con-

sequently sites should have been selected using the same objectives.

The pool of sites used to compare with the results of problem

identification were taken from the Coarse Sieve for 1978 - 1980.

Sites considered at this first stage of Priority Ranking represent

current views of problem location (given that political, financial

and other extraneous considerations have intervened).   If the new

problem identification method was to have an effect in producing a

different pool of sites, then there should be a difference between

the results of the two methods.   Data was not available for detailed

scores achieved by sites in the Coarse Sieve and precise ranking was

impossible.   However, details of their success in moving on to the

Fine Sieve was available and comparisons of site distribution and

characteristics were still possible.

Data for the whole of the West Midlands were used to assess

problems existing at that time and to place conditions in the case
study area in context.

The following framework was used to compare the output from
problem identification for the case study area with the Coarse Sieve:

(i)   comparison of sites in the Coarse Sieve, with those emerging as
       problems in the case study;

(ii)   what are the respective distribution of problems?;

(iii) do they differ? why is this so?

(i)   Comparison of sites in the Coarse Sieve and problem identification
       Sites which reached the Coarse Sieve for the years of 1978 - 1980
are listed in Figure 5.1 and mapped in Figure 5.2.   Those sites also
in the Case Study area are indicated and Figure 5.3 shows the factorial
scores they achieved through problem identification.   High positive
scores represent the existence of notable highway problems, whilst
negative scores the converse.   Twelve of the 114 sites were located
in the case study area, a relatively small proportion of the total,
implying that problem conditions in general were less severe than in
the rest of the county.   A number of these sites are compared in terms
of their respective scores and ranked position using the problem
identification technique.

Alcester Road, Salisbury Road, is characterised by the problem
scores for the three highways which make up this site, shown in Figure
5.3.   A map of the site is shown in Figure 5.4.   In terms of compre-
hensive problem scores, highway conditions are close to the case study
average.   This conceals a wide variety of detailed problem conditions
which are revealed by close examination of the individual problem
scores.   For example, Alcester Road (1486-1616) scores heavily for
factor 3 (congestion), reflecting severe congestion problems at this

FIGURE 5.1 - SITES REACHING COARSE SIEVE STAGE OF PRIORITY
RANKING 1978 - 1980

CASE STUDY ?	SITE	YEAR(S)	PASS/FAIL
1.	Middle Ring Road/Small Heath B.P.	1980	Pass
2.	Bilston B.P.	1980	Pass
3.	Anchor Road B.P.	1980	Pass
4.	Alcester Road/Salisbury Road	1980/1979	Pass
5.	Brickyard Road, Aldridge	1980	Pass
6.	Wolverhampton High Street	1980	Pass
7.	West Boulevard	1980	Pass
8.	Queen Victoria Road, Coventry	1980	Fail
9.	Outer Ring Road, Coventry	1980	Fail
10.	Henwood Road, The Rock	1980/1979	Pass
11.	A34 Stratford Road Dualling	1980	Pass
12.	Dog Kennel Lane	1980	Fail
13.	Reynolds Lane to M42	1980	Fail
14.	Cannock Road/Park Lane	1980	Pass
15.	Buckhouse Lane	1980	Pass
16.	Gravelly Hill to Kingstanding Road	1980	Pass
17.	Six Ways, Erdington	1980/1978	Pass
18.	Keyway, Owen Road	1980	Pass
19.	Far Gosford Street, Coventry	1980	Pass
20.	Blackheath B.P.	1980/1979	Pass
21.	Washwood Heath Road/High Street (1)	1980	Pass
22.	Wood Green - Mywood	1980	Pass
23.	Wolverhampton Road/Pleck Road	1980/1978	Pass
24.	Bordesley Green - Victoria Road	1980	Pass
25.	Washwood Heath Road/High Street (2)	1980	Pass
26.	Shellfields B.P.	1980	Pass
27.	Rushall B.P.	1980	Pass
28.	Coppice Lane	1980	Fail
29.	Stubbers Green Road	1980	Pass
30.	Ashmore Lake Road	1980	Pass
31.	Darlington Street	1980	Pass
32.	Acocks Green B.P.	1980	Pass
33.	Highgate Road/M.R.R./Hartford Road	1980	Pass
34.	Brierley Hill B.P., Mill Street	1980	Pass

35.	Hams Bridge Road	1979	Fail
36.	Chester Road, College Road, Jockey Rd.	1979	Fail
37.	Holloway Circus	1979	Fail
38.	Lifford Lane	1979	Fail
39.	Hagley Road (5 Ways - Plough & Harrow)	1979	Fail
40.	Middle Ring Road (Lawley Street)	1979	Pass
41.	Swan - Harvey Road	1979	Fail
42.	Chester Road - Tameside Drive	1979	Pass
43.	Thimble Mill Lane	1979	Pass
44.	Northfield B.P.	1979	Pass
45.	Highgate Road/Stratford Road/Warwick Rd.	1979/1978	Fail
46.	Highgate Road/Moseley Road	1979	Fail
47.	Parsons Hill, Bell Lane	1979	Pass
48.	Oxford Street, Coventry	1979	Pass
49.	Foleshill B.P., Coventry	1979	Fail
50.	Fletchamstead Highway, Coventry	1979	Pass
51.	Charter Avenue, Coventry	1979	Fail
52.	Lockhurst Lane, Kingsfield Road	1979	Pass
53.	Hillfields Road, Vicarage Road	1979	Fail
54.	Lye B.P.	1979	Pass
55.	Lower Gornal, Milking Bank	1979	Fail
56.	Moss Grove, Stallings Avenue	1979	Pass
57.	Queens Cross Improvement	1979/1978	Fail
58.	Great Bridge B.P.	1979	Pass
59.	Widney Manor Road/Whitefield Road	1979	Pass
60.	Pleck Road, Rolling Mill Street	1979	Fail
61.	Queslett Road, Aldridge Road	1979	Pass
62.	Queslett Road, Kings Road	1979	Pass
63.	Bescott Road, Wednesbury Road	1979	Pass
64.	Bridgnorth Road, Compton Road West	1979	Pass
65.	Ward Street, Millfields Road (Bilston)	1979	Fail
66.	Chapel Ash	1979	Fail
67.	Wednesfield B.P.	1979	Fail
68.	Willenhall Road, Moseley Road	1979	Pass
69.	Dudley Road, Parkfield Road	1978	Pass
70.	A457 B.P. - Rolfe Street to Grove Lane	1978	Pass
71.	Fish Inn Junction	1978	Pass
72.	Eagle Street	1978	Fail
73.	Rednal Road	1978	Pass
74.	Middle Ring Road - River Rea to Moseley Road	1978	Pass

75.	Chester Road, Tyburn Road	1978	Pass
76.	Cole Hall Lane	1978	Pass
77.	Old Pleck Road	1978	Pass
78.	Green Lane	1978	Pass
79.	Bentley Road North	1978	Pass
80.	Knowle Relief Road	1978	Fail
81.	Birmingham Road, Parkfield Road	1978	Pass
82.	Camp Hill, Westhill Road	1978	Pass
83.	Roseville Ring Road	1978	Pass
84.	Maypole Lane	1978	Pass
85.	Clapgate Lane	1978	Pass
86.	Swan Lane	1978	Pass
87.	Dudley Port, Sedgley Road	1978	Pass
88.	Sutton High Street	1978	Pass
89.	Eden Street	1978	Pass
90.	Penn Road, Goldthorn Hill, Coalway Road	1978	Pass
91.	Warwick Road, Rotten Row	1978	Pass
92.	Warwick Road, Dovehouse Lane	1978	Pass
93.	Deedmore Road	1978	Pass
94.	Selly Oak Centre	1978	Pass
95.	Willenhall B.P.	1978	Pass
96.	Coventry Road, Kings Road	1978	Pass
97.	Middle Ring Road - Newtown Row	1978	Pass
98.	Saltley Gate	1978	Pass
99.	High Street, Brettel Lane	1978	Pass
100.	Station Road, Stechford	1978	Pass
101.	Hillfields	1978	Fail
102.	Wolverhampton Ring Road	1978	Pass
103.	Corporation Street/Aston Street	1978	Pass
104.	Dudley Southern B.P.	1978	Pass
105.	Shepwell Green Improvement	1978	Pass
106.	Lichfield Street	1978	Fail
107.	Stafford Road, Bushbury Island	1978	Pass
108.	Middle Ring Road - Garrison Lane	1978	Pass
109.	Middle Ring Road - Coventry Road	1978	Pass
110.	Middle Ring Road - Camp Hill	1978	Pass
111.	Coventry Road - Muntz Street	1978	Pass
112.	Thimble Road, Hall Street	1978	Pass
113.	Eve Hill Junction	1978	Pass
114.	Rowleys Green Lane	1978	Pass

FIGURE 5.2

COARSE SIEVE SITES 1978-1980

SITE	NODE	FACTOR 1 (ENVIRONMENT)	FACTOR 2 (PUB.TRANS.)	FACTOR 3 (CONGESTION)	FACTOR 4 (ROAD SAFETY)	FACTOR 5 (MAINTENANCE)	COMPREHENSIVE FACTOR
ALCESTER RD/SALISBURY RD							
Salisbury Road	1485-1486	96	-85	-453	-24	41	-29
Alcester Road	1486-1535	-23	-108	354	-81	73	5
Alcester Road	1486-1616	-329	-135	1670	-157	118	-34
WEST BOULEVARD							
West Boulevard	1261-1262	176	-76	-1406	45	26	-73
HIGHGATE RD/M.R.R.							
Middle Ring Road	1545-1547	-294	-123	1637	-209	90	-13
LIFFORD LANE							
Lifford Lane	1381-1382	-378	41	1862	-245	-181	-18
Pershore Road	1374-1382	151	-85	-457	-46	51	12
Pershore Road	1385-1382	379	-72	-1409	71	47	39
Forchouse Lane	1615-1382	-429	-123	1637	-189	89	-77
HAGLEY ROAD (5 Ways - PLOUGH & HARROW							
Hagley Road	1457-1619	267	-94	-461	-72	61	130
NORTHFIELD BY-PASS							
Bristol Rd. South	1348-1350	-244	453	1505	-106	172	131
Bristol Rd. South	1350-1351	-189	-131	1636	-235	118	47
HIGHGATE RD/MOSELEY RD							
Moseley Road	1546-1547	-370	-126	1649	-181	100	-80
Moseley Road	1547-1634	-267	-116	1045	-118	80	-94
Belgrave Road	1545-1547	-294	-123	1637	-209	90	-13
CLAPGATE LANE							
Clapgate Lane	1245-1339	-59	489	-178	54	116	56
Stonehouse Lane	1245-1338	-7	-104	339	-111	69	10
PARSONS HILL/BELL LANE							
Parsons Hill	1610-1380	419	510	-1533	132	88	168
Walkers Heath Road	1611-1380	-431	-124	1637	-189	93	-79
Broad Meadow Lane	1381-1380	-158	48	538	-133	-185	-39
Monyhull Hall Road	1500-1380	209	-69	-1396	60	14	-52
SELLY OAK CENTRE							
Bristol Road	1389-1392	-120	181	1564	-183	156	144
Bristol Road	1389-1346	-244	-131	1642	-214	112	20
Oak Tree Lane	1389-1391	-289	-125	1640	-207	96	-4
Harborne Lane	1389-1388	-293	-123	1636	-213	92	-7
REDNAL ROAD							
Rednal Road	1606-1607	137	-64	-1434	276	78	-73
Rednal Road	1377-1607	141	-85	-1336	169	35	-75
Rednal Road	1377-1609	83	-81	-1365	151	-3	-113
MIDDLE RING ROAD (RIVER REA - MOSELEY ROAD)							
Belgrave Road	1544-1545	156	-65	-1428	302	75	-109
Belgrave Road	1545-1547	-295	-123	1638	-209	90	-13

N

1485
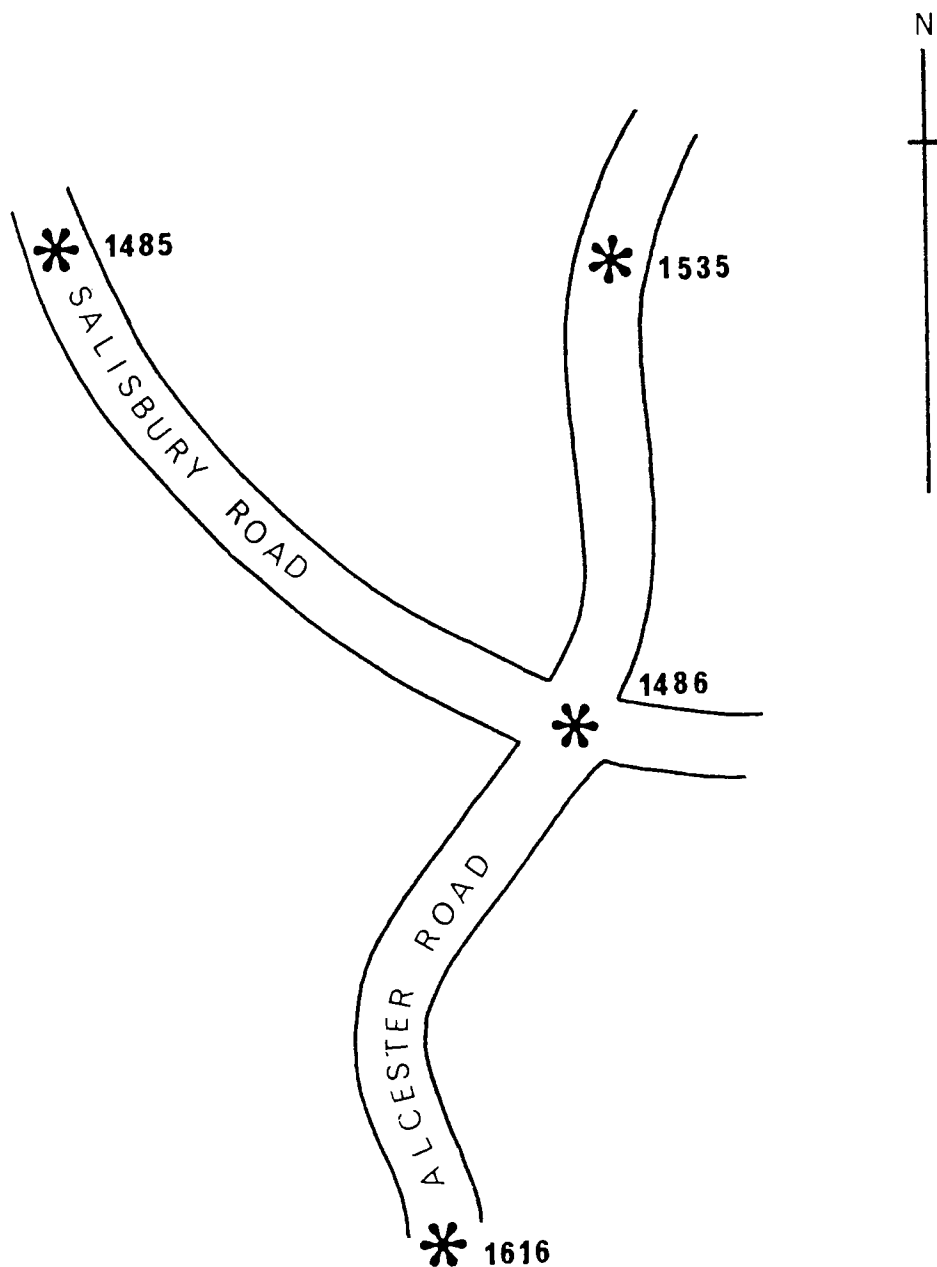
SALISBURY ROAD

1535

1486

ALCESTER ROAD

1616

FIGURE 5.4

ALCESTER ROAD,
SALISBURY ROAD SITE

site. However, this is compensated (and thus disguised in the comprehensive scores) by satisfactory conditions for factor 1 (environment), factor 2 (public transport) and factor 4 (road safety). The other two sites also display some variability, but to a lesser extent.

Compared with the priority given by the Coarse Sieve approach, problem identification suggests that there is no high priority to develop highway schemes at this site - especially if the comprehensive scores were used alone. However, the individual problem scores might stimulate further enquiry as the high congestion score for site 1486-1616 suggests that some remedial action is needed for that problem type. Lower priority would be given to this site using the factorial method, but detail of problem structure might lead to further assessment and eventually scheme design.

West Boulevard (1261-1262) also reached the coarse sieve stage. This is more surprising than the Alcester Road/Salisbury Road site, since the comprehensive socres were less severe. However, these scores hide substantial variability in the individual problem scores. Factor 1 (environment) conditions are relatively poor, although factor 3 (congestion) is significantly better than average. Overall, this site is unlikely to have reached the Coarse Sieve of Priority Ranking if problem identification had been used. Reference to discussion of this site at the Coarse Sieve suggested that the reasons for its inclusion were based around poor access afforded to local fire and emergency services. This is clearly an extraneous factor which the problem identification technique could not normally accommodate. However, problem identification provides evidence of detailed structure for improvements at a site if developments were approved for other, non-highway reasons. Thus in this case, environmental, road safety and maintenance conditions could be incorporated

into highway improvements justified by emergency service requirements.

Lifford Lane (1381-1382) includes need for improvement at node 1382 and thus a large number of other links (Figure 5.5). Need for investment emerges clearly at these sites, especially from the individual scores. Comprehensive scores suggest that problems are wide-ranging - those on the Pershore Road are worse than average, with those on the other links noticeably better. At the same time, individual scores suggest that factor 1 (environment) and 5 (maintenance) are generally high priorities, whilst factors 2 (public transport) and 4 (road safety) are low priorities. A site displaying the range of scores shown by Lifford Lane suggests that the user should investigate further, particularly where they are combined in such a complex way. This might be limited simply to looking at the original site data. Problem identification would agree with the inclusion of Lifford Lane in the Coarse Sieve, but would point to the structure of problem condition and the specific needs of that site, allowing a fuller appreciation of the local needs and possible design solutions.

Parsons Hill, Bell Lane (1380) is a junction treated with some priority in the Coarse Sieve during 1978-1980. It is defined in problem identification by a number of highways which meet at the intersection (Figure 5.6). Problem scores vary considerably between site and problem factor. In comprehensive terms, only Parsons Hill emerges as requiring attention, a d it does so with comparative force. The structure of problems on this link is dominated by environmental, public transport and road safety problems, whilst congestion conditions are very good. Parsons Hill has priority through junction 1380. Although other links at this site do not emerge as problems, each exhibits its own individual deficiencies. West Heath Road - congestion and maintenance ; Broad Meadow Lane - Public transport and congestion; and Monyhull Hall Road - environment and road safety.

172 (i)

N

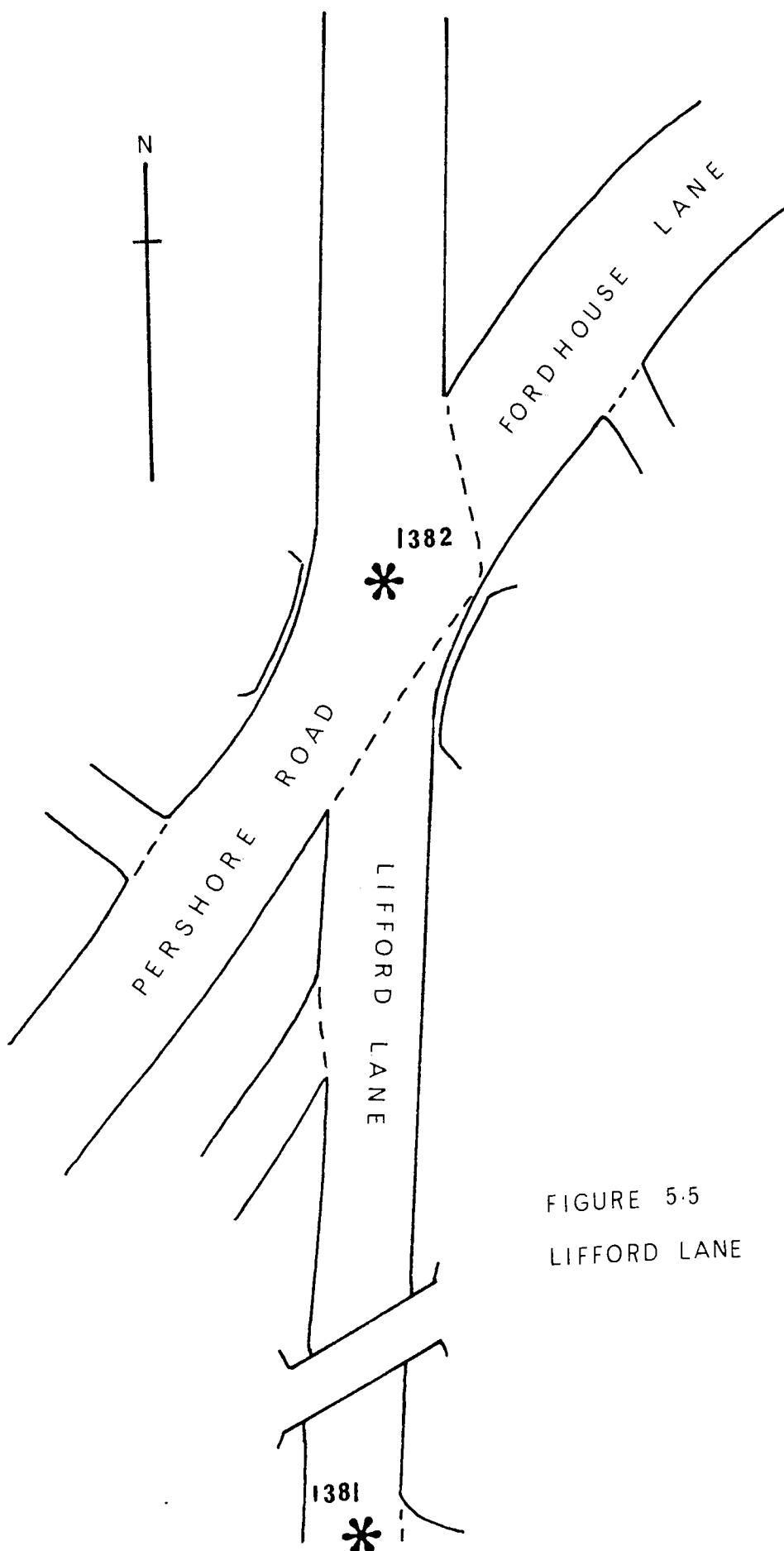1382

FORD HOUSE LANE

PERSHORE ROAD

LIFFORD LANE

FIGURE 5·5
LIFFORD LANE

1381

N

*1381

BROAD MEADOW LANE

*1500

MONYHULL HALL ROAD

1380

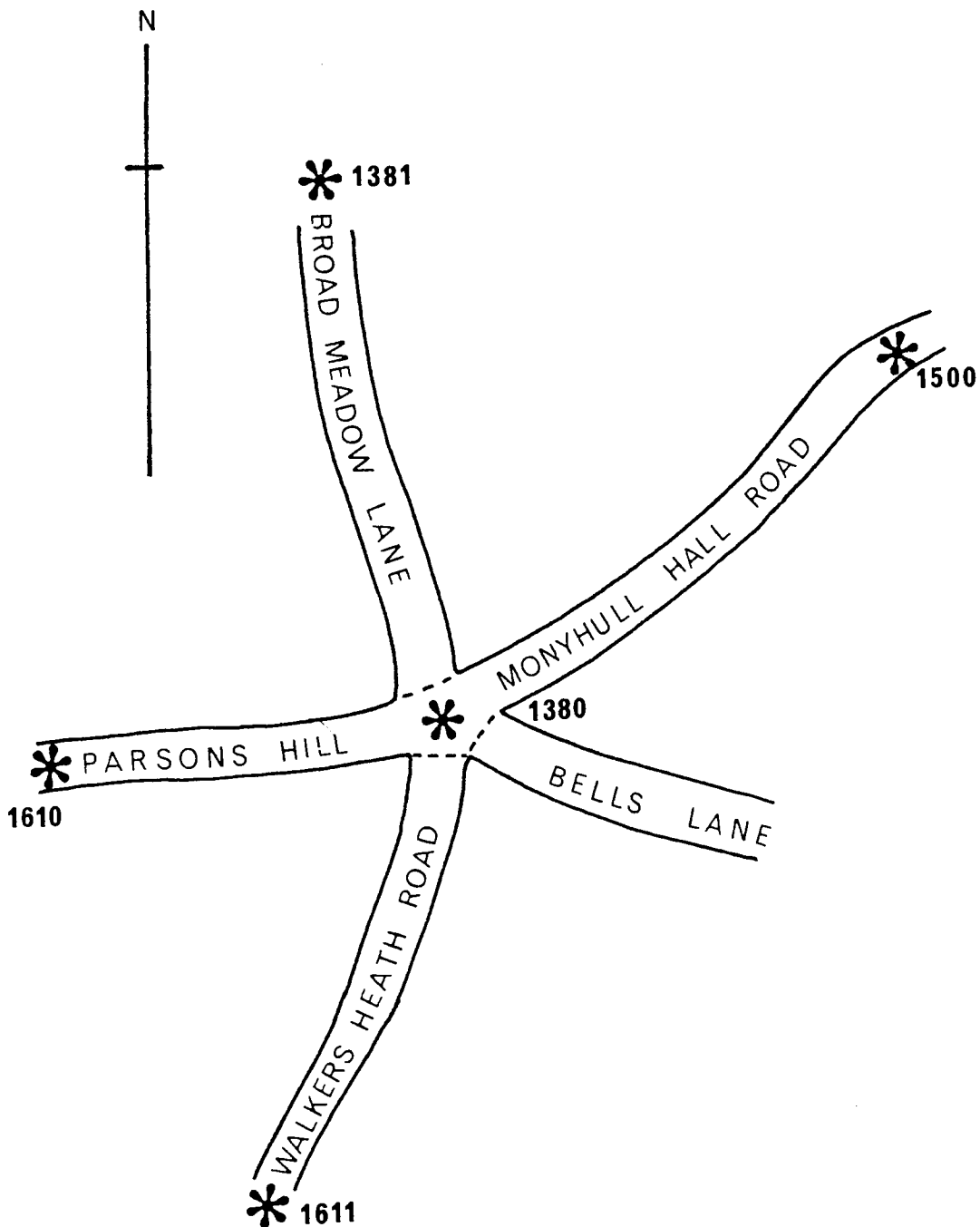*PARSONS HILL

BELLS LANE

1610

WALKERS HEATH ROAD

*1611

FIGURE 5.6

BELLS LANE, PARSONS

HILL SITE

All this suggests that this site would reach the Coarse Sieve only after detail of problem conditions had been studied.

Clapgate Lane (1245-1339) a so received priority from the existing approach. Problem identification produced a relatively high comprehensive problem score and individual scores for public transport, road safety and maintenance suggest that improvements should be in those areas. This suggests options for design purposes which point to highway reconstruction and re-alignment, a view confirmed by local knowledge. The priority given to this site by the Coarse Sieve is not wholly justified by the problem identification scores, but it clearly exhibits some need for investment.

The other sites which reached the Coarse Sieve exhibited a variety of problem scores and priorities suggested by them. Scores for all sites are given in Figure 5.3. Particularly notable are the comprehensive scores for the Middle Ring Road (River Rea) and Rednal Road. Using these socres, neither would proveed to the Coarse Sieve. Similarly good scores are also achieved by Highgate Road/Moseley Road but this hides very poor conditions for traffic flow balanced by good conditions for environment, public transport and road safety. Severe problems are exhibited by Northfield By-Pass, Hagley Road (Five Ways) and part of Selly Oak. They would clearly reach the Coarse Sieve. Each, however, contains a variety of reasonable scores for individual factors. Clearly, close attention needs to be paid to the detail of problem conditions.

In summary, there is some correspondence between sites which reached the Coarse Sieve for 1978 - 1980, and those indicated as problems by the factorial approach. However, this correspondence is far from absolute and undoubtedly there are some sites which reached the Coarse Sieve which problem identification would have rejected at a

173

much earlier stage - West Boulevard and Rednal Road are two examples. However, the majority of sites fall into the area between; exhibiting overall, relatively small problems but hidden within this are a series of more serious individual problem conditions which merit further attention. In some cases, these individual problems are the reason why a site reached the Coarse Sieve. However, other sites with few problems overall also have few serious individual problems, and it is unclear why they were treated with priority.

The effect of problem identification is clearly to alter a number of priorities for scheme design and particularly to illustrate detail of problem severity and condition, so that the choice of sites can be matched to highway resources and objective needs. This in turn would affect both the priorities allocated to sites and schemes designed for them.

(ii) Comparison of sites from problem identification with their priority allocated in the Coarse Sieve

Figure 5.7 shows site scores for the most severe deficiencies indicated through problem identification. Those that reached the Coarse Sieve in 1978 - 1980 are also noted. There is clearly a degree of overlap and existing site generation techniques correspond with some of the priorities emerging from problem identification. Given the existence of other factors (e.g. political, organisational, financial considerations) which intervene, the correspondence is good. However, a number of sites feature in only one pool and respective priorities are rarely the same. Thus, Bell Hill (1349-1350) features in both (in the Coarse Sieve as Northfield By-Pass), but is afforded only relatively low priority in the Coarse Sieve. It emerges as the most significant overall problem in the factoral method. Long Nuke Road and Lordswood Road do not enter the Coarse Sieve at all.

	FACTOR 1 (ENVIRONMENT)	FACTOR 2 (PUBLIC TRANSPORT)	FACTOR 3 (CONGESTION)	FACTOR 4 (ROAD SAFETY)	FACTOR 5 (MAINTENANCE)	FACTOR (COMPREHENSIVE)
1	Harborne Lane (1391-1405)	Bell Hill (1349-1350) (*)	Frankley Beeches Rd. (1351-1352) (*)	Frankley Beeches Rd. (1352-1605)	Frankley Beeches Rd. (1351-1352) (*)	Bell Hill (1349-1350) (*)
2	Harborne Lane (1397-1405)	West Heath Rd. (1371-1372)	Lifford Lane (1381-1382)	Belgrave Rd. (1544-1545)	High St., Harborne (1335-1400)	Longbridge Lane (1361-1362)
3	Bristol Rd. South (1360-1366)	Long Nuke Rd. (1341-1342)	West Heath Rd. (1371-1372)	Pershore Rd. South (1375-1376) (*)	Bristol Rd. South (1348-1350) (*)	West Heath Rd. (1371-1372)
4	Pershore Rd. (1386-1491)	Parsons Hill (1380-1610) (*)	Edward Rd. (1536-1537)	Frankley Beeches Rd. (1351-1352) (*)	Bristol Rd. South (1539-1541)	Pershore Rd. (1544-1618)
5	Bristol Rd. (1393-1394)	Alvechurch Rd. (1370-1371)	Edgbaston Rd. (1483-1484)	Rednal Rd. (1606-1607) (*)	Bristol Rd. (1389-1392) (*)	Hagley Rd. (1456-1619) (*)
6	Bristol Rd. South (1346-1347)	Pershore Rd. South (1375-1376) (*)	Alcester Rd. (1486-1616)	Shenley Fields Rd. (1344-1390)	Hagley Rd. West (1263-1326)	Parsons Hill (1380-1610) (*)
7	Pershore Rd. (1537-1618)	Lordswood Rd. (1334-1335)	Long Nuke Rd. (1341-1342)	Shenley Fields Rd. (1343-1344)	Hagley Rd. (1456-1619) (*)	Bristol Rd. South (1351-1353) (*)
8	Parsons Hill (1380-1610) (*)	Clapgate Lane (1245-1339) (*)	Nursery Rd. (1400-1401)	Tessall Lane (1356-1357)	Pershore Rd. South (1375-1376) (*)	Long Nuke Rd. (1341-1342)
9	Pershore Rd. (1490-1491)	Bristol Rd. South (1348-1350) (*)	Hagley Rd. West (1259-1264)	Queensbridge Rd. (1487-1488)	Hagley Rd. West (1263-1264)	Bristol Rd. (1389-1392) (*)
10	Bristol Rd. South (1353-1355)	War Lane (1335-1336)	Edgbaston Park Rd. (1394-1441)	Tessall Lane (1354-1356)	Bristol Rd. South (1360-1361)	Pershore Rd. (1537-1618)

Correspondence is better for some factors than for others. Factors 1 and 3 are especially poor, whilst factors 2 and 5 are very good. It is difficult to be definite about why this should be the case, although clearly both methods appear to have given similar priority to public transport and maintenance, and rather different priorities to congestion and the environment. Figure 5.8 shows the spatial distribution of problems by each method. Clear differences exist in the pattern of sites with those in the Coarse Sieve concentrated upon major roads and sites of pedestrian and vehicle conflict. Problem identification produces a more even distribution and would result in changes in the pool of sites and their detail. Sufficient correspondence exists to suggest that the problem identification methodology produces results that reflect real problems - one would not expect total discordance between the two methods, but sufficient differences also exist to result in a noticeable change in resource allocation. These changes are typified by an increase in the number of small sites appearing through problem identification - War Lane (1335-1336), Tessall Lane (1354-1386) and Long Nuke Road (1341-1342) - sites excluded from the Coarse Sieve altogether. Output from problem identification in the form shown in Figure 5.8 would draw attention to sites of this type and those exhibiting major (well-known) problems, and provide a basis for comparison and selection for further assessment.

Conclusions

This chapter has shown that the introduction of problem identification has ramifications both for the T.P.P. highway evaluation process and the results it produces. The effects upon the process take a number of forms. Firstly, in its implications for highway data through generating more consistent and reliable sources of
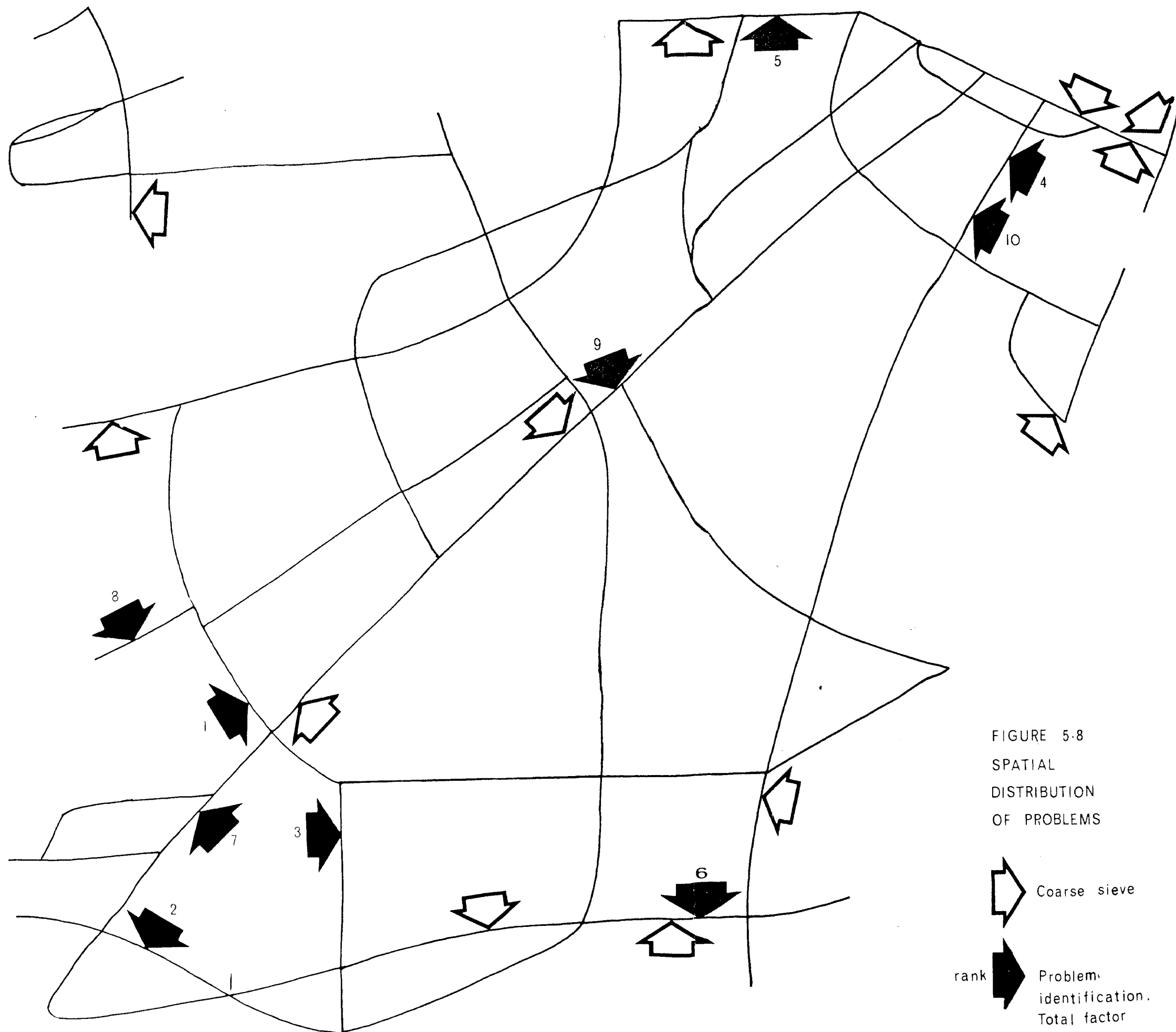
FIGURE 5·8
SPATIAL
DISTRIBUTION
OF PROBLEMS

Coarse sieve

rank   Problem·
identification.
Total factor

information indicating the value of each variable, describing highway conditions and the contribution made by each variable, and by suggesting the structure of problems and the opportunities for solution to those problems. Secondly, problem identification has significant implications for the Priority Ranking process. Clearly the two should work well together, and their interface is significant in that the former provides the information for the latter. Detail is provided of the priorities in local, objective terms for each problem site, and the original highway data is retained to act as a basis for scheme evaluation. The same set of information is used for both operations, and consistency throughout the process is aided by use of the same criteria and distributional weights. Although no formal link exists between the two processes, this allows flexibility inherent in the local government decision-making process to act satisfactorily within the consistent approach to highway evaluation.

Techniques used by problem identification may also have ramifications for Priority Ranking. Factor analysis has obvious attributes to deal with the problems of aggregation, valuation and measurement characteristic of scheme evaluation. It also provides evidence of the value of data sources used in Priority Ranking, and the process of problem identification acts as a filter for highway sites ensuring that only those exhibiting the most significant problems reach scheme evaluation.

Problem identification has two other implications for Priority Ranking. The first is in terms of site justification - selection of schemes based upon a defensible problem identification technique makes that selection more robust, whilst the development of detailed techniques capable of allocating priorities between sites exhibiting similar problem conditions forms the second.

Problem identification also has ramifications for the results of that process. Comparisons between sites generated using existing methods and those using the factoral technique revealed a distinct change in distribution of priorities and their characteristics.

Given that problem identification is known to be based upon local priority objectives and upon carefully and consistently selected data variables, the results it produces are likely to reflect real priorities in a more consistent way than existing methods, characterised by expertise, intuition and informed guesswork. Sufficient overlap between the results of the two methods suggests that these priorities are realistic.

Mention needs to be made of the significance of choice of both data variables and distributional weights. Their derivation and selection was described in Chapter 3. Data variables were chosen within constraints existing in the West Midlands and any results from problem identification must be seen in the light of this. Weights were derived in the same way as for Priority Ranking, ensuring consistent priorities within the evaluation process. The selection of each was important for the derivation of priorities. A series of sensitivity tests was carried out using different sets of weights and variables to distinguish their effects. The results are given in Appendix 11 and the effect is marked in both cases. Clearly, their choice needs to be made carefully and justified in terms of constraints, data availability and objectives. The results of the Case Study represent one selection which has been justified in those terms. Changes in policies, priorities and data availability and reliability will lead to changes in variable choice and weights. Their significance needs to be noted.

Given the effect of problem identification upon the process and

results of highway evaluation, is it a useful and valuable adjunct?
Even if no change in distribution and characteristics of problem sites
had occurred, it provides evidence of data validity and reliability
and problem structure and its basis in local objectives and priorities
helps to justify site selection whilst facilitating the allocation of
priorities between similar sites.   Consequently, even without any
tangible effect upon the choice of sites, it would be a valuable
addition to the evaluation process.   However, it has been shown that
it does affect the choice of sites, their priority and characteristics
and as such should be regarded as a desirable improvement.   Although
it is difficult to prove that site selection is more consistent and
flexible to change, at the same time it is known that problem identi-
fication is based upon county council policies, using the most
appropriate and best available data.   As such, it is a marked improve-
ment upon the process of site and scheme generation that existed
before.

CHAPTER 6 - KEY RESULTS AND FURTHER RESEARCH

A number of key results emerge from this research and the development of an improved methodology for highway evaluation. They can be summarised as follows:

(i)   Introduction of problem identification to form the basis of scheme generation has ensured that the evaluation process as a whole has been completed effectively so that the needs of the highway network are taken into consideration in the selection, design and assessment of schemes. This helps to ensure the efficient allocation of resources, the effective identification of priority problems, and the achievement of local objectives. By applying the principles of classical factor analysis to the needs of highway evaluation, it has proved possible to avoid violating the majority of contextual constraints which were identified. In particular, a methodology has been developed which not only scales and scores problem conditions, allowing comparisons between sites and problem types, but also has achieved this without recourse to methods of measurement, valuation and aggregation which are dubious in their assumptions and methodologically unsound. Despite only limited practical application to evaluation problems in the past, classical factor analysis (and multi-variate analysis in general) has a widespread history of use in the natural, physical and social sciences, and is a reliable and acceptable statistical technique which can act as a basis for achieving aggregation and scaling of multi-variate criteria.

(ii)   The results from the improved methodology illustrate the priorities that exist between sites and site conditions, facilitating the allocation of resources between them, even where the level of problems is similar and the need for investment marginal. Clearly, in a situation where severe problems (and the need for investment) is

179

openly apparent, the most difficult decisions will focus around the allocation of resources to marginal developments and a technique which can provide evidence of need in these circumstances will be valuable.

(iii) The calculation of inter-correlations between highway variables, forming as it does the basis of the methodology for problem identification, is invaluable in helping to reflect the structure of highway problems, and consequently the need for and characteristics of alternative suitable designs.   Information upon inter-correlations was previously unavailable and is produced at an early stage of the factoring process.   Its interpretation relies upon the experience of the user but as such also encoura es flexibility in scheme design and problem assessment.

In a similar fashion, the factoring process has been designed to produce an assessment of aggregate and disaggregate problem conditions. Aggregation is achieved in a reliable and consistent way without recourse to an intermediate common metric and the problems this creates. The detail of problem condition is retained in the disaggregate problem scores and rankings, helping the design process.   Meanwhile, the aggregate data facilitates comparisons between sites and the associated allocation of resources.

(iv) Information is also provided upon the value of each highway variable used in the identification of problems.   The importance attached to each factor can be assessed using information upon the variance explained by each and consequently the contribution made by each data variable towards factor description.   Clearly, those variables contributing little can be discarded with little loss of information - helping to rationalise and economise the monitoring process without the loss of valuable detail.

(v)   By providing detail of both aggregate and disaggregate problem

condition, problem identification provides information upon the link-

age between problem conditions and value for money solutions.   Poten-

tial solution designs are clearer, as s the degree of problem

severity, and by taking both elements of information and calculating

the likely cost of solutions to identified problems, the relationship

between them can be assessed.   Clearly, although this is far from

ideal as a means of linking problems and solutions, it makes some

progress towards ensuring that consideration is given to this impor-

tant relationship in the evaluation process.

(vi) In practical terms, the technique produces a different set of

priorities for highway sites compared with those derived using the

traditional proces es of scheme generation.   Clearly, since the

methodology of problem identification introduced here provides a more

reliable and justifiable process of aggregation and valuation, deriv-

ing priorities from local policies, it is reasonable to assume that

the assessment of highway conditions which emerges is a better

reflection of local needs leading to more responsive resource alloc-

ation.   Sufficient overlap exists between the results of both

existing and proposed methodologies to suggest that the new set of

priorities is realistic and acceptable.

(vii) Problem identification has been designed to work with Priority

Ranking and to ensure that the advantages of scheme appraisal are

preserved.   A consistent process, from the derivation of priority

problems to the allocation of resources to schemes, is ensured

through the use of consistent priority weights and the selection of

highway criteria derived from the same policies and objectives.

Priorities are thus seen to emerge directly from the identification

of policies and, as such, are flexible to changes in those policies

as administrations change.   As a consequence, it reflects up to date

priorities between needs and recognises the political nature of the

decision-making process.   The output from problem identification is

directly of use to Priority Ranking, indicating the pool of sites

from which schemes are needed, their characteristics and priorities.

Together, problem identification and Priority Ranking fulfill the model

of evaluation proposed by central government and as such will gain

widespread support in attracting financial assistance.

These results need to be viewed in the light of current (and

foreseeable) resource allocation procedures and the Rate Support and

Transport Supplementary Grant allocation systems that exist.   Two

basic requirements of a highway evaluation methodology emerge.

Firstly, a technique which describes problem condition and scheme

merits clearly, consistently and accurately, thus attracting financial

support, and secondly, a method that can allocate this support between

competing projects once it has been attracted.   The flexibility

inherent in the resource allocation procedures for local authorities

(whereby grant aid once attracted can be transferred both between

projects and between sectors), makes the need for a methodology that

can indicate priorities between inve tments that much greater.

Although the development of an evaluation technique which could indic-

ate absolute problem conditions would be widely welcomed, the very

nature of problems and the political decision-making process makes

this impossible.   Consequently, a relative problem identification and

evaluation process is needed which can indicate priorities between

investments without having to determine their absolute significance.

The methodology developed in this research achieves this.   It

describes problem condition in detail and in so doing facilitates the

assessment of highway needs.   At the same time, it does so in

relative terms - allowing problem ranking in terms of changing political priorities, and by so doing, enables allocation of resources between sites that are in competition.

A number of deficiencies in problem identification remain. In the main, they are practical deficiencies which, with time and resources, may be overcome. The most significant are the difficulties which may emerge in gaining acceptability for a relatively complex and sophisticated statistical approach to evaluation. Clearly, care will be needed in presenting its application both to officers and members. Closely allied to this are difficulties which may emerge because of its complexity since few users may fully understand its assumptions and implications. However, the same might be said of the inadequacies of cost-benefit and points-rating techniques which have current favour. Obvious drawbacks remain in its application to a limited highway network and the inadequacies in data that exist. Clearly, given time and effort, these inadequacies will be overcome and do not detract from the abilities of the methodology in general.

Further Research Issues

A number of important issues remain unresolved which do not detract from the methodology proposed in this research, but which present problems for future consideration in the light of current developments.

Neither problem identification nor Priority Ranking incorporate a satisfactory mechanism for risk and uncertainty - issues which bedevil evaluation and forecasting and which throughout highway appraisal need further attention. Looking back at Figure 1.16, the framework for a scheme selection methodology, issues of uncertainty played an important role, forming element I, currently not covered. The

significance of risk and uncertainty in any evaluative framework has been recognised for some time and Knight (1921) placed considerable emphasis upon imperfect knowledge in economic appraisal, an issue further taken up by a number of economists, including Haveman (1977), who stressed both micro and macro impacts, and Arrow and Lind (1970).

Stuart (1974) was one of the earlier writers to distinguish its importance in plan evaluation, suggesting:

> 'that sensitivity analysis is needed to
> explicitly acknowledge and deal with plan
> evaluation uncertainties.   These uncert-
> ainties will exist regardless of the evalu-
> ation framework chosen,'

although both Pouliquen (1970) and Reutlinger (1970) had described the impact of risk upon highway evaluation with examples from World Bank projects in Tanzania.   Other recent examples of attempts to incorporate risk and uncertainty into appraisal include Lin (1975) in network planning, and Shalal and Kahn (1982) using a 'decision-theoretic' framework.   The latter also indicated the areas of highway planning that were most susceptible to uncertainty and needed to incorporate some form of probabilistic planning technique.   They included:

- unexpected changes in traveller's choice of mode

- errors in the estimation of basic determinants of travel, such as future land use activities

- errors in data measurement

- errors in simulation and modelling

- technical developments: socio-economic, environmental and political changes

- lack of information

Despite considerable interest in risk analysis, typified by the work upon taxonometric evaluation by Gilbert and Jessop (1978), and the existence of a number of techniques for incorporating uncertainty

into appraisal, little beyond the use of a limited range of forecasts in traffic levels in COBA has been achieved. Priority Ranking and problem identification includes none, and single year estimates are used. Clearly, further practical application of risk/uncertainty methodologies is needed to demonstrate their validity, forming an early requirement of further research.

Problem identification and Priority Ranking have concentrated upon the appraisal of highway projects and little, if any, attention has been paid to public transport investment, either in terms of capital or revenue expenditure. With the increasing pressure upon financial support for public transport, the need to be able to assess and compare the value from alternative investments has increased. This need has been compounded by the clear imbalance in resources allocated to highways, a phenomenon attributed by Cheung (1977) to the absence of a formal and consistent public transport evaluation methodology.

Traditional approaches to public transport evaluation concentrate upon the financial and operating characteristics of proposals, typified by methodologies described by Ochojna (1979) for Greater Glasgow, Waters (1982) for rail investment in British Columbia, Hamilton (1982) for bus services in Durham, and more theoretical economic discussions from Starkie (1979) and Button (1980). An alternative approach based upon accessibility measures has come from Jensen (1976), but in general there have been few new developments. However, a number of authors have indicated that a series of standards or criteria are needed, broader than simply financial or operating considerations, including social and environmental effects - examples come from Sagner and Barringer (1978), Chan and Ellis (1978), Skinner (1980) and Gleason and Barnum (1982). Clearly, there is a need to extend public transport evaluation beyond the purely financial and operational level,

but as yet little has been achieved in practice.   Interesting develop-
ments which may improve appraisal include the use of multi-criteria
approaches, described by Massam (1978), Roy (1972) and Roy and
Huggonard (1982).   Clearly, the range of issues pertinent to the
evaluation of public transport expenditure requires a technique
capable of trading off a complex set of criteria.   Multivariate
analysis appears to offer considerable potential.

In a similar way, maintenance expenditure is becoming an
increasing burden upon planning authorities and evaluation of mainten-
ance conditions and needs is restricted to the financial and operational
criteria typical of MARCH and CHART.   The inter-relationships between
maintenance expenditure and other highway issues (e.g. accident rates,
environmental conditions, etc.) are largely ignored despite serious
ramifications for the estimation of value resulting from investment.
Clearly, a multivariate approach may provide benefits.

In more general terms, evaluation of transport investment and
comparisons between different sectors (highways, maintenance, public
transport, etc.) would be valuable and provide evidence of the optimal
distribution of resources.   Currently, expenditure is distributed
haphazardly, and largely dominated by projects that are committed
and the use of a variety of evaluation methods which concentrate upon
financial and operational characteristics alone.   Again, multi-
variate analysis might have much to offer in comparing the merits of
differing transport sectors and their respective needs.

Current practice in highway evaluation is to assess both problem
and solution upon an individual site basis and to examine only the
network consequences of implementing that one scheme.   A problem
that exists is one of achieving the maximum net benefits over the

whole road network by selecting the optimal combination of schemes from all that exist.   This in turn means that problems need to be identified upon more than an individual basis so that inter-related problem issues can be assessed.

Interest in network evaluation has existed for some time. Farbey and Murchland (1966) described the derivation of a network of highways for new towns which optimised a number of requirements, whilst traditional geographical research has focussed upon the structure and optimisation of networks (both highways and others) typified by the work of Haggett and Chorley (1969).   Mackinnon and Hodgson (1970) provide one of very few references to network evaluation in transport planning, with examples of various techniques to achieve optimisation.   More recently, developments in West Sussex (1981) have attempted to include network ramifications in the evaluation of highway proposals, whilst Jansen and Bovy (1982) have discussed the relationship between the level of detail and its effect upon network planning and traffic flows.

Clearly, opportunities exist to extend highway evaluation beyond its current limitations to encompass full scale network effects.   The techniques proposed by Gilbert and Jessop (1978) is one approach based upon statistical inference and probability theory which offers considerable potential.   Other techniques centre around programming methods which have been rarely tested in a transport context.   Examples include Dorfman et al (1958), Eilon (1969), Laidlaw (1972) and Zeleny (1974).   The issue of network evaluation is further discussed in Appendix 12.

Frequent reference in discussion of highway appraisal has been made to benefits over and above those incorporated in any formal analysis - including the effect of highway investment upon economic

187

development and employment. Clearly, in the current economic situation these effects, if they do exist, take on even more significance. The implication is that where such development effects exist, a road project would merit higher ranking than that given to it under present appraisal schemes.

The importance of such effects in highway evaluation was little discussed prior to 1970 and the emergence of a paper by Gwilliam (1970) who suggested that highways might have significant secondary effects. His views were reiterated by Dodgson (1973), who provided an economist's view of these effects. However, in recent years, the ability of highway investment to redistribute or create employment and economic development has been realised and incorporated into a number of studies, the best example coming from Merseyside, described by Lees (1978), Arnott (1979) and Skewis (1979), each of whom stressed that although development effects existed, they were not over-riding and could not be construed as a factor meriting further highway development by themselves. However, as Botham (1979) stressed, quoting Gwilliam and Mackie (1975):

> 'At the present time, little hard evidence exists of the majority of such effects, nor is a method of analysis for measuring them readily available, so that their inclusion within the evaluation process has been left mainly to political intuition.'

Other recent work by Patterson and May (1981), the Greater London Council (1977) and Parkinson (1981), the latter discussing potential that exists for adapting COBA to accommodate the effects of developments resulting from highway investment, has reflected more than just a passing interest. In the West Midlands, policies exist to promote economic and employment regeneration but neither are included directly within the problem identification or Priority Ranking framework. Given their relevance at this time, these issues require

further research and assessment.

A practical difficulty encountered in the research surrounded the definition of highway sites to which conditions could be attached. Criteria such as air pollution, congestion and the like are inadequately defined by firstly designating a series of links and then allocating average values within these links to each of them. The length of link, and its precise boundaries, affects the definition of problems, average values conceal district variations in intensity within a link and clearly, differently defined sites will produce different problem ranks and scores.

This problem is one that effects a number of transport planning issues, including that of traffic modelling which currently relies heavily upon predetermined highway links and nodes to allocate traffic data. Our earlier discussion focussed upon the ideal of continuous site definition with no nodes, which would allow appraisal of problems without pre-set site boundaries - but currently this has not been achieved. Further research is needed to develop methods of data allocation which avoid the arbitrary definition of sites, which detract from the advantages achieved through multivariate analysis. Techniques such as structural mapping and alternative network description methodologies (typified by the work of Haggett and Chorley, 1969) may provide alternative solutions to the drawbacks of traditional arrangements.

The research described in this thesis has concentrated upon the development of a problem identification process as part of highway evaluation, taking as a starting point the existing West Midlands Priority Ranking methodology. This methodology represented a significant improvement upon traditional evaluation techniques, combining the best of cost-benefit and points rating approaches. It is

intended that identified problems will form direct input to Priority

Ranking, but this fails to take account of how the problems can be

translated into scheme solutions in a servicable and practical way.

Essentially, the two processes work separately and yet need to be co-

ordinated so that scheme solutions are designed to meet problems in

the way that maximises efficiency and meets local objectives.   This

issue of problem-solution linkage remains largely unresolved.

Solutions to sizeable problems do not necessarily generate

sizeable benefits and are not necessarily the most efficient way of

using resources.   Common practice is to tackle largest problems

first and progress made down the ranked list until available finance

is exhausted.   However, this leads to the smaller problems being

ignored which, although clearly less important, may still generate

solutions which are highly efficient in their use of resources.   Large

problems are often costly to solve and it remains the cost/benefit

ratio which is of interest in scheme selection, not problem size.

This leap from problems to solutions is one that has received

little attention.   Central government has given little advice except

to exhort that the leap be made, whilst research has concentrated upon

scheme evaluation at the expense of project specification.   The need

to address this issue is important, since it is only of limited use

to identify problems rigorously and consistently, if this does not

ensure cost efficiency.

This difficulty is one with ramifications for both problem

identification and Priority Ranking and only by designing the former

to accommodate the needs of the latter can it be overcome.   The

essential problem is one of achieving project specification using

identified problems as indicators of need, without having to make

recourse to designing solutions for all potential problems prior to

evaluating each.

A number of studies have shown that highway problems fall into a limited number of categories with close relationships existing between road characteristics, land use and transport problems (Thomson, 1967; Wardrop, 1968; O'Flaherty, 1974). One approach to the issue of problem-solution linkage might begin by assembling indicators of highway problem condition along with other data upon land-use, road type and traffic characteristics to establish whether categorisation could be achieved. Following categorisation, examination of characteristic solution types might facilitate derivation of relationships between problem and solution type, a practice currently informally already undertaken by local authorities in predicting future financial demands. These 'bandings' of traffic problem, solution and costs would permit estimates to be made of solution efficiency which could then be used to allocate priorities between problem sites and schemes. Statistical techniques of factor and cluster analysis are two approaches to categorisation which offer many advantages and have been extensively applied in the current research. A wide range of other aggregation methods also exist and would need to be assessed. Clearly the need to continue research into problem-solution linkages exists, and the use of multivariate analysis appears to offer a profitable approach.

A common thread brings together each of these research issues. Multi-variate analysis provides opportunities to work towards their effective solution, opportunities which are all the more pertinent in the light of the methodological developments in problem identification which have been achieved. The potential exists to derive an integrated evaluative framework based upon a multi-variate approach which recognises the disparate nature of highway (and other sectoral) appraisal and the need to avoid recourse to traditional but largely

191

unsubstantiated techniques.   The diverse characteristics and impacts

of development and employment effects, the difficulties inherent in

problem-solution linkage, the issue of site definition and the

characteristics of public transport, maintenance and other evaluation

procedures, are all problems to which multi-variate methods might

provide at least a partial solution.   Multi-dimensional analysis, in

particular, typified by the work of Clarke and Rivett (1978), Rivett

(1977, 1978, 1980) and Preston (1982) in structural mapping, provides

further opportunities for evaluation research which remain unrealised.

The potential that exists is substantial and with the continuing con-

straints upon resources, one that is unlikely to diminish.

Clearly, considerable effort and research is needed to continue

improving upon the existing highway evaluation process and the

methodologies available for the measurement, valuation and aggregation

of indicators of problem condition and scheme merit.   However, it is

hoped that the work described in this thesis makes some contribution

towards improving the methods of highway evaluation within the exist-

ing and foreseeable transport grant allocation process and has

indicated the potential of currently available techniques appropriate

to the problems of highway evaluation which remain to be further

applied and tested in a practical context.

THE TRANSPORT SUPPLEMENTARY GRANT AND T.P.P. SYSTEM

The administration of expenditure on transport is divided between central and local government.   Central government is responsible for motorways and trunk roads and for expenditure by nationalised industries (e.g. National Bus Company, British Rail, etc.).   Local government is responsible for expenditure on local transport, including capital infrastructure, parking, traffic management, public transport, maintenance of highways and concessionary fares.

Finance for local transport comes from three sources - income from charges (e.g. parking, bus fares);   local rates;   and central government grants and loans.   Rate Support Grant (R.S.G.) is the main source of grant, whilst Transport Supplementary Grant (T.S.G.) is intended to supplement R.S.G.   especially for authorities with high transport budgets relative to their population.

Total grant aid to local authorities is calculated as a proportion of 'relevant' expenditure - the latter including all expenditure charged against the rate levy.   This proportion, and the form of grant it takes, is the subject of a series of negotiations, each year, between local and central government.   A series of forecasts of expenditure over the coming five years are prepared, and compared with the level of expenditure set out in the last White Paper on Public Expenditure.   More detailed consideration is given to the first year of the plan period, giving an agreed total of relevant expenditure which should coincide with the White Paper.   The next stage is to agree the percentage contribution to relevant expenditure by grants.   The amount attributable to specific grants is then deducted from the total grant and the remainder distributed through R.S.G.,   In principle, R.S.G. is a block grant, and local authorities have discretion over its disposal.   In

practice, there is pressure to conform to a national pattern from central government. T.S.G. is specifically earmarked for local transport, and is available only for certain projects.

This new system of local transport grants (including T.S.G.) was introduced from 1st April, 1975, and the objectives are set out in Departmental circular 104/73 (1973). The new system was designed to:-

(a) promote the development and execution of comprehensive transport plans by the new county councils and the G.L.C.;

(b) eliminate bias towards capital or current expenditure or towards particular forms of expenditure;

(c) distribute central government grant in a way that reflects as far as possible the needs of individual areas;

(d) reduce the degree of detailed supervision by central government over individual schemes.

To meet these objectives, it was proposed to:-

(a) replace as many of the existing specific grants as possible by a new unified system covering current and capital expenditure, roads and public transport;

(b) absorb part of the money distributed in the form of specific grants into the needs element of the rate support grant;

(c) distribute the remainder as a transport supplementary grant for the year to each county council and the G.L.C., whose estimated programme of expenditure as accepted by the Minister for Transport exceeded a prescribed threshold. The intention was to set the threshold sufficiently low in

the early years to allow most countries to qualify for

T.S.G. and to fix the rate of grant close to the average

of the specific grants to be replaced (about 70-75%).

Over time, however, the grant rate would be reduced, the

threshold level raised and the resources released

absorbed into the needs element of R.S.G.;

(d) Fix a block loan sanction on the basis of accepted

expenditure.

T.S.G. is available only for certain items of expenditure. This
includes:-

- public transport (except new buses, concessionary fares and
  specific categories - e.g. school buses)

- highways (except minor estate roads, toll bridges and
  tunnels)

- traffic regulation

- parking provision

- road safety

- freight handling facilities

T.S.G. is not available for airports, harbours or canals.

A key characteristic of T.S.G. is that it is paid for future,
planned expenditure. Decisions on the allocation of T.S.G. and loan
sanction are made annually in the context of the R.S.G. negotiations and
have regard both to the national resource constraints and to the progress
a county council is making towards formulating and implementing suitable
comprehensive policies to meet the transport needs of its area. Each
county council and the G.L.C. submits to the Department of Transport an
annual document containing a statement of its transport policies and a
costed programme giving effect to them - a Transport Policies and

Programme (T.P.P.).   Each contains:-

(a) detailed estimates of expenditure for the following
     financial year;

(b) a 5 year expenditure programme which is rolled forward
     annually, the first year of which provides the basis
     for grant and loan sanction calculations;

(c) a provisional statement of transport objectives and
     strategy for 10-15 years;

(d) a statement of past expenditure and physical progress,
     and the extent to which the programme is meeting the
     objectives and policies underlying it.

The T.P.P. thus contains a costed programme of expenditures for the
forthcoming financial year - the 'bid'.   These bids are based upon
guidelines from central government who issue upper and lower limits -
although in recent years this advice has been noticeably curtailed.
However, local authorities have been made aware of the overall level of
resources likely to be available.

The main role for central government is to consider each of these
competing bids and to determine how they should be resolved and
resources allocated.   The basic approach can be summarised as

TSG to County X = (Total Accepted Expenditure County X

                 - Threshold County X)   * Rate of Grant

The Department of Transport defines values of the total accepted
level of expenditure, the threshold and the rate of grant, such that, in
total, the amount of T.S.G. awarded corresponds with what is available.
Any or all of these variables could be adjusted to meet resource con-
straints.   In practice, it is usually the level of expenditure that is

varied.

The level of accepted expenditure is the amount of expenditure from each county which central government decides to accept for grant purposes. If the Department decides not to accept sufficient expenditure to enable a county to undertake the whole of its proposed programme, the county can decide to supplement the expenditures from other sources (e.g. the rates), or to reduce the scale of its programme. The former option is now less likely following recent legislation. This is outlined later.

The threshold is the level of expenditure above which it becomes eligible for T.S.G.. The threshold level has been set at such a level that most counties qualify for T.S.G. - this ensures that each counties' transport programmes are scrutinised.

Except for the first year, the threshold has been defined as a sum per head of population - in 1978/9, for example, it was £9.992. An alternative 'safeguard' threshold also exists. The purpose of this is to ensure that counties with large amounts of previously committed expenditure receive grant on the whole of that expenditure. Categories of expenditure included in this arrangement are highways and public transport capital schemes over £½ m., and the contractual obligations of Metropolitan Counties to grant aid loss-making rail services. Since 1978/9, it has also covered shire counties support on rural bus services. Counties receive grant on the difference between total accepted expenditure and whichever threshold is lowest. The way in which government determines the combination of accepted expenditure, threshold and grant rate will have a marked effect upon the distribution of grant between counties.

The preparation and submission of the T.P.P. and consequential allocation of T.S.G. constitutes a rolling programme of work, involving

continuous interaction between central and local government and between

groups within the latter.   A typical sequence of events is outlined

below:-

Year 0 (December)	Allocation of T.S.G. for the coming financial year (1).
Year 1 (Jan - March)	Preparation of programme for coming year in light of grant award. Integration with overall county budget.
Year 1 (February)	Publication of government White Paper on Public Expenditure containing projected allocation of resources to roads and transport for the following financial year (2).
Year 1 (March)	Receipt of transport expenditure guidelines (if any) from Department of Transport Regional Controller's Office.
Year 1 (April - June)	Preparation of T.P.P.. Consultations with District Councils, operators, etc. Progress through committees to council. Decisions on priorities.
Year 1 (July)	Submission of finalised T.P.P. to D.T.P.. Discussions with Regional Controller.
Year 1 (Autumn)	Reconciliation of competing claims by D.T.P..
Year 1 (December)	Decision from Regional Controller's Office announcing allocation of T.S.G. to individual counties for Year 2.

Consequently, although the T.P.P. contains a 5 year programme, the

main focus of the system as a whole is upon the year ahead. One facet of the arrangements is that counties do not know until December the resources they will have for transport in the next April.

Recently, some changes have been made to this procedure. Under the 1980 Local Government Planning and Land Act (Sections 51 and 53), amounts previously paid in the form of supplementary grants (e.g. T.S.G.) specified in the Local Government Act 1974 (Section 56, paras. 1 - 8), could now be dealt with as part of the main block grant of the new system of rate support grants. Power was taken to withhold T.S.G. (if required), which otherwise would have been payable. The new R.S.G. mentioned above consists of a 'block' and 'domestic rate relief' grant. In practice, there has been no change, and the system of T.S.G. remains, but the opportunity now exists to eliminate it at a stroke.

Another consequence of this act was the abolition of the division of schemes between the 'Key' and 'Locally Determined' sectors which previously existed. Large highway schemes used to be allocated to the former and smaller schemes to the latter. Each local authority would receive specific grant to cover a part of each approved Key Sector scheme, and a single grant to cover Locally Determined Schemes, which were grouped together with other small-scale planning, housing, etc., schemes. Since 1980, grant is awarded to each local authority, based upon their T.P.P. submission in the form of Proscribed Capital Expenditure. This is awarded for all accepted highway schemes, regardless of size, and it is up to the local authority to distribute it accordingly to whatever projects they wish. Money awarded to the transport sector can be spent on any transport project, or even transferred to education, planning, etc. However, the D.T.P. is unlikely to view favourably in future years any authority that openly spends grant on schemes not approved by central government and which are

clearly aimed to abuse the flexibility inherent in this grants system.

Under the Local Government Finance Act, 1982 (Sections 1 - 7), the 1980 act mentioned above was amended to give the Secretary of State specific power to adjust entitlements to block grants in order to encourage reductions in local government expenditure. Previous 'over-spenders' now could be formally penalised by reducing grant on the basis of the failure in previous years to keep to central government guide-lines.

The whole system of grants is in a state of flux, and it is likely that wholesale changes will take place in the foreseeable future, generally giving central government even more control over local trans-port expenditure (amongst other types).

C.O.B.A.

Prior to 1972, the Department of Transport's standard method of highway investment appraisal for inter-urban schemes was to calculate an 'estimated' first year rate of return (E.R.R.). This involved calculating manually the expected benefits in the year following opening of the completed scheme and dividing this figure by the capital cost of the scheme. The result would be expressed as a percentage. If this E.R.R. was greater than the existing commercial return prevailing at the time (e.g. the bank lending rate), then the proposal was worthwhile.

This method only took into account estimated benefits in the first year. In practice, benefits continue to accrue over a much longer period than this and also increase as traffic flows continue to increase. Clearly, it is important to take account of these future benefits, and C.O.B.A. was introduced and designed to achieve that by applying a standard evaluation period of 30 years. It is currently used to evaluate all highway schemes costing £1 m. or more.

Any major highway investment implies a stream of costs followed by a stream of benefits. In C.O.B.A., benefits are expressed in terms of savings in:-

    (a)   travel time costs;

    (b)   vehicle operating costs;

    (c)   accident costs;

    (d)   maintenance costs,

which result when the scheme is completed. Because costs are spread over the construction period (which may be a number of years) and benefits accrue over a 30 year period, it is obviously not very meaningful

simply to add up costs and benefits, compare the two and regard the
result as a measure of scheme worth. It is necessary first to reduce
these two streams to single present value equivalents before the
economic return of a scheme can be assessed. To achieve this, dis-
counting is used, and C.O.B.A. currently uses a 7% discount rate.
Therefore, the present value of benefits (N.P.B.) is the discounted sum
of annual differences in user costs on the highway network under con-
sideration with an without the scheme over a 30 year period discounted
to a base year (currently 1976), i.e.

$$N.P.B. = \frac{B1}{(1 + 0.07)} + \frac{B2}{(1 + 0.07)^2} + \frac{B3}{(1 + 0.07)^3} \dots \frac{B30}{(1 + 0.07)^{30}}$$

where B1, B2, etc., are the benefits in each year. Similarly, the
present value of costs (P.V.C.) is given by

$$P.V.C. = \frac{C1}{(1 + 0.07)} + \frac{C2}{(1 + 0.07)^2} + \frac{C3}{(1 + 0.07)^3} \dots \frac{Cn}{(1 + 0.07)^n}$$

where C1, C2, etc., are construction costs in each year. A scheme is
considered to be acceptable if the present value of benefits is equal or
greater than the present value of costs,

i.e. $NPB \geqslant PVC$

For the purposes of comparison between schemes, the N.P.V. of the
scheme is quoted as a ratio to the present value of costs,

i.e. NPV/C

The Computer Program

C.O.B.A. is a computer program designed to assist decision-makers
responsible for the investment of public funds in the provision of
inter-urban highway schemes, by assessing the comparative economic merits

of alternative proposals for investment.   C.O.B.A. concentrates upon
those effects of road investment which are most susceptible to monetary
evaluation.   Other aspects are either ignored or relegated to a
general and rather subjective framework as recommended by S.A.C.T.R.A.
(1979).   We return to the role of the framework in a later section.
The attached flow diagrams show the main relationships and process in
C.O.B.A.

C.O.B.A. is based upon the concept of the fixed trip matrix.
This assumes that for any given time of day, the same number of trips
will be made between each O and D pair before and after scheme com-
pletion.   This implies no trip generation, re-distribution, change in
modal split or time of trip making.   For the fixed trip matrix to be
maintained, flows on entry and exit links of the highway network
appropriate for each scheme should not change as a result of the scheme
completion.

The advantage of adopting the fixed trip matrix is that in order
to calculate the benefits of a road scheme, it is possible to sum the
time, vehicle operating, accident and maintenance costs on the original
'do-minimum' and the proposed 'do-something' network.   Since it is
assumed that people make the same number of trips between the same
origins and destinations by the same modes and at the same times of day,
the reduction in the summed costs of carrying out the same activities
is the benefit of the road scheme.

In order for the program to operate, certain basic data is
required to be input by the user.   The first stage is to code the high-
way network under consideration.   For links (highways between junctions),
the length, width, hilliness, bendiness, traffic flow and composition,
together with accident rates, is required.   For junctions (nodes), the
type and layout of the junction is required, together with proportions

FIGURE A1

COBA EVALUATION SYSTEM

```
┌─────────────────────────┐ ┌─────────────────────────┐
│          USER           │ │          USER           │
│          COST           │ │          COST           │
│           ON            │ │           ON            │
│    EXISTING NETWORK     │ │    IMPROVED NETWORK     │
│    DISCOUNTED OVER      │ │    DISCOUNTED OVER      │
│        30 YEARS         │ │        30 YEARS         │
│                         │ │                         │
│           A_1           │ │           A_2           │
└─────────────────────────┘ └─────────────────────────┘
```

A_1

A_2

```
┌─────────────────────┐      ┌──────────────────────────┐
│   CONSTRUCTION      │      │      USER BENEFITS       │
│       COST          │      │   = REDUCTION IN USER    │
│        OF           │      │       COST FROM          │
│                     │      │      IMPROVEMENT         │
│   IMPROVEMENT       │      │        SCHEME            │
│                     │      │                          │
│        C            │      │   ⟨B⟩ = A_1 - A_2        │
└─────────────────────┘      └──────────────────────────┘
```

$$\leqslant B = A_1 - A_2$$

```
┌───────────────────────┐
│      CRITERION        │
│        FOR            │
│   PROJECT APPRAISAL   │
│                       │
│   (≤ B) - C    NPV    │
│   ─────────  = ───    │
│       C         C     │
└───────────────────────┘
```

$$\frac{(\leqslant B) - C}{C} = \frac{NPV}{C}$$
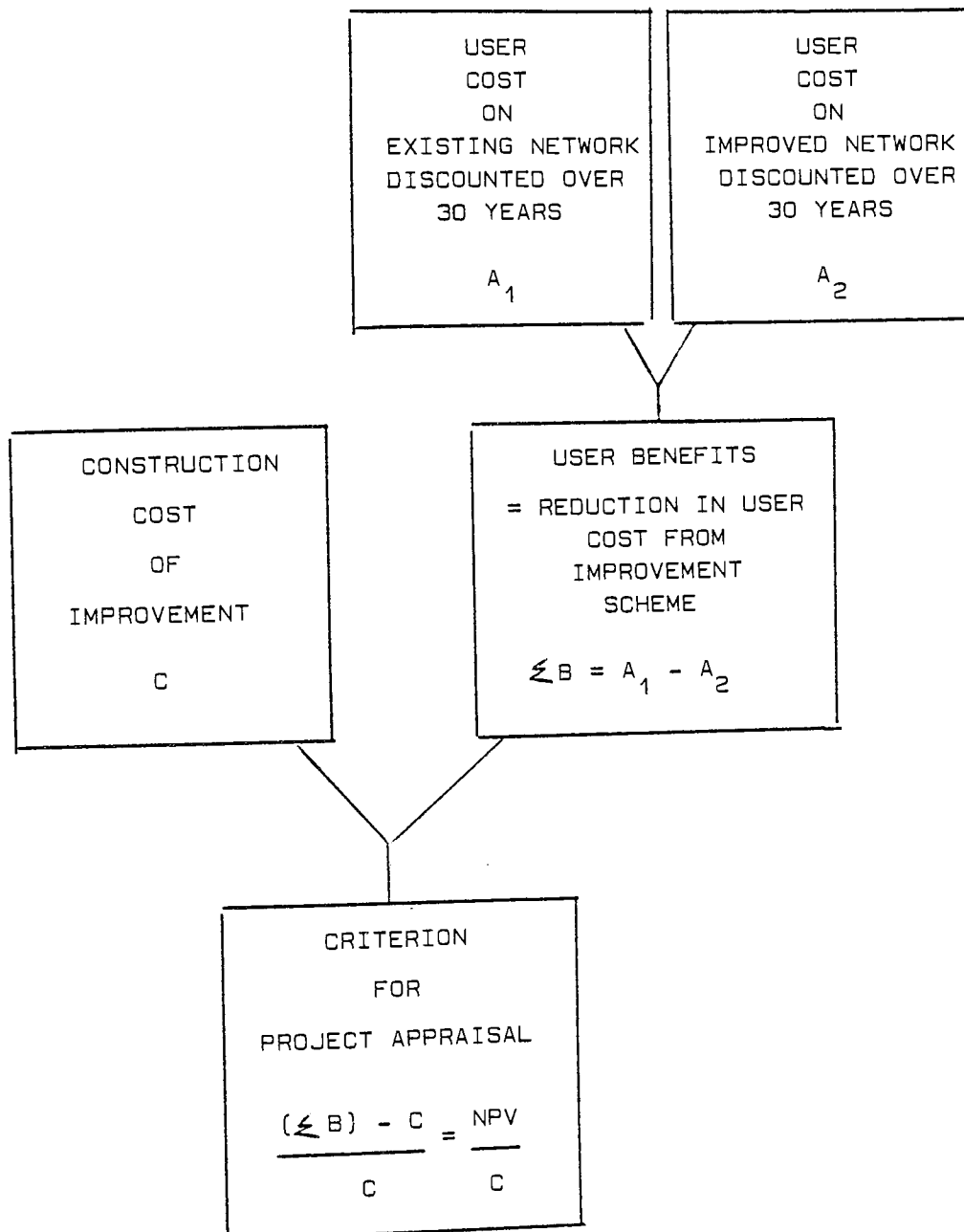
FIGURE A.2 - COST CALCULATION ON A ROAD NETWORK IN COBA

16 hour flow
on each link

↓

total yearly flow
on each link

↓

Flow increasing
yearly by a   ←——   yearly flow by
growth factor   class of vehicle
for each vehicle   on each link
class

↓

four flow groups
and four vehicle
classes on each
link

↓

average hourly
flow for each flow
group for each
scheme year and
vehicle class

ACCIDENTS   JUNCTIONS   LINKS

↓   ↓   ↓

number of   average delay   average speed
accidents   at each junction   of vehicles in
for each link   for each flow   each flow group
in each   group in each   and scheme year
scheme year   scheme year   for each link

↓   ↓

accident costs   time spent on
for each link   each link for
for each scheme   each class of
year   vehicle for each
                                                    scheme year

↓

Total accident
costs for each   Total link
of 30 scheme   Total junction   transit costs
years   delay costs for   for each of 30
                         each of 30   years
                         scheme years

↓

Total discounted
network costs
over 30 years

of turning traffic. Geometric delay and maximum delay assumptions are also input.

Once basic data is input, the program will operate automatically applying assumed changes in traffic growth and economic parameters to each of the 30 years, producing user costs for both 'do-nothing' and 'do-something' situations. The difference between these two values is then discounted to the present value year, where all discounted values are summed and compared with present value year construction costs (including land acquisition) to produce an NPV/C ratio. Each option is evaluated separately.

Recent Developments

C.O.B.A. has been continually revised since its introduction in 1972, although the basic approach to economic appraisal remains the same. The latest revisions were incorporated in 1981. Economic changes included revised traffic growth estimates, values of time and predictions of G.D.P.. Traffic engineering changes included alterations to speed/flow relationships for motorways and single carriageway roads, changes in average speeds by vehicle type, roundabout capacity calculations, geometric delays at junctions, queueing delays, and a number of revisions of maintenance costs and accident costs.

The Framework

The Advisory Committee on Trunk Road Appraisal (A.C.T.R.A.) reported in 1977 that although the methods used by the Department of Transport for highway appraisal were basically sound, there was a need to ensure that assessment was not dominated by factors which were susceptible to valuation in monetary terms. A revision of approaches to the evaluation of non-monetary factors, in particular, was needed. The method chosen should satisfy six criteria:-

(i)   it should be generally comprehensible to the public

        and command their respect;

(ii)   the public should be able to identify how different

        groups of individuals would be affected by the scheme;

(iii)   it should be comprehensive in terms of the different

        kinds of effects of the road scheme;

(iv)   it should allow effective control of decentralised

        minor decisions;

(v)   it should not be expensive to use;

(vi)   it should balance costs and benefits (however described)

        in a rational manner.

The Committee decided that a framework approach should be adopted

which would incorporate all aspects of a proposal - the economic and

financial results from C.O.B.A., the environmental and social implications,

and the administrative, land use, conservation and development effects.

Where possible, the effects would be quantified and valued in monetary

terms.   Where not, appropriate comments would suffice.   The results of

use of the framework would be available at the public consultation stage,

and public inquiry stages, along with a summary of main effects.   It

would be accompanied by a summary of additional views not included in

the framework.   An example of part of a typical framework showing the

summary of main effects of a proposal is given overleaf.   This type of

framework, helping to show all consequences of highway development and

make them more readily comparable, is now standard practice.

FIGURE A.3 - AN EXAMPLE OF A COBA FRAMEWORK.

	Effect		Modified Blue Route
Group 1 : Travellers			
All vehicle travellers	Time savings	£m (PVB)	6.62
	Savings in vehicle operating cots	£m (PVB)	-0.21
	Accident Savings	£m (PVB)	0.19
Group 2 : Occupiers			
Residential	Number of properties demolished		13
	Number of properties subject to noise increase of:		
	(a) more than 5dB(A)L$_{10}$		74
	(b) more than 15 dB(A)L$_{10}$		0
	Number of properties subject to noise decrease of:		
	(a) more than 5dB(A)L$_{10}$		404
	(b) more than 15 dB(A)L$_{10}$		0
	Number of properties within 300 m of centre line subject to visual obstruction		26
Commercial	Number of office buildings experiencing 5dB(A) decrease in noise		6
	Effect on trade in Warren Street shops		Reduced
Hospital	Noise		3dB(A)L$_{10}$ increase
School	Change in noise level in 1 class room, assembly hall and playground		5dB(A)L$_{10}$ Reduction
Farming	Number of farms affected		12
	Land take (hectares) -		
	Grade II		6.8
	Grade III		25.0
Golf Course	Land take (hectares)		0
Methodist Chapel	Land take (hectares)		0.6

APPENDIX 3

FACTORIAL ANALYSIS

This appendix aims to do no more than outline the basic principles of factorial analysis relevant to this research. Readers interested in rather more detailed discussions are referred to Rummel (1970), Fruchter (1954) and Harman (1960).

Factorial analysis is a group of techniques which forms one part of a larger variety of methods known as multivariate analysis. In general terms it is a means by which the regularity and order within phenomena can be discerned, described and manipulated. It relies upon the (reasonable) assumption that as phenomena occur in space and time, they are patterned. As these co-occurring phenomena are frequently independent of each other, there exist a number of distinct patterns. Factor analysis takes any number of measurements and observations of these phenomena and resolves them into distinct patterns of occurrence. By so doing, it makes explicit and more precise the linkages between observations that exist, but may be difficult to discern otherwise.

More specifically, given an array of correlation coefficients for a set of variables, factorial analysis enables the user to see whether some underlying pattern of relationships exists and its strength, such that the data may be re-arranged or reduced to a smaller set of factors or components that can be viewed as 'source variables' accounting for the observed inter-relationships in the data. Thus, it aims to reveal underlying inter-relationships within a data set, not readily identifiable from the raw information. Clearly, this makes it most appropriate where some form of inter-related structure is expected within the data.

Factorial analysis is not a single approach and it subsumes a large number of techniques, each with common characteristics but varying in application according to data type and the objectives of the analysis.

Uses

Possible uses to which the capabilities of factorial analysis might be adapted are many and varied. Nevertheless, the most common applications may be classified into one of the following categories:-

(a) exploratory uses - the exploration and detection of patterning of variables with a view to the discovery of new concepts and a possible reduction in data;

(b) confirmatory uses - the testing of hypotheses about the structuring of variables in terms of the expected number of significant factors and their relative strengths;

(c) uses as a measuring device - the construction of new indices and scaling mechanisms based upon the derivation of factors and the strengths of relationship of variables to them.
An evaluation device.

Clearly, in the context of the current research, it is this last category that is most pertinent. However, the advantages of the other categories will also be realised in the process of using factorial analysis for evaluation purposes.

The Factor Model

Two basic steps characterise the factorial approach.

(a) Preparation of the correlation matrix. Taking a set of variables relevant to the study (in our case, a set of high-way criteria [noise level, congestion, etc.] for a set of highway sites), the first step involves calculating appropriate measures of association between them. These variables are

207

defined by the user and ideally represent the universe of the
issue under consideration. The choice of variables is very
important, and differing variables ought to produce differing
factor solutions. Also significant is the choice of measure
of association and although most factorial analyses require
Pearman Product Moment correlation coefficients, others may be
appropriate in specific circumstances.

Given that a matrix of correlations forms the basis of
factorial analysis, the user may then choose to calculate
correlations between variables (or attributes) or association
between individuals (or objects). The former is termed R
type factor analysis and the latter Q type. In terms of this
research, they would be represented by correlations between
problems (R type) or sites (Q type).

(b) Extraction of initial factors. The second step is to explore
data reduction possibilities by constructing a new set of
variables (or factors) on the basis of the inter-relationships
existing in the original set. In doing so, the analyst may
define the new variables as exact mathematical transformations
of the original data, or make inferential assumptions about
the structuring of variables and about their sources of
variation. The former is 'principal components analysis',
the latter 'classical factor analysis'. Whether defined or
inferred factors are used, initial factors are usually
extracted in such a way that they are independent of each
other - orthogonal. Each of the two basic approaches are
described below.

(i) Principal Components Analysis
Principal components analysis is a method of transforming a

given set of variables into a new set of composite components that are uncorrelated with each other. No particular assumption about the structure of the original variables is required. One simply asks what would be the best linear combination of new components - best in the sense that they would account for more of the variance in the data as a whole than any other linear combination. The first component is the best single summary of linear relationship exhibited in the data. The second component is the second best linear combination of original variables, given that it is orthogonal to the first. To be orthogonal to the first, the second component must account for the proportion of variance not accounted for by the first. Thus the second component may be defined as linear combination of variables that accounts for the most residual variance after the effect of the first component is removed from the data. Subsequent components are defined similarly until all the variance in the data is exhausted. The principal components model can be expressed as:-

$$Z_j = a_{j1}F_1 + a_{j2}F_2 + \ldots\ldots\ldots + a_{jn}F_n$$

where each of the n observed variables is described linearly in terms of n new uncorrelated components F_1, F_2 .... F_n, each of which is, in turn, defined as a linear combination of the n original variables.

Since each component is defined as the best linear summary of variance left in the data after the previous components are taken care of, the first n components - usually much smaller than the number of variables in the set - may explain most of the variance in the data. The user then might retain only the

first few components, consequently reducing data handling,

simplifying the description of the issues at stake, but with

minimum loss of information.

(ii) Classical Factor Analysis

Here, an assumption is made that the observed correlations

are largely the result of some underlying regularity in the

data, and if that regularly does <u>not</u> exist, the method, unlike

principal components analysis, has no validity.   More

specifically, it is assumed that the observed variables are

influenced by a number of determinants, some of which are

shared by other variables in the set, whilst others are not

shared at all.   The part of the variable influenced by shared

determinants is called 'common', that part not shared is

'unique'.   Under this assumption, the unique part of a

variable does not contribute to relationships amongst vari-

ables.   Clearly, observed correlations between variables must

be the result of the correlated variables sharing some of the

common determinants.   The implicit faith is that not only

will the common determinants account for all the inter-

relationship in the data, but that their number will be

smaller than the original variables.   The basic model takes

the form:-

$$Z_j = a_{j1}F_1 + a_{j2}F_2 + \ldots + a_{jm}F_m + d_j U_j \quad (j = 1, 2 \ldots n)$$

where Z_j = variable j in standardized form (mean = 0, σ = 1)

F_1 = hypothetical factors

U_j = unique factor, variable j

a_{ji} = standardized multiple-regression coefficient of
variable j on factor i (factor loading)

d_j = standardized regression coefficient of variable
j on unique factor j

The following are assumed to hold among the hypothesised variables:-

correlation $(F_i, U_j) = 0$ $(i = 1, 2 \ldots n, j = 1, 2 \ldots n)$

correlation $(U_j, V_k) = 0$ $(j \neq k)$

That is, the unique factor U_j is assumed to be orthogonal to all the common factors and unique factors associated with other variables.   This means that the unique portion of a variable is not related to any other variable or to that part of itself which is due to the common factor.   Therefore, if there is any correlation between the two variables j and k, it is assumed to be due to the common factors.   Further, if the common factors are assumed to be orthogonal to each other, the following emerges:-

$$r_{jk} = r_{j}F_1 + r_{j}F_2 r_{k}F_2 + \ldots + r_{j}F_m r_{k}F_m$$

$$= a_{j1}a_{k1} + a_{j2}a_{k2} + \ldots + a_{jm}a_{km}$$

$$= \sum_{i=1}^{m} a_{ji}a_{ki}$$

That is, the correlation between variables j and k is the sum of the cross-products of the correlations of j and k with the respective common factors.

Classical factor analysis can be thought of as a technique whereby a minimum number of hypothetical variables are specified in such a way that after controlling for them, all the remaining partial correlations between the variables would become zero.

The basic factor postulate assumes the existence of residual variance not accounted for by common factors and which does not contribute to the inter-correlations of the variables. However, the exact amount of this unique variance, or its complement 'communality', is not known and has to be estimated. The determination of communalities is difficult and ambiguous. One of the main characteristics differentiating factor techniques is the procedure used to estimate communality.

Factoring Methods

Five differing approaches to deriving factor solutions (principal components and classical) were available through the S.P.S.S. package used in the research.

a)   Principal factoring without iteration; main diagonals unchanged. Here the main diagonal of the correlation matrix is unaltered and principal components are extracted as exact mathematical transformations of the original variables. It thus requires no assumptions about the general structure of the variables.

In this method, eigenvalues are used to represent total variance described by each component and the importance of a component can be evaluated by examining the proportion of the total variance accounted for. Eigenvalues are calculated from all the sum of all the squared loadings for each factor and thus indicate the information explained by each component.   The number of significant components which are to be retained for subsequent analysis is determined by specifying a minimum eigenvalue criterion (and thus minimum variance explained) - traditionally 1.0, although this is ultimately a user choice.   This value ensures that only components accounting for at least the amount of average variance of a variable will be treated as significant.   However, this value can be changed and consequently so can the number of components.

b)   Principal Factoring with iteration; main diagonals changed.

Here we have a classical factor technique whereby the main matrix diagonal

is replaced by an estimate of communality, usually the squared multiple

correlation between variables in the matrix. The factors which result

are no longer exact transformations of the original variables. An

inferential leap has been made by assuming that only part of the variables

are involved in the patterning that exists and that if the common source

of variance is removed, the remaining correlations between variables become

zeros. It is assumed, therefore, that there is a unique factor or unique

variance of a variable not involved in any other variable. By replacing

the diagonals in the matrix, the presumed unique variance is removed, and

only the remaining portions are analysed.

However, there is no agreed method of calculating communalities,

although the theoretical upper and lower bounds are known. The commun-

ality problem remains unresolved despite the fact it is vital to the

derivation of factors. This method utilises an iterative procedure to

estimate communalities. Firstly, the number of factors to be extracted

from the original correlation matrix is determined, and the main diagonal

replaced by estimates of communality. Secondly, the same number of

factors is extracted from the reduced matrix and the variances accounted

for by the factors become new communality estimates. This process con-

tinues until the differences is successive communality estimates are

negligible.

Three other factoring methods were available. They are less well

known and their merits are still subject to some debate. Consequently,

they are outlined briefly here.

c)   Rao's Canonical Factoring. Here the guiding principle is to find

the solution whereby the correlation between the set of hypothesised

factors and the data variables is maximised. It is based upon the

213

classical factor model using only estimated common variance. It also assumes that input data is only a sample of the whole. It provides a significance test to estimate the number of factors needed to achieve a good fit between factors and data at a specified significance level.

d)   Alpha Factoring.   This differs from canonical factoring in that variables are considered a sample from the universe of variables rather than the sample being of sites, individuals, communities, etc., for a complete range of variables.   The aim is to make inferences about the universe of variables from a sample.

e)   Image Factoring.   Here the user is provided with a method for estimating the exact proportions of common and unique variance based upon Gutman's Image Theory.

Rotation

Regardless of whether factors are defined or inferred, the exact configuration of the factor (or component) structure is not unique - a factor solution can be transformed into another, without necessarily violating the basic assumptions or mathematical properties that exist. There are many statistically equivalent ways of defining the underlying dimensions of the same set of data.   This indeterminacy is in a way unfortunate, as it means that there is no unique and generally accepted optimal solution.   On the other hand, not all the statistical factor solutions are equally meaningful.   Some are more parsimonious or simpler than others; each tells the user something different about data structure. The original (unrotated) factor solution may, or may not, have shown up a useful or meaningful patterning of variables.   Each factoring method originally extracts orthogonal factors in successively decreasing order of importance.   The first factor tends to be a general factor loading on each variable; the second is more specific but tends to be more difficult to interpret.   Furthermore, each tends to be bipolar - including both

negative and positive loadings, further complicating analysis.

To overcome these problems, the complete original orthogonal factor structure can be rotated until a simpler and more definite clustering of variables is found (if one exists). Factors describing these clusters may remain orthogonal if the original structure is retained but rotated about a common origin in space until patterns are shown up more clearly. Alternatively, oblique rotation allows factors to rotate and become correlated if the patterning of variables so demands. It produces a more accurate description of the data but is more complex and difficult to interpret. Figure A4 shows an unrotated factor solution and its ortho-gonally rotated equivalent. The consequential loadings of variables upon factors (their relationships) are also shown. An important fact to note is that the factors are structured in geometric space in accordance with their inter-correlations. If orthogonal, they lie at 90° to each other. If not, they do not necessarily lie at 90° to each other. Unlike three dimensional geometry, factorial analysis can describe an infinite number of dimensions, representing each factor (thus if there are 20 data variables, 15 significant factors, there will be 15 dimensions) each (if orthogonal) at 90° to all the others. Factor loadings then des-cribe the relationship of each variable to each of the factors.

There are a number of procedures for rotating solutions and four differing ones were used in the research, three orthogonal and one oblique. There is no 'a priori' reason why clusters of variables should be ortho-gonal to one another. Greater emphasis was given to orthogonal solutions merely because they are easier to interpret, and simplification of a com-plex multi-variate situation (highway conditions) was the main reason for carrying out the factor analysis. It is important to note that both rotational methods remove one or both of the requirements of a principal components solution - that is (a) that each component removes the maximum possible amount of variance whilst (b) remaining orthogonal to all others.

	Unrotated		Rotated	
Var.	F1	F2	F1	F2
1	.76	.48	.25	.85
2	.83	.51	.27	.92
3	.59	.73	-.02	.95
4	.63	.66	.01	.91
5	.77	-.60	.98	.08
6	.64	-.71	.97	-.08
7	.72	-.53	.91	.09
8	.81	-.58	.96	.13

This is important to note when interpreting a rotated factor analysis solution.

The four types of rotation used in the research are described below:-

(i) Quartimax rotation. Orthogonal. Here, the objective is to make the complexity of a variable a minimum - and to achieve this by rotating the solution until a variable loads highly on one factor and almost zero upon all others. This means achieving the minimum of the cross product of factor loadings for variable j, such that:-

$$\sum_{p < q = 1}^{m} \sum_{j = 1}^{n} \left(a_{jp} a_{jq} \right)^2 \longrightarrow \text{minimum}$$

where $p < q$, and each refers to common factors. Communalities do not change with orthogonal rotation and consequently the amount of variance explained by an orthogonal solution will remain the same. The maximum possible simplification is reached if every variable loads only on one factor. Quartimax aims to achieve this ideal. Since the method emphasises simplification of the rows of the factor matrix, the first rotated factor tends to be a general factor - i.e. many variables load high on it - whilst subsequent factors tend to be subclusters of variables.

(ii) Varimax rotation. Orthogonal. In contrast to the quartimax rotation, varimax aims to simplify the columns. Here a simple factor is one with only 1's and 0's in a column. Such a simplification is equivalent to maximising the variance of the squared loadings in each column. It is the most commonly used rotation method, although the reasons for its choice are more often than not based upon tradition and past practice. The computational formula is:-

$$n \sum_{p=1}^{m} \sum_{j=1}^{n} \left(\frac{a_{jp}}{h_j}\right)^4 - \sum_{p=1}^{m} \left(\sum_{j=1}^{n} \frac{a_{jp}^2}{h_j^2}\right)^2 \longrightarrow \text{maximum}$$

(iii) Equimax rotation; orthogonal. This rotation follows the methods of quartimax and varimax, but aims to compromise the two, hence trying to achieve a simplification of both rows and columns.

(iv) Oblique rotation. Oblique rotation follows the same simplification principles exhibited above, but the requirement of orthogonality of factor axes is relaxed. The original factor axes are allowed to rotate freely to best summarise any clustering of variables. A variety of techniques exist and the one available in this package was the 'direct oblimin' method whereby the simplification of the matrix was achieved by simplifying the expression:-

$$\sum_{p<q=1}^{m} \left(\sum_{j=1}^{n} a_{jp}^2 a_{jq}^2 - \frac{\sigma}{n} \sum_{j=1}^{n} a_{jp}^2 \sum_{j=1}^{n} a_{jq}^2\right)$$

where a's are factor pattern loadings and σ is an arbitrary value by means of which the user can control the obliqueness of the solution. It is normally set at zero.

Factors are allowed to become correlated _if_ such correlations exist in the data. However, if the data does not include correlated patterns, then an orthogonal solution will result. The difference between oblique and orthogonal solutions then becomes whether the orthogonality is imposed or empirical.

A Geometric Model

A geometric interpretation of the patterns defined by a factorial analysis can help to understand the processes involved.

Each variable in the research problem (e.g. noise level) can be

thought of as defining a co-ordinate axis in geometric space.   Although

constrained by our own inadequacies, the number of dimensions is unlimited,

only controlled by the number of variables under consideration.   Within

this space, each variable can be considered a point located according to

its value for each site.   Thus for three sites, and two variables, the

geometric structure shown in Figure A5 might result.   This can be dis-

played in vector form (Figure A6).   In the case of this research, all the

highway problem variables plotted as vectors in a geometric space of 164

sites (dimensions) would describe the vector space of that data.   Within

this space, the angle between any two variable vectors measures the

relationship between them for those 164 sites.   The closer to 90° (ortho-

gonality), the less the relationship between them.   A value of 90°

reflects the total absence of correlation.   The smaller the angle, the

greater the correlation.   An angle close to zero means that sites high

or low on one variable are similarly high or low on the other.   Obtuse

angles simply mean a negative relationship.

If there were 10 problem variables projected into the 164 dimen-

sional space of the research problem, then the patterns shown in Figure A7

might result. This configuration of vectors would then reflect inter-

relationships between the problem variables.   Characteristics highly

inter-related would cluster together; those at right angles would be

unrelated.   By inspection, any clustering of variables can be discerned

and these clusters index the patterns of relationship in the data.   If

dealing with only two or three sites, clusters could be found simply by

plotting the characteristics as vectors.   However, with 164 sites,

factorial analysis enables clusters of vectors still to be defined when

the number of sites exceeds three.   Each factor or component defines a

distinct cluster of variables and acts as a best fit regression line,

passing as close to the variable points (within the cluster) as possible.

SITE 3

VAR
1

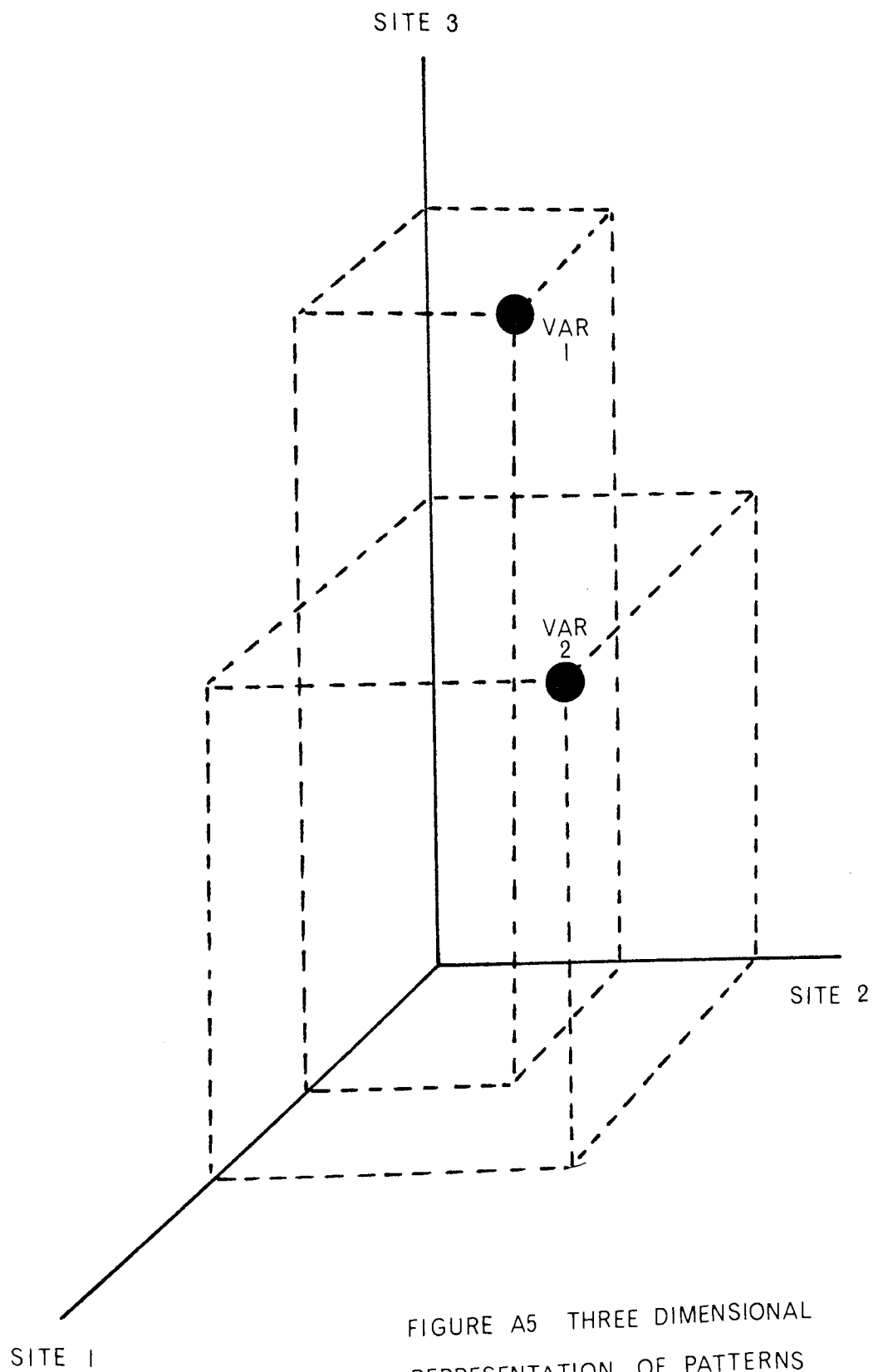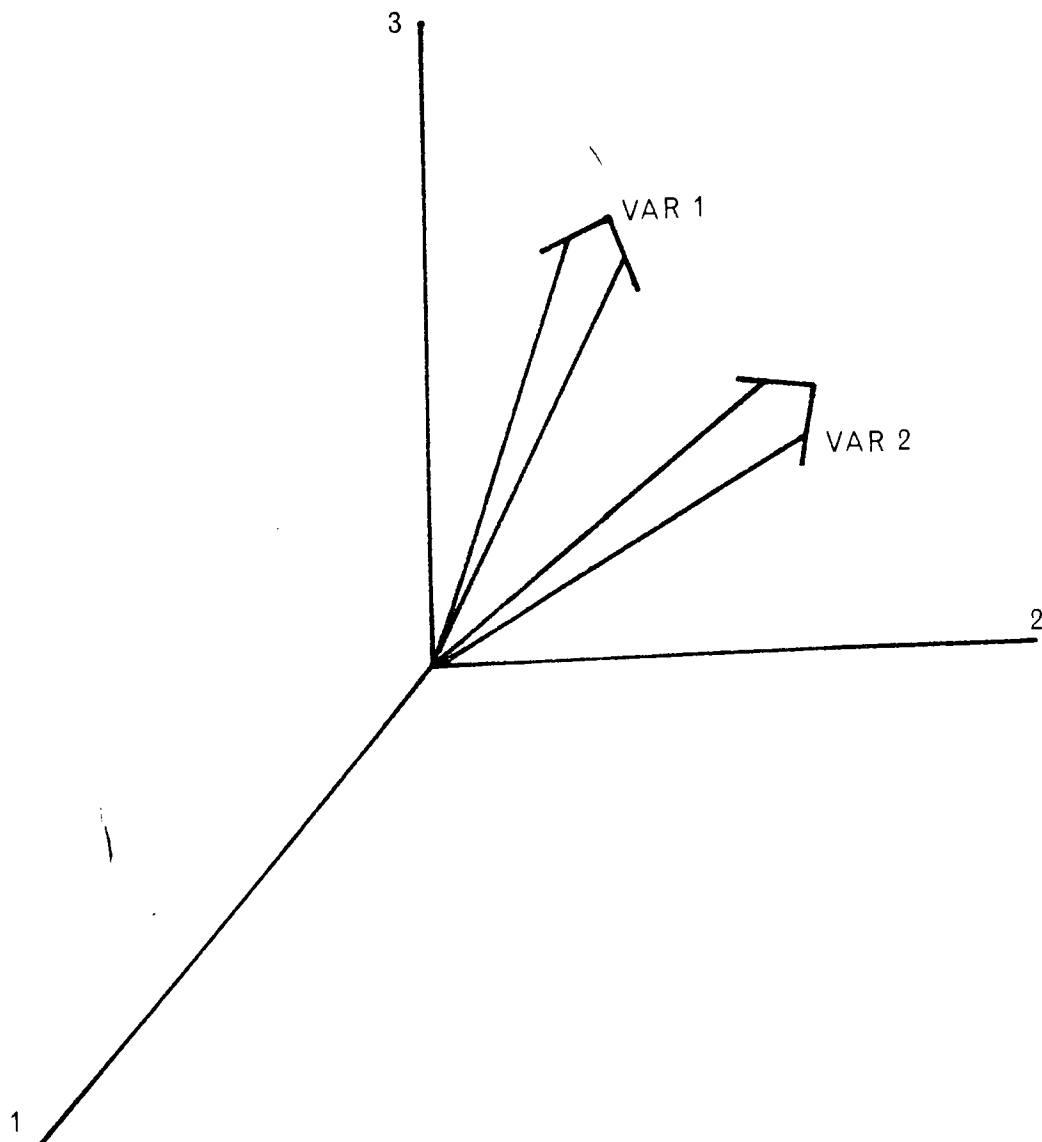VAR
2

SITE 2

SITE 1

FIGURE A5 THREE DIMENSIONAL
REPRESENTATION OF PATTERNS
DELIMITED FOR THREE SITES
AND TWO VARIABLES
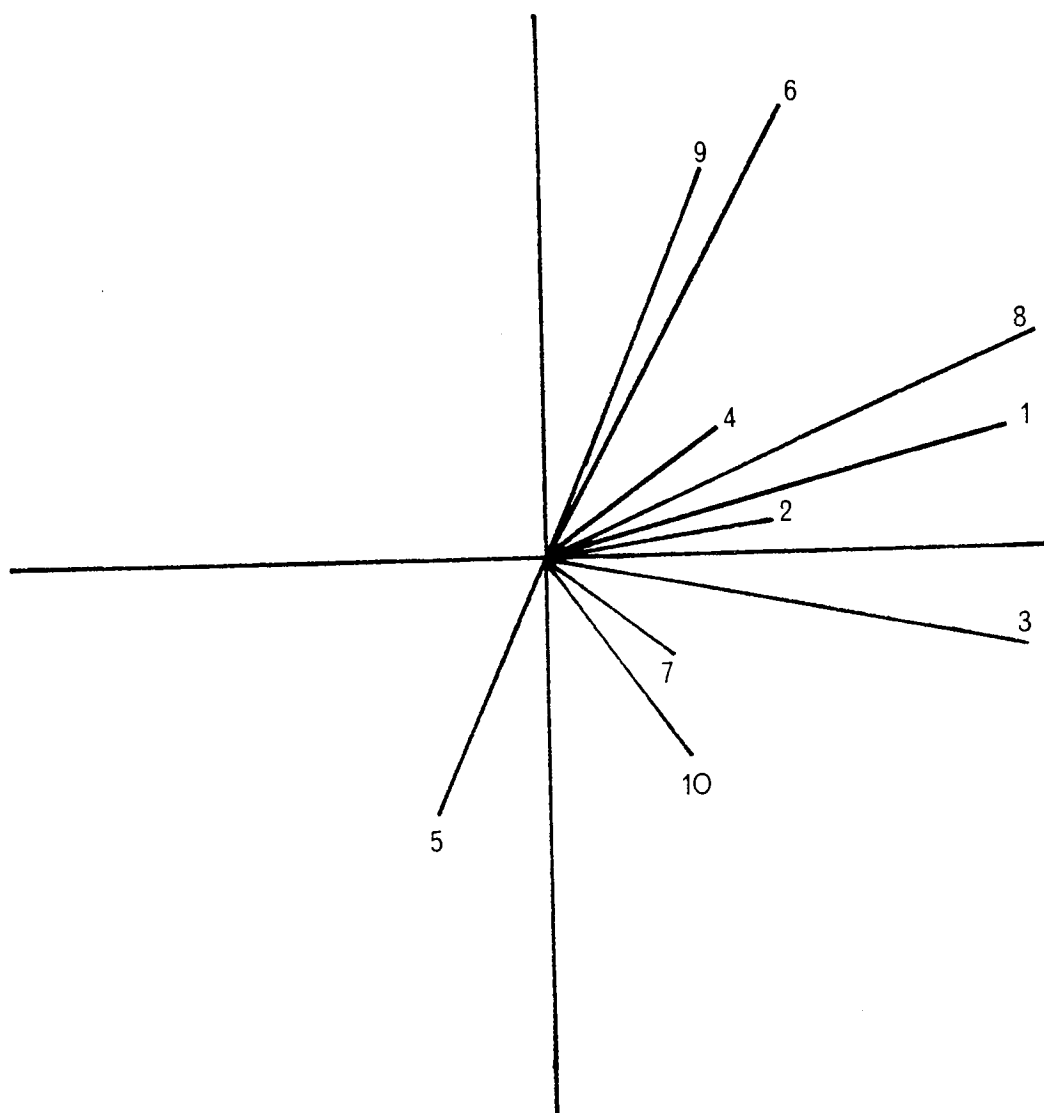
FIGURE   A6

VECTOR   REPRESENTATION

FIGURE A7

AXES PROJECTED THROUGH

CLUSTERS OF VARIABLES

Factors or components derived from Figure A7 might be as shown in Figure A8. The projection of each vector point onto the factor/component axes defines the clusters. These projections are the factor loadings, as shown in Figure A8. These factors/components enable the user to define a complex set of data in a limited number of measures which are derived directly from the original data, but which are able to summarise the patterning that exists.

Factor Score Coefficients

However, although we have a means of summarising data, describing the relationships that exist and defining new relationships which might not be obvious at the outset, we do not have a means of scaling and scoring in aggregate terms (i.e. of combining disparate data variables in a rational and consistent way). The key to this issue is the use of factor score coefficients which reflect the relationship between each data variable and the newly derived factors. Their derivation and application is described in detail in Appendix 4. Here, their use is outlined briefly. Using the factor score coefficients, a scale can be created which allows comparison between conditions (in this case highway problems) of differing sorts, measured in differing units, and also between sites. This is achieved using the coefficients and the standardised raw data. Standardisation is achieved through:-

$$Z_1 = (Var\ 001 - mean\ Var\ 001)/standard\ deviation\ Var\ 001$$

producing standardised scales for each problem type (e.g. noise level) with a mean of 0 and a standard deviation of 1. This allows comparison between variables as all problems are now measured in the same standardised units with the same mean and distribution. This standardised data is multiplied by the appropriate coefficients which allow for the strength of retlationship between variable and factor. Initially this produces a standardised score for each problem type on each factor at each site.

FIGURE A8 - FACTOR MATRIX (UNROTATED)

Factors

Variable	1	2	3	4
Congestion	-0.42	-0.27	0.03	0.19
Noise	0.06	0.36	0.47	-0.01
Air pollution	0.27	0.01	0.55	-0.18
Pedestrian danger	0.35	0.08	0.67	0.55
Bus delay	0.81	0.03	0.11	0.01
Accessibility	0.88	0.07	-0.32	0.07
Accident rate	0.89	0.12	-0.01	0.11
Bridge problems	0.12	0.96	0.09	0.18
Maintenance condition	0.08	0.91	0.43	-0.22
Visual intrusion	0.11	0.23	-0.31	0.26

(Positive scores indicate conditions above the mean, negative below).
Subsequent aggregation of this standardised data produces scores in
"problem units" for each site on each factor and for each site for all
factors upon one scale, and thus allows comparison between factors and
sites.   Since each factor can be associated closely with one problem
(e.g. environmental problems; congestion problems, etc.), then compari-
sons are possible between problem types as well.

Interpretation

        Factor loadings, and the factor score coefficients, are derived
through the computer process.   However, making use of these results is
largely a matter of individual interpretation and research experience.
There is no formal analytical process that has to be carried out.
Statistical tests can be applied to the differences between rotations,
factoring methods, choice of variables, use of scales and other user
decisions that exist, and intuitive assessments are also utilised fre-
quently.   There are few rules, and with the flexibility inherent in the
method, almost any results can be produced.   This can be both an advan-
tage and a disadvantage.

        A commonly used interpretation of factorial results is one based
upon factor loadings and leads to the derivation of a classification
structure.   Three types of classification structure can be distinguished
using the strength of loading to describe the type of factor which
emerges;

        -   symbolic (simply naming factors; A, B, C, etc.)
        -   descriptive (environmental; delay; road safety, etc.)
        -   causal (where, e.g., maintenance and road safety problems appear
                in one factor - possibly one causes the other).

        Although classification of this type is inevitably intuitive, it
does convey the dominant themes in factor classification and allows, in

the case of this research, the allocation of problem types to factors

and thus their scaling and scoring using the factor score coefficients.

FACTOR SCORES

Whilst the processes of factor modelling and estimation are normally the chief interest in factorial analysis, when the methodology is applied to evaluation questions, it is desirable to go a stage further and to estimate the scores of an individual on the hypothetical factors in terms of the observations of the characteristic x-variates for that individual. This is the process of factor scoring.

In a principal component analysis the components are, as we have seen, linear functions of the original variates from which they have derived. Hence there is no difficulty in estimating the scores of any individual on the components. In factor analysis, on the other hand, where the common factors do not fully account for the total variance of the variates, the problem is more difficult. Here the factors are not linear functions of the variates alone and the scores of an individual on them cannot therefore be found exactly. They cannot even be estimated in the usual statistical sense, and some minimum variance or 'least squares' principle has to be invoked in order that reasonable estimates may be obtained.

Estimation in factor analysis is thus, in a sense, a two-stage procedure. First the parameters in the model are estimated, then these are used to provide estimates of individual factor scores. A number of estimation methods can be identified.

Method 1

One of the simplest ways of estimating factor scores is first to single out all those data variables that have factor loadings on the factor above a certain selected cutoff value, for example, .50. The

raw scores for these data variables may be added up to provide a rough estimate of the factor score on this factor for a given individual. The same procedure is followed for each other individual. The raw score for any variable with a negative loading of -.50 or less would be subtracted rather than added because the data variable is negatively related to the factor. This method has the disadvantage that only an arbitrary cutoff point is used to determine which variables have high enough loadings to be used as estimates of the factor score. The higher the cutoff is set, the fewer will be the data variables used as factor score estimators. The lower the cutoff, the less related will some of the variables be to the factor and hence the more impure will be the factor scores. This method also has the disadvantage of giving disproportionate weight to those variables with greater raw-score variabilities. It is a rather crude method, therefore, but under some circumstances it may be quite adequate, such as for rough exploratory work and where the variables do not differ greatly among themselves in variability. The factor scores obtained in this fashion are not likely to be uncorrelated among the various factors even if the factor solution is an orthogonal one.

Method 2

A somewhat more sophisticated approach than the previous one is to scale the raw scores for all variables to the same mean and standard deviation before adding scores for those variables with loadings above the cutoff. This ensures that every variable will receive the same weight as every other variable in determining the factor scores. This refinement is usually worth the effort involved unless the variables are reasonably similar in the size of their standard deviations in the raw-score form. Since standard deviations of raw scores can and do vary over a wide range, failure to standardize scores in factor score estimation can result in markedly uneven weights for the different

factor score components.

Method 3

The two methods just described do not base the weights assigned to factor score component variables on their loadings on the factor. That is, a variable with a high loading on the factor does not necessarily have a higher weight in computing the factor score than a variable with a lower loading. A further refinement in factor score estimation, therefore, is to weight the various scores after they have been scaled to the same mean and standard deviation. The weight for each score is the factor loading of that variable on the factor or perhaps an integral value approximately proportional to the factor loading. This method can be applied just to those variables with factor loadings above a specified cutoff value, or it can be applied to all the variables. Variables with small loadings, of course, would have little effect on the total factor scores.

The advantage of this method is that it allows those variables with the highest loadings on the factor to have the greatest effect in estimating the factor scores. A disadvantage is the greater computational effort required to obtain the factor scores. A more subtle disadvantage is the possibility that differences in factor loadings among those variables with loadings above the cutoff point are due more to vagaries of variable selection and rotation than to any real differences in their value for estimating the factor scores. To the extent that this is true, this method would not represent an improvement over Method 2.

Method 4

If n factors are extracted from an n × n correlation matrix, with 1's used as communalities, residuals will vanish and factor scores may be calculated as follows:

$$Z = PF$$

where :   Z is an n x N matrix of scaled scores on the data variables,

P is an n x n matrix of factor loadings,

F is an n x N matrix of scaled factor scores.

Then

$$P^{-1}Z = P^{-1}PF$$

and

$$F = P^{-1}Z$$

This solution for the matrix of factor scores F requires that P, the matrix of factor loadings, have an inverse.   This will not be true unless as many factors are extracted as there are data variables. Computing the inverse of an n x n matrix can become very time-consuming as n increases, making this a laborious method for computing factor scores.   Other objections to the method, however, are even more serious.   Since a primary objective of factor analysis is to account for the overlap among many data variables through the use of a much smaller number of factor constructs, the idea of extracting as many factors as there are data variables has little appeal to the empiric-ally oriented scientist.   It might well have appeal in certain kinds of problems for the theoretician.

Where unities are placed in the diagonals of the correlation matrix and a principal component solution is obtained, it is possible to derive factor scores for both rotated and unrotated factors without computing an inverse and without even extracting n factors.   These procedures and other methods for obtaining factor scores have been described rather completely by Harman (1960).   Some of these methods permit the calculation of factor scores that are uncorrelated with each other, a property that is important for some research purposes.

Method 5

Multiple regression methods can also be employed to estimate

factor scores using the following basic equation:

$$z_{fi} = B_1 z_{1i} + B_2 z_{2i} + B_3 z_{3i} + \dots B_n z_{ni}$$

where : z_{fi} is a standard score in factor f for person i,

z_{1i} is a standard score in variable 1 for person i,

z_{2i} is a standard score in variable 2 for person i,

B_i is the standard regression coefficient for variable i.

The standard scores on the n variables used to predict the factor scores are known. These variables could consist of all the data variables in the factor analysis, in which case many of the B_i weights would be very low because their loadings on the factor would be low, or the variables included could be a subset of these, restricted to only those with loadings above a selected cutoff point. The development here, however, will presume that all variables are being used.

The equation above is like the standard multiple regression equation where n predictors are being used to predict a single criterion variable. To obtain the B_i weights for this equation, it is sufficient to know the correlations among the predictors and the correlations of the predictors with the criterion, that is, the validity coefficients. In the application to the problem of estimating factor scores, the factor scores become the predicted criterion scores, the variables in the factor analysis are the predictors, and the orthogonal factor load-ings or oblique structure coefficients are the validity coefficients. The unknown B_i weights are obtained through the solution of the following normal equations using the principle of least squares:

$$B_1 + B_2 r_{12} + B_3 r_{13} + \dots + B_n r_{1n} = r_{1f}$$

$$B_1 r_{21} + B_2 + B_3 r_{23} + \dots + B_n r_{2n} = r_{2f}$$

$$B_1 r_{31} + B_2 r_{32} + B_3 + \ldots + B_n r_{3n} = r_{3f}$$

$$B_1 r_{n1} + B_2 r_{n2} + B_3 r_{n3} + \ldots + B_n = r_{nf}$$

This may be expressed in matrix form as follows:

$$RB = r_f$$

where R is the matrix of known correlations among variables 1 through n; B is a column matrix containing the unknown B_i weights: and r_f is a column matrix of correlations between the variables and the factor, that is, orthogonal factor loadings of oblique structure coefficients. Provided the matrix R has an inverse, these equations may be solved as follows:

$$B = R^{-1} r_f$$

Thus, the column of B_i weights to be used to predict the factor scores from the data-variable scores is obtained by multiplying the inverse of the matrix of correlations among the data variables by the column matrix of correlations of the data variables with the factor.

An advantage of using all variables in the regression equation is that the inverse R^{-1} may be obtained once and used for all factors merely by changing the r_f column, depending on which factor is being considered. If only some of the variables are used to obtain a given set of factor scores, the R^{-1} matrix for predicting that factor must be derived from an R matrix containing only those variables that are being used.

The factor scores obtained in this way are least-squares estimates, given the correlations that constitute the data. These factor scores will not be independent of one another from factor to factor, even for an orthogonal factor solution. This may be a handicap for some theoretical investigations, but it is not for most

practical purposes.   Obtaining these least-squares factor scores does require a considerable amount of computation.   The precision obtained is a positive feature, but it must be remembered that somewhat different rotations might alter the factor loadings sufficiently to nullify any real gain from this additional refinement in factor score computation. Capitalization on chance errors in multiple regression analysis is also a fact of life that must be remembered in considering whether least-squares factor scores are worth the additional cost over simpler methods. This method was adopted in the research.

BUS AID RANKING PROCESS IN THE WEST MIDLANDS

The West Midlands County Council, in conjunction with the Passenger Transport Executive, initiate a list of bus trouble spots. The list of sites is compiled from various sources of information and consist of places where buses or passengers are thought to experience some difficulty.

Bus trouble spots are classified into the following categories:-

1.   General congestion along a length of highway which may include several junctions and parking problems which cannot be allocated to one problem.

2.   Specific problem spots causing delay: traffic signals, roundabout, priority junctions, difficulty in leaving a bus-bay, right-turn.

3.   Poor geometry of roads used by buses: bend, tight radii, lack of width, visibility, poor alignment, poor surface.

4.   Lack of suitable roads.

5.   Low or weak bridges precluding the use of certain types of bus.

6.   Parking, loading or unloading, which delays buses.

7.   Impact of traffic management, highway and development schemes causing indirect routing or delay.

8.   Pedestrian movement that causes delay.

9.   Poor location of bus stops.

10.   Lack of satisfactory turning facilities.

Each problem is investigated and scores are allocated, based on the following criteria:

1.   Delay to person.

       a) this includes the delay to the maximum number of buses
       in one hour - usually a peak hour;

       b) the degree of occupancy of the vehicles at the parti-
       cular trouble spot in the specified peak hour;

       c) the level of delay experienced at the trouble spot.

2.   Hierarchy.

       this specifies the importance of the route.

3.   T.P.P. Scheme.

       this takes into account whether work at the trouble spot is
       programmed in the T.P.P..

4.   Operational criteria.

       this indicates the degree of operational difficulty the
       trouble spot causes the P.T.E. (e.g. Union pressure,
       scheduling difficulties, etc.).

5.   Safety.

       this involves the safety aspect of the bus trouble spot and
       includes:-
       bad bends, turning circles, radius, vertical alignment,
       lay-by/stops located on roads with fast moving traffic.

The scores of the bus trouble spots are computed and are shown in the attached figure, and the program is designed to rank the schemes according to the total scores for each scheme input. Each scheme is scored under the different ranking heads and weighting factors are specified for each ranking head. The total score for each scheme is then calculated as follows:-

$$S = \sum_{i=1}^{i=n} S_i \times W_i$$

Where S is the total score for a scheme

S_i is the total score for ranking head i for a scheme

W_i is the weighting factor for ranking head i

N is the number of ranking heads

The program will rank up to 999 schemes in this manner and a scheme can be scored in the range -9 to +99 under each ranking head. Up to 31 ranking heads may be used and weighting factors between -9 and +99 may be specified. Up to 35 different groups of schemes may also be identified and ranked.

Finally , solutions are produced for those sites selected by the ranking process as having the worst problems, and a programme of work is drawn up to implement those solutions. An example of computer output is given.

SCORES AND WEIGHTS IN BUS AID RANKING

1. PERSON DELAY *   - buses   - no./hour at peak

                     - occupancy   - 0 - 0.33   -   3 points

                                      - 0.34 - 0.67 -   2 points

                                      - 0.68 - 1.0 -   1 point

              - delay   - slight   -   3 points

                               - moderate   -   2 points

                               - bad   -   1 point

2. HIERARCHY   - score range 1 - 3

3. T.P.P. SCHEME COVERAGE

        - in T.P.P. - years 1 - 3   -   3 points

                        years 4 - 5   -   2 points

        - not in T.P.P.   -   1 point

4. OPERATIONAL CRITERIA   - score range 1 - 4

5. SAFETY   - radius problem   -   3 points

                    - bad bend   -   1 point

                    - turning circle   -   2 points

                    - n/a   -   4 points

*   PERSON DELAY   no. of buses
                        =   ———————————————————————
          SCORE   occupancy   *   delay
                                   score   score

PD	(CS) Score
0 - 0.1	- 4
0.1 - 0.3	- 3
0.3 - 0.7	- 2
0.7 - 1.6	- 1
1.6 - 4.0	0
4.0 - 10.0	1
10.0 - 30.0	2
30.0 - 75.0	3
75.0 +	4

Weighting Factors (W_F)

Person delay	15	Operational	12
Hierarchy	10	Safety	8
T.P.P. Scheme	10		

$$\text{Bus Aid Score} = \sum_{n=1}^{n=5} \left(W_{F_N} \times CS_N \right)$$

where W_{F_N} = weights for all criteria (N)

CS_N = scores for all criteria (N)

Order	Scheme Reference No.	Scheme Name	Score
1	18-1	St. Martin's Circus, Digbeth Approach.	256
	33-1	Salford Circus.	256
	168-1	Lichfield Road/Cuckoo Road Junc.	256
	303-1	Broad St., Granville St./Sheepcote St.	256
5	447-1	Holloway Circus, Birmingham.	256
	541-1	Five Ways, Edgbaston.	256
	19-1	Lordswood Rd./War Lane/Harborne Rd.	236
	294-1	High Street, Harborne.	236
	98-1	Gravelly Hill/Kingsbury Road.	236
10	11-1	Bordesley Green East & Meadway	216
	21-1	Bristol Rd. - Church Rd., Northfield.	216
	23-1	Stratford Rd./Warwick Rd. Junc.	216
	16-1	Masshouse Circ., James Watt Q'way.	216
	200-1	Fazeley St. and Gt. Barr Street.	216
15	35-1	Stechford Rd./Coleshill Road.	216
	17-1	Lancaster Circ., James Watt Q'way.	216
	31-1	6 ways Erdington (Sutton New Road).	204
	28-1	Selly Oak.	204
	368-1	6 ways Erdington, Junc.	204
20	166-1	Newtown Row/Miller St. to Moorsom St.	196
	308-1	Gate Inn and Parkfield Road.	196
	etc.,		

BIRMINGHAM DISTRICT

THE M.A.R.C.H. HIGHWAY MAINTENANCE SYSTEM

During 1974, the County of the West Midlands resolved that the allocation of maintenance finance should be on the basis of need, as defined by an objective assessment system.   The system chosen was 'M.A.R.C.H.', and represents a computer based resource allocation methodology for maintenance works, which is also used by a number of other local authorities.

For the M.A.R.C.H. method to work, the highway network under consideration is divided into maintenance lengths, each of reasonably uniform geometry, construction and traffic loading.   These have been defined for the West Midlands, and there are 26,000 such lengths in the County. The average urban length is 233 metres;   the average rural, 415 metres. For each length, two sets of data are collected, termed Record data and Condition data.   The former describes the road type, geometry, etc., the latter the maintenance condition.   The collection and updating of this data represents the major costs of M.A.R.C.H..

Both sets of data are assembled onto a computer master file, together with cost information upon the expense of maintenance works, materials and the like.   From this data, the program derives three sets of information:-

(i)   A series of points ratings which relate to how far below a specified intervention level are various aspects of highway condition. The highest such rating for each maintenance length is the "critical rating" and it is this value which determines the place of each maintenance length in the overall priority ratings.

To obtain the points scores, and thus priorities, consideration is given to types of deterioration, the length of maintenance

length and traffic and pedestrian usage. If the priority ratings were calculated on the basis of percentage lengths of deterioration, any long maintenance length would be artifically suppressed. This would be because the likelihood of a given percentage of deterioration would be higher on a short maintenance length than a long one. However, similarly, if the priority ratings were calculated purely on the basis of the length of deterioration, short maintenance lengths would be suppressed. The likelihood of a given length of deterioration occurring is higher on a long maintenance length than a short one.

Consequently, priority ratings are determined using the following formula, which is supposed to balance the two effects:-

$$\text{Rating} = \frac{P \times F1 + (DL \times F2 \times k)}{DPF \times TFF}$$

where :   P = % length of area of deterioration

F1 = percentage factor

DL = length of deterioration (or area/element width)

F2 = length factor

k = scale factor

DPF = defect priority factor

TFF = traffic or footway factor.

This formula is applied to each part of the highway lengths that are deemed to be deteriorated. The highest priority which emerges for each length forms the score for that length. Scale factor k is used to reduce the length element of the rating formula to the same order as the % element (k - 100/average length of element). F1 and F2 finely tune the balancing effect described above and are calculated by trial and error. The defect priority factor (DPF) reflects the relative importance of the various elements of the highway. Thus account is taken

that it is more important to treat 100 square metres of carriageway deterioration than 100 square metres of verge deterioration. Traffic factors (TFF) relate to the relevant traffic usage of the length in question. The defect priority and traffic factors currently in use are shown in the attached figures (A9 and A10).

(ii) Suggested treatments needed to correct recorded defects based upon the information held on file. Clearly, this advice is not always followed and specific site circumstances may require alternative procedures.

(iii) Budget costs required to carry out the proposed treatment.

All this information is shown in the printouts from the M.A.R.C.H. run. Various configurations of output can be produced, including costed lists of sites in priority order sorted on county-wide or a more localised basis, basic record/condition data, lists of lengths requiring a particular treatment, etc.

The major advantage of M.A.R.C.H. is that budget costs are given for defect corrections. These costs are totalled for each maintenance length and their running total kept throughout the priority list. As a result, it should be a simple matter to determine those schemes that can be afforded within the available structural maintenance budget for any year. Costs shown above the total expenditure cut-off level are then apportioned to the districts in which the work occurs, thus providing information on the distribution of need.

One additional output from M.A.R.C.H. gives an estimate of the cost required to bring the whole of the highway network up to a defined yardstick standard. This estimate is derived using condition data and input unit costs for remedial works. These figures, calculated over

FIGURE A9 - DEFECT PRIORITY FACTORS

Assessment Item	DPF
Whole Carriageway Deterioration - minor	0.20
" " " - major	0.20
Wheel Track Deterioration	0.25
Wheel Track Rutting 13 - 18 mm	0.30
" " " over 18 mm	0.20
Skidding Resistance Failure	0.25
Unsatisfactory Patching	0.35
Edge Deterioration - Severity A	0.35
" " - Severity B	0.25
Kerb 'Lift'	0.35
Kerb 'Provide"	0.45
Kerb Deterioration 'Replace"	0.30
Verge Deterioration	0.60
Footway Deterioration	0.30

FIGURE A10 - TRAFFIC FACTORS

Traffic Group	Description	Weighting Factors
01	Motorways Trunk Roads Other roads carrying over 1000 commercial vehicles per day in each direction.	0.10
02	All other roads within a town/city centre.	0.30
03	Roads carrying 250 to 1000 commercial vehicles per day in each direction.	0.30
04	Bus routes in residential areas. Industrial Estate roads. Roads carrying 75 to 250 commercial vehicles per day in each direction.	0.50
05	Roads carrying 10 to 75 commercial vehicles per day in each direction.	0.70
06	Minor estate roads and cul de sac. Roads carrying less than 10 commercial vehicles per day in each direction.	1.00

a period of time, can provide a basis for the evaluation of long term

changes in condition of the highway network and when used in conjunction

with actual allocated expenditure, provides objective information upon

the inter-relationship of expenditure and highway condition.   The

standards used in this process are normally those proposed by the

Marshall Committee.   Clearly, they represent merely a yardstick against

which changes can be assessed.

					Problems 3 = severe; 2 = definite; 1 = slight								
District * Programmed	No.	Bridge Name and Location	Type and Owner	Grid Reference	Weight limit	Height limit	PTE	Maintenance	Delay	Safety	Development	Pedestrian	TOTAL
					A	B	C	D	E	F	G	H	
Birmingham	1961	Scribers Lane Bridge	Rail/ Road	102798							0		
	1962	Station Rd.Bridge Erdington	Rail/ Road	109923							0		
	1963	Station Rd.Bridge Wylde Green	Rail/ Road	115941							0		
	1964	Stratford Rd.Bridge	Rail/ Road	084855							0		
	1965	Summer Rd.Bridge	Rail/ Road	108920							0		
	1966	Tamworth Rd.Bridge	Rail/ Road	123972							0		
	1967	Thimble Mill Lane Bridge (N)	Rail/ Road	088894							0		
	1968	Thimble Mill Lane Bridge (S)	Rail/ Road	087891							0		
	1969	Cole Hall Lane Bridge	Road/ River	144885							0		
	1970	Popes Lane Bridge	Rail/ Road	035794							0		
	1971	School Road Bridge	Road/ Canal	092795							0		
	1972	West Heath Rd.Bridge	Road/ River	025788							0		
	1973	Wychall Rd.Bridge	Road/ Rail	028792									

BRIDGE PROBLEM RANKING IN THE WEST MIDLANDS

Bridge problem ranking in the West Midlands developed from the 'Operation Bridguard' process introduced by the Department of the Environment in areas where there were many bridges in poor condition. The Department of the Environment took responsibility for those bridges in worst conditions and helped to repair and improve them. The work of assessing these bridges has continued beyond the involvement of the D.O.E. to take the form described in this appendix.

The problem ranking of bridges is designed to provide a 5-year rolling programme of bridge works not already part of highway schemes for the T.P.P's bridge improvement programme. In addition, it aims to enable those responsible for bridge efficiency and design to appreciate the problems at each site and to plan maintenance and improvements accordingly.

The system consists of two inter-related parts; a map of the county showing the various bridge locations together with a visual presentation of problems; and a schedule of all the problem bridges listed by District. Other useful information is also attached - Grid reference, location detail, ownership, etc. Each bridge is then checked against eight problem categories - weight limit, height limit, P.T.E. problems, maintenance, delay, safety, development and pedestrian problems, - and given points according to the severity of condition. Points are then added to produce a total score for each bridge, aiming to represent the range and magnitude of problems at that site. Each problem category is scored using a range of points which reflects the significance attached to each. Thus weights are explicitly included in the scales adopted. Worst bridges are then dealt with in sequential

order, as far as is practicably possible.   The following sections outline

the scores and scales for each category.

(1) Maintenance

Different scores are used depending upon the ownership of the

bridge.   W.M.C.C. bridges are scored more highly since they require

improvement solely at the cost of the County Council.

	Score	
State of Repair	W.M.C.C.	Other
Modern bridge. No significant maintenance problems. (All B.R. road/rail bridges)	0	0
Old structure but in generally sound condition.	1	0
Maintenance repairs of a non-structural nature.	2	0
Some structural problems but not of a severe nature. Potential long-term weakness.	3	1
Recurring structural repairs or difficulties of access.	4	3
Likely short remaining life.	5	5
Structure beyond reasonable repair. Reconstruction urgent.	6	6

(2) P.T.E. Scores

If the bridge is not on a bus route and no possible opportunity to re-route exists.	0
Slight possibility of re-routing.	1
Reasonable possibility of re-routing.	2
Medium bus trouble spot.	2
Severe bus trouble spot.	3

(3) <u>Pedestrian/Bridge Problems</u>

    No footpath - heavy traffic flow.   5

    No footpath - light traffic flow <u>OR</u> narrow footpath,

      one side only - heavy traffic flow.   4

    Narrow footpath, one side only - light traffic flow,

      <u>OR</u> narrow footpaths both sides - heavy traffic

      flow.   3

    Wide footpath, one side only - heavy flow, <u>OR</u>

      narrow footpath, both sides - light flow.   2

    Wide footpath, one side only - light flow, <u>OR</u> wide

      footpath both sides - heavy flow.   1

    Wide footpath both sides - light flow, <u>OR</u> separate

      walkway both sides - heavy flow.   0

          Narrow footpath =   2 m.

          Wide footpath   =   2 m.

Each score is also assessed in relation to the pedestrian flow.

(4) <u>Development</u>

    Bridges scored under this category are those which will be affected
by a development or will affect development access. This is any bridge
which lies on a route from development to an orbital and arterial road
or motorway.

    A number of aspects are scored:

        (a) position of bridge with regard to the development;

        (b) type of development;

        (c) size of development;

        (d) type of problem.

    Two stages exist:

(i) Bridge problem and type of development.

Weight Limit	Housing	Industry
low; less than 10 tons	2	3
medium; 10 - 14 tons	1	2
high; greater than 14 tons	0	1

Height Limit	Housing	Industry
low; less than 12'	2	3
medium; 12 - 15'	1	2
high; greater than 15'	0	1

Pedestrian (scores)

4 - 5	bad	1
2 - 3	poor	½
0 - 1	good	0

(ii) Position of bridge and size of development.

	large	medium	small
only route	5	4	3
main route	4	3	2
main route	3	2	0
minor route	1	0	0

To obtain a development/bridge score, the weight/height limit score is added to the pedestrian scores to obtain a total for stage 1. This is multiplied by the score for stage 2. Each site is then scored using the following table:-

0 - 3	gives	0
4 - 8	gives	1
9 - 14	gives	2
15 - 20	gives	3

(5) <u>Weight/Height Limits</u>

Weight	–	low	10 tons	3 points
			10 – 14 tons	2 points
			14 tons	1 point
Height	–		12'	3 points
			12 – 15'	2 points
			15'	1 point

(6) <u>Safety</u>

Sites are scored from a maximum of 4. The procedure to produce a score is as follows:-

(a)   Extract current three year accident details from computer files for each site for 50 m. either side of bridge.

(b)   for each site, count number of injury sites within that area.

(c)   site with greatest number of injury accidents is scored 4.

(d)   the number that must be divided into the highest number of injury accidents at any site to reduce that accident total to 4, is then divided into the injury accidents at the other bridge sites. These numbers are then rounded to the nearest half, to yield the accident score for that bridge.

(7) <u>Delay</u>

Scores are allotted from a range of 0 – 3, using local assessment of conditions.

FIGURE A.12 - 1979 WEST MIDLANDS BRIDGE PROBLEM RANKING - COMPUTER OUTPUT

Bridge	Owner	Weight	Height	Pte.	Mce.	Delay	Accs.	Dev.	Peds.	Total
Icknield St.	B.R.	0	2	3	5	0	0	2	3	15
The Radleys	B.R.	0	2	3	0	1	1	2	4	13
Cole Hall Lane	W.M.C.C.	2	0	0	5	0	1	1	2	11
Bournville Lane	B.R.	0	1	1	3	0	1	0	4	10
Mackadown Lane	B.R.	0	1	2	0	0	2	2	3	10
West Heath Rd.	W.M.C.C.	0	0	1	2	0	1	0	5	9
Station Rd., Erd.	B.R.	0	1	2	0	0	1	0	4	8
Cotterills Lane	B.R.	0	2	2	0	0	4	0	0	8
School Rd.	B.W.B.	1	0	2	0	0	2	0	3	8
Lifford Lane	B.R.	0	2	2	0	0	1	0	3	8
Rocky Lane	B.R.	0	3	2	0	0	2	0	0	7
Broad Meadow Lane	B.W.B.	2	0	1	0	0	1	0	3	7
Stratford Rd.	B.R.	0	2	2	0	0	2	0	1	7
Summer Rd.	B.R.	0	2	2	0	0	3	0	0	7
Forge Lane	B.R.	0	0	2	0	0	0	2	3	7
Perry Aqueduct	B.W.B.	0	2	2	1	0	2	0	0	7
Church Hill	B.R.	0	0	2	0	0	3	0	0	5
Lichfield Rd.	B.R.	0	2	0	0	0	3	0	0	5

HIGHWAY CAPACITY CALCULATIONS

As part of the identification of highway problems, there existed a clear need for a measure of highway capacity and the location of delay or congestion. Data directly measuring these phenomena was not available in the West Midlands and an estimate of problems associated with highway capacity had to be derived from the information that was available upon traffic flow, geometric characteristics and traffic signal timings. From this information, an estimate of overload was derived. This was calculated from

$$\text{overload} = \text{traffic flow} / \text{highway capacity}.$$

Following central government recommendations, a value of 0.85 or above was taken as representing severe conditions.

Highway capacity varies according to the characteristics of links and nodes. The calculation of a capacity figure for each link was based upon the lowest value found, with nodal constraints allocated to the appropriate arm. A different form of calculation was used to assess the capacity of highway links, roundabouts, mini-roundabouts, priority junctions and traffic signals. A separate nodal program was used to calculate capacities and overloads using traffic flow figures.

Roundabouts

Standard British practice for the design of conventional round-abouts is contained in the Department of the Environment Technical Memorandum H2/75. It recommends that the capacity of the weaving section of a roundabout should be calculated by:-

$$Q_p = \frac{160w \ (1 + e/w)}{1 + w/L}$$

where w is the width of the weaving section in metres,

e is the average width of entries to the weaving

section in metres,

L is the length of the weaving section in metres.

Care was taken in the case study that the following conditions were not

normally invalidated:-

- there were no standing vehicles on the approaches,

- the site of the roundabout was level and approach gradients did

not exceed 4%,

- w lay between 9.1 and 18.0 m.,

- e/w = 0.63 to 0.95,

- w/L = 0.16 to 0.38,

- e^1/e^2 = 0.34 to 1.14.

Mini-Roundabouts

In similar fashion, the same technical memorandum gives advice of

how to calculate the capacity of mini and small roundabouts.   The

formula is:-

$$Qp = k(\leqslant w + a^{1/2})$$

where Qp = practical capacity in veh./hr.

w = sum of the basic road widths on all approaches

in metres

a = area, in square metres, added to the junction

by flared approaches

k = a factor dependent on type of roundabout

between 40 and 70.

Traffic Signals

There is a relatively simple formula for the calculation of

traffic capacity at a signalised intersection.   The maximum number of

vehicles crossing a stop line during a signal cycle (a green period, and a red period for a 2-phase system and the time during which the signal is effectively green) is given by:-

$$\frac{\text{saturation flow} \times \text{effective green time}}{\text{cycle time}}$$

$$\text{p.c.u./hr.} = \text{saturation flow} * \lambda$$

where λ = proportion of time a signal is effectively green.

saturation flow = 525 w pcu/hr.

w = width of the approach.

This formula is appropriate for all junctions with a width at the stop line of 5.5 metres or more, and no clearly parked vehicles. These assumptions were closely watched in the case study. Average cycle and green times had to be measured for all signalised intersections in the case study area as the majority were vehicle actuated and thus timings varied according to traffic patterns.

Priority Junctions

The capacity of priority junctions was calculated using the graphs given in Roads in Urban Areas (Department of the Environment/Department of Transport, 1977), which take account of traffic flows on the major and minor arms and the visibility from the side road. This visibility had to be recorded from visits to each site. The appropriate curves to calculate capacities are shown in Figure A13. Provision was made in the computer programs to calculate any given capacity with knowledge of visibility and flows.

Link Capacity

On some (albeit few) occasions, the major limiting factor upon traffic flow occurred along the link rather than at a junction. In this

FIGURE A13   CAPACITY OF PRIORITY
JUNCTIONS

major road traffic (total both directions – exclusive of turning traffic) (vph)

traffic entering junction from side road (vph)
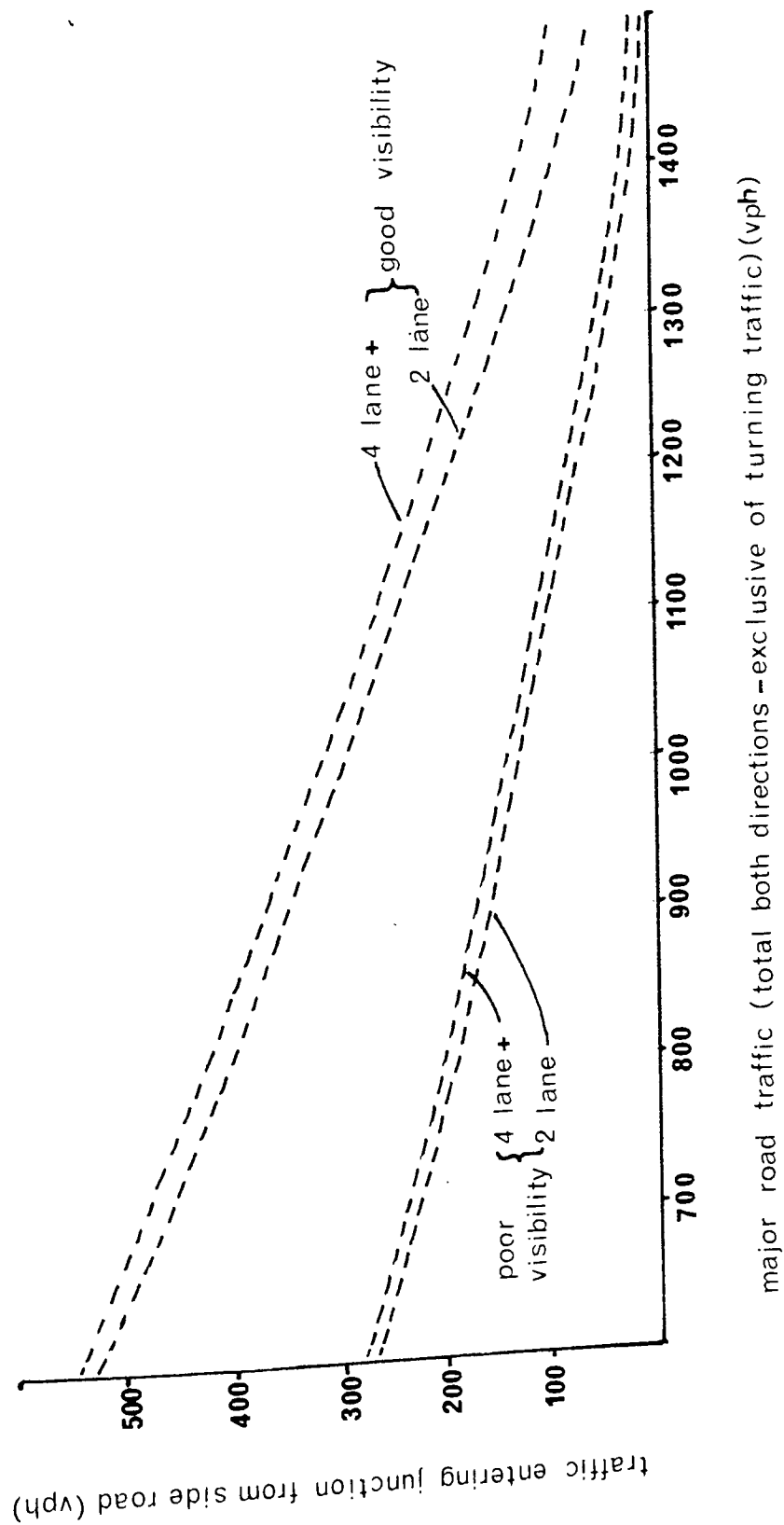
case the advice given in Roads in Urban Areas was taken, which neces-
sitated obtaining information upon road widths and road characteristics.
The appropriate figures are given in Figure A14.

Having calculated the traffic capacity of each link and attributed
the lowest capacity level to each, overload calculations could then be
carried out using traffic flow figures for the year in question (in our
case 1979). These overload figures, and the associated computer pro-
grams, could be used to indicate the existence of problems and were used
directly as part of the factorial analysis process as the indicator of
traffic congestion.

Practical capacities of two-way urban roads

Effective width of carriageway in feet	2-lane			3-lane		4-lane			6-lane		
	20'	22'	24'	30'	33'	40'	44'	48'	60'	66'	72'
	Capacity pcu's per hour BOTH directions					Capacity pcu's per hour ONE direction					
Urban motorway with grade separation								3,000			4,500
All-purpose road, no frontage access, no standing vehicles, negligible cross-traffic	1,200	1,350	1,500	2,000	2,200	2,000	2,200	2,400	3,000	3,300	3,600
All-purpose street, high-capacity junctions, 'No Waiting' restrictions	800	1,000	1,200	1,600	1,800	1,200	1,350	1,500	2,000	2,250	2,500
									2,200	2,450	2,700
									for dual carriageways		
All-purpose street, capacity restricted by waiting vehicles and junctions	300 to 500	450 to 600	600 to 750	900 to 1,100	1,100 to 1,300	800 to 900	900 to 1,000	1,000 to 1,200	1,300 to 1,700	1,500 to 2,000	1,600 to 2,200

Practical capacities of one-way urban roads

Effective width of carriageway in feet	20'	22'	24'	30'	33'	36'	40'	44'	48'
Description	Capacity in pcu's per hour								
Urban motorway with grade separation			3,000			4,500			6,000
All-purpose road, no frontage access, no standing vehicles, negligible cross-traffic	2,000		2,200	2,400	3,000	3,600	4,000	4,400	4,800
All-purpose street, high-capacity junctions, 'No Waiting' restrictions	1,300		1,450	1,600	2,150	2,400	2,650	3,000	3,350	3,700
All-purpose street, capacity restricted by waiting vehicles and junctions	800		950	1,100	1,650	1,900	2,150	2,500	2,800	3,200

SENSITIVITY TESTING - NORMALITY, ROTATION,

ITERATION AND CUT-OFF POINT

Factorial analysis encourages the user to make his own choice about many issues which need to be considered. The choice of any of these may have significant ramifications for the factor solution and thus for the problem scores and rankings that emerge. Consequently, a series of sensitivity tests were carried out to assess the importance of the choices made and to see if some rules for guidance would emerge for future decision-makers. The four issues central to factorial analysis but which involved considerable flexibility were data normality, method of rotation, iterative level and the cut-off point for extracting factors.

(i) Data Normality

Considerable confusion has emerged in recent years concerning the need for the data variables in a factorial solution to be normally distributed. Whilst the majority of opinion has stressed the need for normality, as only then can a set of variables be linearly related (given that one variable is already normal) and factorial analysis assumes linearity between variables, Roff (1977) and Clark (1973) both suggest that the effects of normalisation are negligible upon factor solutions. Consequently, the need to clarify the effects of normalisation was apparent in the case study.

As a first stage, values of skewness and kurtosis (peaking) were calculated for the problem data variables in original form and are shown in Figure A15 along with the values of mean and standard deviation. The tendency towards lack of normality for some of the data was clear, particularly within the public transport and maintenance variables. To produce a more normally distributed set of data, the $\log_{10}$ values of each were taken, and the effect of this upon the statistics shown in

FIGURE A.15 - DATA TRANSFORMATION AND ITS EFFECT ON DISTRIBUTION

DATA VARIABLE	Mean		Standard Deviation		Kurtosis		Skewness	
	Before	After	Before	After	Before	After	Before	After
Overload	3.457	1.113	3.671	0.116	-1.761	-1.783	0.343	0.298
Fatal Accs.	0.000	1.000	0.001	0.000	25.467	26.476	4.912	4.928
Serious Accs.	0.002	1.001	0.005	0.000	68.626	70.995	7.504	7.512
Slight Accs.	0.004	1.088	0.008	0.090	36.890	38.046	5.232	5.228
Noise level	74.671	1.872	4.539	0.030	15.261	151.995	-2.788	-2.113
CO level	9.724	0.930	4.786	0.236	0.671	0.880	0.768	-0.774
Smoke level	47.059	1.665	9.424	0.080	2.893	85.264	1.409	-7.742
Public transport (OPL)	0.287	1.010	0.989	0.036	9.428	9.552	3.361	3.331
(safety)	0.061	1.002	0.410	0.016	58.898	55.662	7.479	7.219
Maintenance (MARCH)	815.476	2.323	1257.470	0.915	6.180	-1.244	2.612	-0.468
(OPL)	1.252	1.051	0.259	0.010	-0.730	1.972	0.681	-0.068
Bridge Problems	0.183	1.006	1.126	0.036	43.390	41.446	6.636	6.401

248(ii)

that Figure is clear. Skewness was calculated using Pearson's coefficient of skewness, which indicates how far from symmetrical the distribution is (a normal distribution is symmetrical). The coefficient is:-

$$\frac{mean - mode}{standard\ deviation}$$

and only if the result is zero is the distribution symmetrical and thus, possibly normal. For positive values the skew is to the right; negative to the left. Kurtosis measures degree of peaking: if the distribution is very peaked, it is said to be leptokurtic, whilst if it is wide it is platykurtic. The amount of kurtosis in a distribution is measured by:-

$$\frac{(x - \bar{x})^4}{standard\ deviation^4}$$

The numerical dividing line between a platy and lepto-kurtic distribution is a value of 3. Any value greater than 3 indicates a leptokurtic distribution. Any value less, a platy.

In general, transformation improved the distribution of the data, although there were exceptions. Mean values approximated to the value of 1.0 in the majority of cases. Maintenance condition was an exception although the improvement exhibited was still substantial (from 815.476 to 2.3237). Standard deviation values also improved, the figures for maintenance condition, noise, CO, smoke and congestion being most notable. Values of skewness and kurtosis, however, revealed mixed effects. Many kurtosis values did not improve and, in fact, some worsened, suggesting increased peaking. These included congestion, fatal, serious and slight accidents and public transport (operational) conditions. Noise and smoke values became substantially worse. Skewness values did generally improve and only serious accidents, smoke and CO deteriorated notably.

The case for transformation is not entirely clear.   Certain indicators benefitted significantly and would have been unmanageable otherwise - maintenance condition is the best example of this.   However, others were clearly worsened.

The recent discussion about the value of transformation has focussed attention upon carrying out partial manipulation of those variables most in need.   This appears to be particularly appropriate to the control situation.   Rummel (1970) emphasises that transformation of variables which do not require it, or for which it worsens their distribution, is not recommended.

The effect of transformation upon a selection of sites with weighted factor solutions is shown in Figure A16.   The effect is clearly dramatic both in altering individual and factor and total factor ranks and scores.   Certain negative and positive signs are interchanged, reflecting substantial changes in relative problem condition.   Particularly notable are the occasions where total factor score is little altered but individual factor scores are considerably different.   This implies that the structure of problem condition has been markedly affected by the data transformation.   Ridgacre Road (173258) is a good example. Clearly care needs to be taken in assessing where and when to apply transformation and to be sure of its necessity.   The mean, standard deviation, kurtosis and skewness figures need to be carefully assessed prior to selecting variables for transformation on each occasion. Partial transformation would appear to offer the most suitable solution to this problem.

(ii) Rotation

Rotation is an important stage of the factor analysis process.   It can lead to the derivation of considerably improved factors and factor loadings and scores and as such can help to describe the composite factors

FIGURE A.16 - COMPARISON OF FACTOR SCORES BEFORE AND AFTER TRANSFORMATION (LOG$_{10}$)

SITE	NODES	FACTOR 1		FACTOR 2		FACTOR 3		FACTOR 4		FACTOR 5		TOTAL	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Ridgacre Rd.	173258	-146.737	134.585	-32.079	-71.140	-95.360	-1393.974	6.103	80.897	-192.579	8.221	-93.408	-91.887
Ridgacre Rd.	173260	-147.750	140.231	-31.446	-69.890	-94.268	-1398.623	-20.666	69.581	-192.303	12.803	-96.935	-89.715
Wvhampton Rd.	176268	-29.195	-316.421	-98.353	-124.312	86.457	1627.788	-80.862	-229.893	112.664	106.078	-26.792	-20.866
Wvhampton Rd.	176263	24.405	-265.539	-98.776	-125.979	75.483	1628.241	-89.133	-237.720	109.475	109.725	-7.950	5.821
Clapgate Lane	245339	-91.082	-58.789	-27.547	489.378	373.564	-178.199	24.463	54.325	294.785	115.669	33.819	56.192
Stonehouse Lane	245338	31.974	-7.120	-66.782	-103.732	- 4.189	339.109	-65.669	-111.396	-42.986	69.315	-16.862	10.477
Bottetort Rd.	246337	-10.256	292.159	-30.687	-70.252	-135.273	-1392.969	-33.306	58.701	-190.975	5.180	-48.388	-9.007
Castle Rd.	246247	-165.393	41.003	-39.352	-90.478	-124.722	-1346.224	157.116	199.083	-198.516	-7.991	-88.152	-132.123
Castle Rd.	247344	-103.483	173.735	-32.772	-73.376	-121.513	-1381.656	25.006	102.607	-190.792	-2.043	-77.332	-68.906
Quinton Rd.	248337	-167.369	-543.671	-100.408	-125.667	100.047	1644.940	49.915	-153.873	119.858	84.085	-64.310	-136.694
Quinton Rd.	248397	-160.307	-534.581	-100.916	-127.255	97.001	1648.030	57.462	-148.793	118.875	83.923	-61.102	-131.372
Ridgacre Rd.	257258	-51.328	256.746	-30.589	-69.312	-125.170	-1393.787	-33.667	62.831	-190.184	5.922	-63.593	-27.544
Hagley Rd. West	251265	-80.401	250.860	-32.290	-74.183	-113.216	-1393.470	-49.024	62.040	-196.568	15.498	-76.451	-30.969
Hagley Rd. West	259257	-113.441	211.412	-32.391	-73.886	-104.574	-1395.451	-51.398	63.770	-196.473	17.111	-88.951	-52.059
Ridgacre Rd.	260251	-83.840	219.118	-31.959	-72.344	-119.819	-1388.634	-12.957	79.409	-192.060	4.711	-73.836	-46.503
W. Boulevard	261262	-137.973	175.547	-31.758	-71.906	-92.309	-1406.364	-87.828	44.650	-197.048	25.532	-101.686	-73.094
Wvhampton Rd.	261253	-57.522	-362.850	-98.814	-124.794	86.925	1633.145	-45.644	-210.208	114.949	100.083	-33.709	-44.136
Court Oak Rd.	261333	-38.630	326.217	-30.407	-70.890	-111.229	-1405.850	-109.381	22.423	-197.984	25.414	-66.513	6.261
Hagley Rd. West	263326	321.599	-74.932	303.889	-137.106	-21.430	1619.780	-57.540	-207.490	89.961	151.510	201.799	110.603
Hagley Rd. West	263264	269.667	-127.650	-115.524	-140.044	117.913	1649.430	-53.920	-224.425	90.711	130.472	97.731	82.145

which summarise problem conditions more accurately and concisely. The
importance of assessing the value of differing rotational methods was
thus paramount. Consequently, comparisons were carried out between
the results achieved using four different rotational methods. These
methods (described in the text) were:-

orthogonal - equimax

varimax

quartimax

oblique - oblimin

Their mathematical function is described in Appendix 3.

Pearson Product Moment correlation coefficients were used to indic-
ate the effect of different applications upon factor scores and Spearman
Rank correlations to reflect the effect upon rankings. Figures A17 and
A18 show the coefficients of correlation which resulted. Comparisons
were carried out between the scores and ranks achieved for each of the
five individual factors, and the summary factor derived for each solution.
Interest focussed upon two issues:-

(i)   Which orthogonal rotation method provided the most

distinctive solution? Was there a marked difference

between them?

(ii) Was there a marked difference between orthogonal and

oblique solutions, suggesting correlation between

factors? If not, would an orthogonal solution

suffice, with its advantages of simplicity, or would

the correlation that existed suggest that a more

precise definition was needed?

Overall, a surprising variety of results emerge from the comparisons
of orthogonal solutions. Quartimax and varimax comparisons revealed
close positive correlation for factors 2 and 4 but poor correlations for
factors 1 and 3. The total factor was moderately well correlated with

PEARSON PRODUCT MOMENT CORRELATIONS - SPEARMAN RANK CORRELATIONS

PEARSON PRODUCT MOMENT CORRELATIONS

Column groups: Quartimax (1, 2, 3, 4, 5, Total) · Varimax (1, 2, 3, 4, 5, Total) · Equimax (1, 2, 3, 4, 5, Total) · Oblique (1, 2, 3, 4, 5, Total)

QUARTIMAX

	1	2	3	4	5	Total	(V)	(E)	(O)
FACTOR 1		-0.0429	-0.2246	-0.1387	-0.0280	0.3076	0.2262		
2	0.0515		-0.2788	0.3284	0.4260	0.5974	0.9091	0.3167	
3	-0.0141	-0.6697		-0.8492	-0.6540	-0.8382	0.0490	0.9438	0.0260
4	-0.2788	0.6657	-0.7380		0.6615	0.8287	0.9994	-0.7120	-0.8919
5	0.0249	0.6620	-0.6795	0.6856		0.6935	0.2705	0.0245	-0.5541
TOTAL	0.3178	0.8200	-0.8564	0.7285	0.6995		0.7466	-0.2196	0.7824
								0.4165	0.5646
									0.4431

VARIMAX

	(Q1)	(Q2)	(Q3)	(Q4)	(Q5)	V1	V2	V3	V4	V5	Total	(E)	(O)
FACTOR 1	0.1986						-0.1445	-0.1150	-0.3684	0.0704	0.1830	0.6599	
2		0.6259				-0.3672		-0.3295	0.0888	0.1238	0.3079	0.9290	-0.6076
3			-0.0152			-0.1700	-0.2104		-0.0599	0.1791	-0.0018	-0.4580	-0.8795
4				0.9886		-0.4179	0.1599	-0.1294		-0.1026	0.7578	0.0256	0.3514
5					-0.2635	0.1805	-0.3322	0.4297	-0.2864		0.1164	-0.4864	0.7874
TOTAL						0.7370	0.1511	-0.2332	-0.0394	0.6444	-0.0864	0.3637	0.5860
													-0.0307

EQUIMAX

	(Q)	(V)	E1	E2	E3	E4	E5	Total	(O)
FACTOR 1	0.2220	0.6669		-0.1641	-0.8836	0.0724	-0.0273	0.1712	-0.2695
2	0.0748	0.3947	0.2475		0.2081	0.0931	-0.0319	0.4659	-0.8639
3	-0.7091	-1.2696	-0.8639	-0.3108		-0.1595	-0.0603	0.0346	0.1398
4		-0.3266	0.2810	0.5481	0.5194		0.7476	0.7271	-0.0841
5	0.1847	0.4781	0.2419	0.2804	0.0881	0.5367		0.5219	-0.4462
TOTAL	0.0128		0.3804	0.1446	0.6871	-0.0544	0.4755	0.5930	-0.1747

OBLIQUE

	(Q)	(V)	(E)	O1	O2	O3	O4	O5	Total
FACTOR 1	-0.1264				-0.0543	-0.7859	0.1466	0.1201	0.4606
2	-0.7411			0.1772		-0.1520	-0.6160	-0.5788	-0.2091
3	-0.7541			-0.6811	-0.4163		0.0896	0.2030	0.0406
4	0.6761			0.2470	-0.5713	0.2651		0.3209	0.7261
5	0.3935			-0.0277	-0.5705	0.3491	0.3808		0.3263
TOTAL	0.5272			0.4137	-0.2972	0.2269	0.7366	0.3190	

SPEARMAN RANK CORRELATIONS

each factor, tending to average out these differences.

Quartimax and equimax comparisons revealed close positive Pearson correlations for factor 2 but a distinctly poor Spearman correlation. A close negative figure for both measures emerged from a comparison of factor 3.

The variation apparent in these comparisons was not expected as the significance of different orthogonal rotations was felt to be only marginal. The importance in selecting one technique was clear, although this was less the case between quartimax and varimax than equimax and quartimax.

Comparisons between varimax and equimax reflected less variability with close positive correlations between factors 1 and 2 and reasonably close correlations for all others except factor 4. However, once again the correlations of rankings were poorer than for scores - a significant issue in the context of ranking highway problems.

Comparisons between orthogonal and oblique solutions were much as expected. Correlations were generally poor, reflecting the association between oblique factors. Quartimax and oblique comparisons suggested some variety in the pattern with the best correlations between orthogonal and oblique solutions. The closest figure was between factors 3 (negative) and 4 (positive). Total factor comparisons were surprisingly good. Equimax and oblique correlations were generally poor, suggesting that the equimax solution was unable to describe the highway problem condition particularly well. Varimax comparisons were the poorest of all, although this was again disguised by the averaging characteristics of the total factor.

A number of conclusions can be drawn from this review of factorial rotation methods.

(i)   The results suggest that different orthogonal methods produce
      markedly different factor scores and rankings. Consequently, its
      choice is important.

(ii) Oblique methods produce different results from those of orthogonal
      techniques and in particular, equimax and varimax rotations. This
      implies that given oblique methods must be more sensitive to factor
      form, allowing inter-correlations to occur, then any orthogonal
      solution which differs from the oblique solution must be inferior.
      Consequently, the quartimax solution, which best matches the
      oblique solution, is the optimal uncorrelated technique. It also
      possesses the advantages of simplicity and clarity and although it
      is far from perfectly correlated with the oblique solution, it
      represents the best alternative to it. Given clear superiority
      over the other orthogonal techniques, it is superfluous to retain
      the latter.

      However, despite this, all rotational options were retained in the
case study for further analysis and in readiness for application to other
data sets where the optimal rotational methods might be different. In
general terms, given close correlation between an orthogonal and an
oblique solution, the orthogonal solution might be selected due to its
advantages in simplicity of interpretation. Given no close correlation,
an oblique solution has to be preferred. Rotational solutions are
highly specific to the data set used in the factor analysis. Different
data, say for a different year or set of sites, will produce different
factor solutions which, in turn, will be affected differently by each
rotation. Consequently, it is impossible to produce a definitive
recommendation for highway problem identification. However, the com-
parisons carried out here do show how significant that choice can be and
how much care needs to be taken in selection and interpretation.

(iii) <u>Iteration</u>

The choice of classical factor analysis necessitated that an estimate of the unique variance had to be made for each variable. This involved inserting estimates of communality into the principle diagonal of the correlation matrix. However, reaching a realistic estimate of communality is not simple. An iterative approach was used whereby first estimates of communality were derived from the correlation coefficients between variables. Successive recalculations were used to reach a point of convergence determined by the successive values of the estimates. Where they lay within 0.001 of each other, reasonably accurate estimates were assumed to have been achieved. However, iteration of this type is costly in computer time and resources and the opportunity exists in the factor programs to alter the test of convergence. Alternatively, a specific number of iterations can be used, varying from the current maximum limit of 25. The significance of the choice of iteration level lies in the nature and use made of the communality estimates. Clearly poor estimates would invalidate the classical factor results. Con-sequently, the optimal balance between iteration level and resource costs needs to be found. One specific test carried out was to measure the effect of varying iteration levels upon resource costs, and the accuracy of the estimates. The results are shown in Figure A19. Clearly, communality estimates improve as iteration levels increase, but significant improvement ceases to occur after a level of approximately 15 iterations. In the case of some variables (notably noise, mainten-ance [operations] and bridge problems), a lower iteration value (say 5) would suffice. In others (maintenance conditions and fatal accident rate), the level needs to be much higher. Clearly a compromise needs to be reached. Details of computer requirements are also given. These suggest increasing costs as iteration levels increase, both in terms of job units and time. The relationship is reasonably linear and con-sequently the criterion for choice can rest with the estimates of
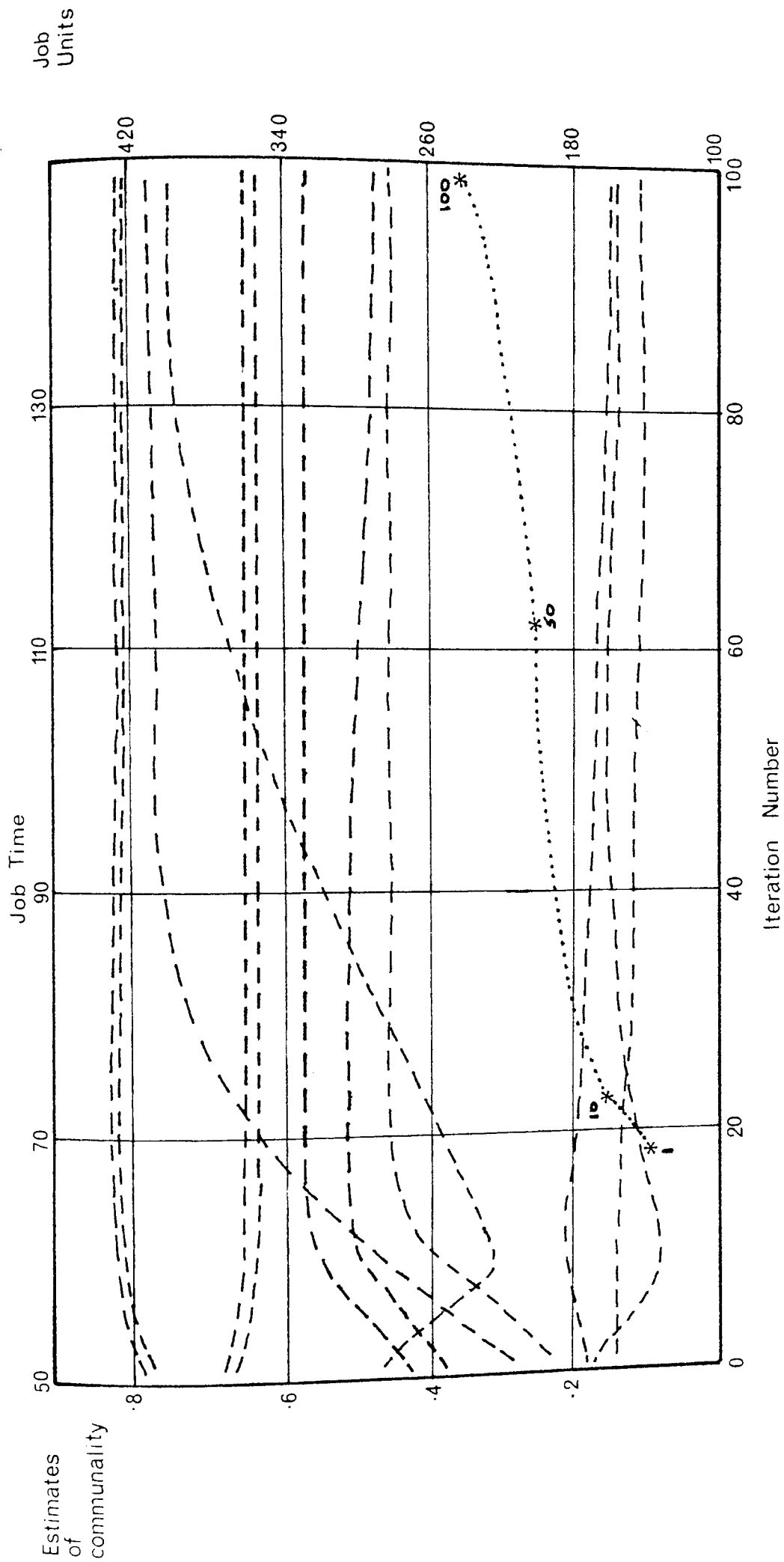
FIGURE A19   ESTIMATES OF COMMUNALITY AND ITERATION LEVEL

communality and how they vary. A choice of 25 appears to be reasonable since it accounts for the majority of change in estimates whilst keeping computer costs to a minimum and thus further iteration is unwarranted.

Clearly, these results are only relevant to this study. However, the correspondence noted with the widely recommended level of 25 (e.g. Nie, Bent and Hull, 1970) suggests that their validity may be much wider.

(iv) <u>Cut Off Point</u>

"Eigenvalues" indicate the contribution made by a factor to the description of variance within the data as a whole. A high value represents greater explanation than a low one. It thus performs an important role in indicating the value of each factor in data explanation. It can be used as a means of selecting factors for further rotation or for higher order factoring and performs the true test of a factor's significance, and the choice of eigenvalue, below which factors are discarded, is consequently important. Convention is to use a value of 1.0 and any factor with a value below this is deemed to be of little interest, whilst those above are retained. In the case study, this resulted in five factors retained for further analysis. Subsequent factoring of these five factors would have produced a further set of eigenvalues which could have been used as the basis for reducing the data set further.

However, the choice of a value of 1.0 is somewhat arbitrary and it is not uncommon for users of factor analysis to vary this value. Further interpretation of the factors and their eigenvalues showed that the choice of 1.0 in this case was justified. At this point (1.0) a noticeable break on the scree diagram in eigenvalues (and therefore explanation) occurred and factors higher than number 5 contributed little to the overall explanation. The value of 1.0 was retained as a result (figure A20). However, the choice remains important, and,

FIGURE A20

EIGENVALUE SCREE TEST
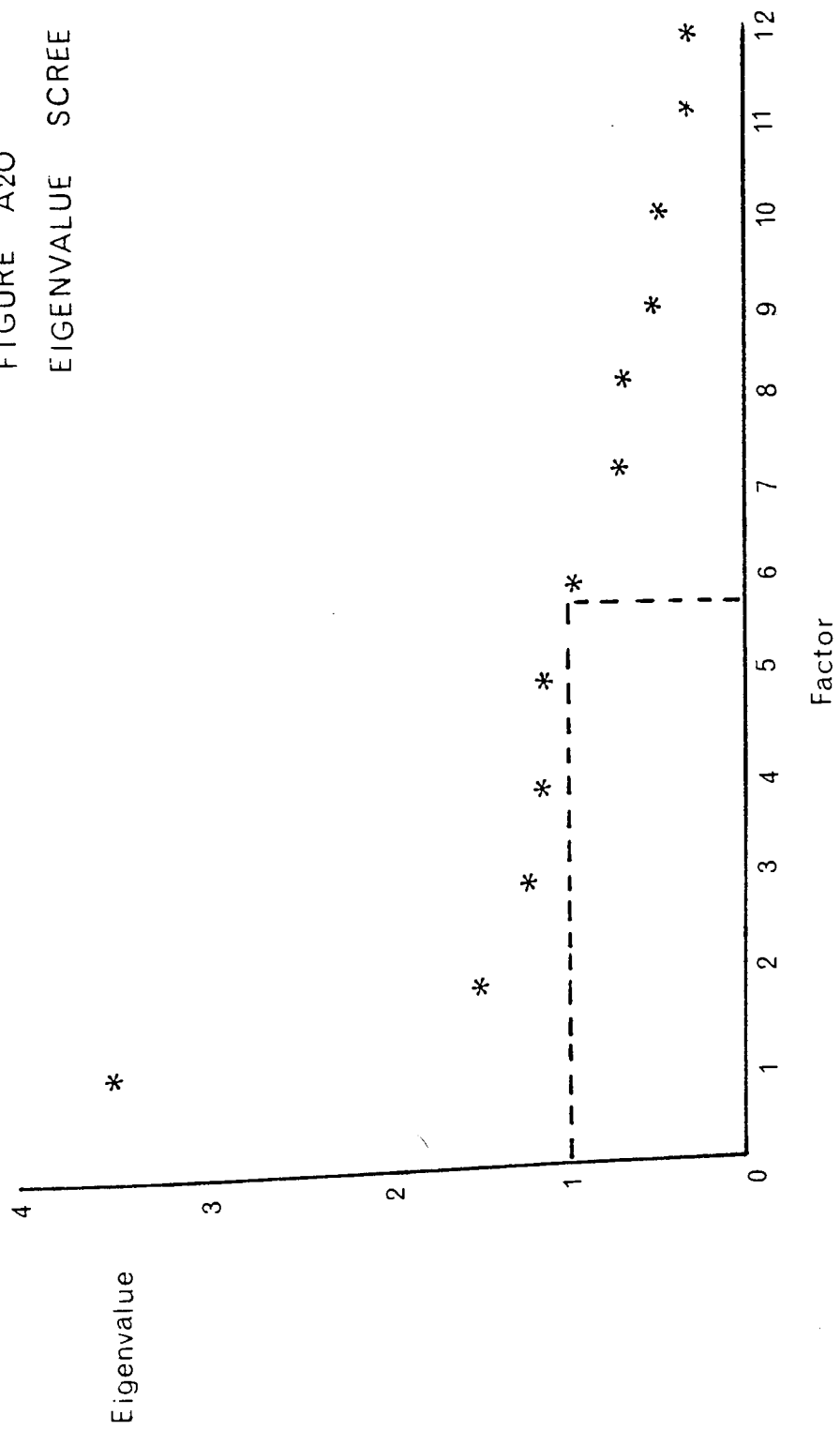
for example, an eigenvalue of 1.1 would have reduced factor retention to 4; one of 0.8 to 6. Clearly, it is important to view the scree diagram on every occasion to ensure that the need for a change in cut off value is not overlooked.

(1) S.P.S.S. PROGRAM

AN EXTRACT

RUN NAME	DATA FACTOR
FILE NAME	FACTOR LOGGED DATA
VARIABLE LIST	AOLO, FAT, SER, SL, DBA, COO, SM, BSO, BSS, M1, M2
INPUT FORMAT	FIXED (7X, F3.1, 1X, F10.5, 1X, F10.5, 1X,
	F10.5, 1X, F10.5, 1X, F10.5, 1X, F10.5, 1X, F10.5,
	1X, F10.5, 1X, F10.5, 1X, F10.5)
INPUT MEDIUM	CARD, DATA
NO.OF CASES	ESTIMATED 1000
COMPUTE	AOLO1 = AOLO + 10.0
COMPUTE	FAT1 = FAT + 10.0
....	....
....	....
FACTOR	VARIABLES = AOLON, FATN, SERN, SLNN, DBN,
	COON, SMN, BSON, BSIN, MIN, M2N/ROTATE = EQUIMAX/
STATISTICS	ALL

(2) SCORING AND RANKING PROGRAM

AN EXTRACT

```
        DO 70  N = 1, 164
        DO 71  M = 1, 5
        SCALUW (M,N) = FTRV (M,N) * OTACC * WTFTR +
        C(SRRV (M,N) * OTACC * WTSRR) + (SLRV (M,N) *
        COTACC + WTSLR) +
        ....
    71  CONTINUE
    70  CONTINUE
        DO 101  JK = 1, 164
        SCALUWT (JK) = (SCALUW (1, JK) * OPVARI) +
        CSCALUW (2, JK)
        ....
        etc.
```

SENSITIVITY TESTS - THE EFFECT OF VARYING DATA

VARIABLES AND WEIGHTS

The choice of data variables to measure the existence (or other-
wise) of highway problems is, at least in part, an arbitrary one con-
strained by the availability of data from the local authority. Ideally,
an alternative configuration of data sources could be envisaged and con-
sequently the importance the form data takes and its effect upon fac-
torial solution needs to be established. This appendix describes some
limited experiments with varied data sets and goes on to look at the
effects of varying the weights used to reflect the priorities attached
to objectives and policies. This latter testing was to establish the
sensitivity of the method to changes in political opinion and its
ability to reflect these changes in problem identification.

(i)   Data Variables

Limited sensitivity tests of changes in variables was made.   The
original case study set of data and the new sensitivity run included
the following problem variables:-

CONTROL RUN

congestion

accident rate - fatal

        - serious

        - slight

noise level

CO level

smoke level

public transport - operations

        - safety

SENSITIVITY RUN

as control run but also

accident numbers - fatal

        - serious and

        slight

maintenance - condition

       - operations

bridge problems

    The choice of extra data variables was made solely on the basis of availability and does not represent the most pertinent pieces of information excluded from the control study. Figure A21 shows the effect of the addition of these pieces of information upon the definition of factors. The distribution of variance explained by the factors has clearly changed, although at an eigenvalue of 1.0 the number retained would still be 5. The percentage of variance explained by the factors would be different (control [12] = 71.6%; sensitivity (14) = 72.8%). More significant changes can be found when comparing the rotated factor matrices (figure A22). A marked change has occurred emphasising the importance of variable choice and the importance of the number of variables used to describe problem conditions. Using the control matrix, the following variables dominate each factor:-

factor 1 : environment (noise 0.77597; CO - 0.84080; smoke 0.83711)

factor 2 : public transport (operational - 0.70188; safety 0.73503)

factor 3 : congestion (- 0.73902)

factor 4 : road safety (accident rate fatal - 0.34405; serious

          - 0.24073; slight 0.63627)

factor 5 : maintenance condition (- 0.67384)

    This is drastically altered by the introduction of the two new variables. Both the relationship of problems to factors and their comparative relationship changes.

factor 1 : environment and congestion (noise 0.54524; CO 0.73415;

          smoke 0.74464; congestion 0.41383)

factor 2 : serious and slight accidents (accident rate slight 0.98791;

          accident number serious and slight 0.98791)

FIGURE A21 - EFFECT OF EXTRA VARIABLES UPON FACTOR

DEFINITION

FACTOR	EIGENVALUE BASIC RUN (12 VARIABLES)	% OF VCE BASIC	EIGENVALUE INCREASED VARIABLES (14)	% OF VARIANCE
1	3.51210	29.3	3.67833	26.3
2	1.67481	14.0	2.35823	16.8
3	1.34079	11.2	1.66766	11.9
4	1.04359	8.7	1.41838	10.1
5	1.01298	8.4	1.07474	7.7
6	0.87530	7.3	0.95024	6.8
7	0.64879	5.4	0.78059	5.6
8	0.63595	5.3	0.64719	4.6
9	0.45173	3.8	0.45786	3.3
10	0.41848	3.5	0.42100	3.0
11	0.20370	1.7	0.22353	1.6
12	0.18179	1.5	0.18203	1.3
13	-	-	0.14016	1.0
14	-	-	-0.00000	0.0

BASIC RUN (12 VARIABLES)

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
Congestion	0.15263	0.11380	0.73902	-0.02783	0.09000
Acc. Rate -					
Fatal	-0.05094	0.00636	-0.16840	0.34405	0.12800
Serious	-0.32823	-0.03509	0.09249	0.24073	0.04946
Slight	0.14990	0.01044	0.06500	0.63627	-0.02059
Noise	0.77597	0.04167	0.16688	-0.06112	0.16525
CO	0.84080	0.01899	0.25612	0.11466	0.16450
Smoke	0.83711	-0.02708	0.24043	0.11024	0.22655
P.T.					
Opl.	0.06291	0.70188	-0.00520	0.10057	0.04434
Saf.	-0.01023	0.73503	0.14514	-0.06556	-0.05370
Maintenance					
Con.	-0.07131	0.00030	-0.06704	-0.04161	-0.67384
Opl.	0.69741	0.01023	0.25848	0.27861	0.17129
Bridge Problems	-0.05208	0.23405	0.19489	-0.07339	-0.18909

INCREASED RUN (14 VARIABLES)

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
Congestion	0.41383	0.05602	-0.17212	0.02734	0.19492
Acc. Rate -					
Fatal	-0.01243	0.10108	0.87452	-0.07504	-0.02541
Serious	0.04693	0.09394	0.02086	-0.52739	-0.02699
Slight	0.06557	0.98791	0.13642	-0.02663	0.00929
Acc. No. -					
Fatal	0.05679	0.16358	0.92548	0.04272	-0.03032
Serious & Slight	0.06557	0.98791	0.13642	-0.02663	0.00929
Noise	0.54524	0.10393	-0.02792	0.59794	0.02666
CO	0.73415	0.15632	0.01138	0.49716	0.01150
Smoke	0.74464	0.18056	0.00323	0.48756	-0.04437
P.T. (Opl.	0.07015	0.07045	0.05604	0.02809	0.57148
{ Saf.	0.05216	-0.04846	-0.01696	-0.01589	0.85933
Maintenance					
Con.	-0.30994	0.01332	-0.10048	0.01677	0.04940
Opl.	0.70976	0.23390	0.05839	0.31028	-0.00143
Bridge Problems	-0.05472	-0.01185	-0.06372	0.01586	0.27985

factor 3 : road safety fatalities (accident rates - 0.87452;

 numbers 0.92548)

factor 4 : environment and serious accident rate (noise 0.59794;

 CO 0.49716;   smoke 0.48756;   accident rate 0.52739)

factor 5 : public transport (operational - 0.57148;   safety 0.85938)

The situation is considerably more confused and the excess of safety variables is clear.   The introduction of the two new safety variables has biased the results so that other problem conditions have become subordinate to them.   Since there are no definitive rules to guide choice of problem variables, it is difficult to prove that this bias has become excessive and the range of variables unrepresentative. However, comparisons with the control factor solution tends to suggest that this is the case.   More significantly, the results of factor rotation are clearly very different and would result in different prob- lem rankings.   The control run is more representative of the policies and objectives of the West Midlands Council and thus must be preferable. However, the ultimate choice of variables will always be open to sugges- tion and cannot be ultimately defined.   Since the choice is so important to the outcome of factorial analysis, it is vital that policies remain the basis of the choice whilst the minimum number of variables is used in order to ensure simplicity.

(ii) Weights

The process used to derive objective and criteria weights was described earlier.   However, the effect of varying these weights was unknown.   Despite the use of weights of this sort in Priority Ranking, little work had ever been carried out to assess the implications of their choice.   As a result, a separate run of the problem identific- ation programs was carried out using a different set of weights from the control run.   Weights were derived for 1979 for the control run, and for 1981 for the sensitivity run.   During this period, policies had

changed with a change in political administration. To assess the effect of weight changes, the problem data and the selection of problem variables was kept the same. This would not normally be the case as problem data in particular would be updated continuously. Both weight sets were derived from discussions with officers and members in a way that would be used in practical application and is currently used for Priority Ranking. The objective weights are given below:-

	1979	1981
access to development	0.479	0.443
private transport	0.160	0.084
public transport	0.120	0.273
road safety	0.170	0.122
environment	0.080	0.078
TOTAL:	1.000	1.000

The 1981 objective weights were applied to the factor score co-efficients and standardised problem data in exactly the same way as the control (1979) data. To test the effect of the weight changes, comparisons of both scores and ranks were carried out using Pearson Product and Spearman Rank correlations. The results are summarised in Figure A23.

In terms of the ranking of problem sites, the change in weights has a notable effect. However, the characteristics of this change and its strength varied considerably. Comparisons of total factor rankings reflected few differences between the two sets of weights and it is the detailed individual factor ranks which reveal much more. Some of these changes stand out. Comparison of the quartimax ranks for factor 3 (- 0.0380), the oblique factor 3 (0.2778), equimax factor 5 (0.2371) and varimax factor 2 (0.1426) suggest that almost totally different rankings

FIGURE A23 - COMPARISON OF PROBLEM SCORES AND RANKS
USING 1979 AND 1981 WEIGHTS

FACTOR SOLUTION 1979		PEARSON COEFFICIENT 1981	SPEARMAN 1981
Quartimax Factor	1	0.2289	0.2648
	2	0.9534	0.7338
	3	0.0748	-0.0380
	4	0.9996	0.9956
	5	0.9756	0.9590
	TOTAL	0.8564	0.8156
Varimax	1	0.3216	0.4203
	2	0.9117	0.1426
	3	0.6584	0.7373
	4	0.7867	0.6887
	5	0.6868	0.5653
	TOTAL	0.5002	0.4143
Equimax	1	0.9850	0.9815
	2	0.9848	0.8642
	3	0.9997	0.9988
	4	0.9987	0.9956
	5	0.3548	0.2371
	TOTAL	0.8976	0.9494
Oblique	1	0.4624	0.4527
	2	0.9483	0.8180
	3	-0.0045	0.2778
	4	0.8110	0.8128
	5	0.5418	0.4329
	TOTAL	0.7026	0.7199

resulted from the change of weights. Some of these changes are explicable in terms of the factors involved. Factor 3 is a public transport factor and since the priority to public transport through the County policies has clearly changed over this period, then changes in rankings on this factor are not only to be expected but to be hoped for. Other major changes were less understandable in these terms.

The effect of the rotational method should also be noted. Factor 1, oblique, varimax and quartimax rotations reveal significant changes with changes in weights whilst for equimax this is far from the case. In general, score changes reflect those of rank changes and need little further interpretation.

It is difficult to assess objectively whether any weighting system has achieved what it set out to do. Clearly, in this case weights are not insignificant and tend to bias results towards the achievement of objectives and policies as they change. Consequently they go some way towards achieving the desired aims. Whether they produce the sought for balance in priorities or not is difficult to estimate and substantially more sensitivity testing is needed to confirm this. Two other conclusions stand out:-

(i) The need to interpret the factor scores and rankings is clear. Only then can the implications of weight changes be ascertained. Recourse to total factor scores and ranks alone is inadequate.

(ii) The question of weighting is very important, as it has a significant effect upon scores and ranks. Care must be taken in deriving appropriate weights to reflect priorities and the relationship of problem variables to criteria and objectives. As far as it is possible to tell, the current weighting system goes some way towards achieving this.

RECONCILING NETWORK AND LOCAL EFFECTS IN TRANSPORT

PROJECT APPRAISAL

INTRODUCTION

Much of the theory, methodology and evaluation of urban trans-
portation planning relates to the planning of systems and this, in it-
self, is a relatively uncontroversial issue.   However, major problems
exist in localized project decision-making for transport planning tools
are often designed for one level of decision-making and yet need to be
applied to the other.   Quite obviously, objectives for performance of
a transport system can only be achieved through the completion of
individual components (the introduction of local projects) - yet despite
this, the links between local and network planning remain very tenuous,
both in theory and practice.

Systems planning deals with entire regions or Counties with accumu-
lated network lengths of hundreds (or even thousands) of miles and so the
efforts of planners are often concentrated upon corridors or generalised
routes rather than individual junctions or links which make up these
networks.   Corridors can sometimes be a number of miles wide - thus
making it difficult to isolate or predict the consequences of networkwide
decisions.   Different modes and their integration may also be involved
and time horizons can be long - say up to 25 years.

Local project planning, which is orientated towards precise loca-
tion and design of components of the network, is characterised rather
differently.   Local impact assessment becomes much easier, and time
horizons are relatively short - say 5 years.

Planning and decision-making at each level requires different
information and techniques and, in particular, political issues vary

considerably. Yet transport planning, through the T.P.P. and Structure

plan, although openly recognising these different demands, fails to pro-

vide a means of ensuring that decisions taken within each process are

compatible, or that planning techniques used for each are appropriate.

The approach to each is different - mathematical modelling for network

planning, engineering design dominating local planning. Although this

is changing, albeit slowly, the two processes, closely linked function-

ally, remain distinct in approach with major difficulties in reconciling

networkwide planning issues and project generation (based on network

strategies) with local project selection and implementation.

PERFORMANCE MEASURES

Meyerson and Banfield (1955) pointed out that public interest can

be conceptualised in two ways:-

1)   Unitary conception: a single set of ends is seen as pertaining

equally to all members of society. Here local project proposals

should not be evaluated in terms of particular localised effects

because local concerns are subordinate to the common good.

2)   Individualistic conception: the aims of society do not comprise

a single system relevant to the entire society. What is relevant

is the achievement of a multiplicity of personal/group ends

whether common or otherwise.

In transport planning, we find a unitary concept inherent in the

adoption of systemwide network planning, but an individualistic approach

dominating in local project selection and implementation and when such

decisions are made in the political arena where personal and group

interests take over those of the community.

This imbalance between network strategies and project selection

and implementation is reflected in the split made by Meyerson and

Banfield in public interest conceptualizations. Not only is there a failure to ensure logical transfer from strategies to projects, but also a failure to define conceptualizations with any rationality. Local aspects are placed subordinate to regional strategies in many transport plans whilst local projects are recommended with little regard to their networkwide achievements or, even when this is not the case, to their impact on the local community.

The importance of bringing the two planning issues together in a rational framework is hard to over-emphasise, for only by so doing will regional network strategies be implemented successfully and in a way that ensures the compatibility of local projects which together make up the network plan.

INSTITUTIONAL PROBLEMS

The institutional responsibilities for transport planning in Britain are important to this issue. The Department of Transport retains responsibility for Trunk Roads and their development whilst County Council's produce Strategic Planning policies and initiatives through the County Structure Plan, but have control only of the development of non Trunk highways. District councils produce local plans which reflect and plan for the consequences of implementing the strategic policies. The consequences of this split in responsibility are clear and cannot help the integration of planning objectives.

Accountability is also stretched, particularly at central government level. Acccountability to the residents of a region/County, whose collective values are essentially ill-defined, is tenuous when it involves a series of obscure and complex institutional arrangements. Whilst this sterile atmosphere may be well suited for conceiving conceptual plans, it serves to encourage unreasonably quick disposal of local distributional issues that exist in every significant transport decision whilst failing

265

to appreciate how the selected strategy can be implemented by a combination of local projects.

CONFLICTS

The basis of recent revolts and major objections to transport planning proposals can be found in this basic divergence of system (unitary) and local project (disaggregated) perspectives. Conflicts arise most often over statements at the project level because the positions of different interest groups may solidify and diverge as abstract statements of regional transport goals are translated into more direct and local disaggregate dimensions. Thus it may be possible for individuals to agree that transportation systems should minimise travel costs, but they may eventually come into conflict over the incidence or distribution of costs related to a particular project proposal. Issues which are external to many interest groups when systems are described in the abstract, are approached differently by different groups as the abstract goals are translated into specific project characteristics. This at least partially explains why network planning rarely leads to controversy - and why when translated into tangible threats to homes, peace and quiet or safety they become rather more controversial.

The essential challenge to the planner, therefore, continues to be the reconciliation of objectives at the system and project levels when the effects and requirements of one intrude upon the other.

The split between Structure Plan strategic policies and objectives and T.P.P. project recommendations becomes of relevance here. Relatively few objections are made concerning the overall aims of a Structure Plan - it is all too abstract and woolly and few individuals feel especially threatened by it. However, the process of implementing those strategic policies, through the annual T.P.P., suddenly means that networkwide strategic policies, and their implications on a local scale, become real.

In combination with this, too often these same local projects, with intense local effects (environmental, safety, etc.), are then selected and justified in local terms alone, with little, if any, reference to the network objectives towards which they are supposed to work.

Thus the implementation of a project may be made without reference to the stimulus which caused its proposal and also without regard to the combined effect of all projects throughout the network. This means that the optimal combination of projects may not be achieved either with regard to local effects (since proposals are generated for strategic purposes), or strategic effects (since each project is only evaluated locally and in isolation). It is important to achieve this optimal combination so that strategic objectives may be best satisfied with the minimum of local disbenefit assured by selecting those local projects that together best satisfy the networkwide aims.

KNOWLEDGE

Two types of knowledge can be recognized in transport planning. Processed knowledge; characterised by traffic model output, cost benefit analysis, appraisal results etc. This type of knowledge possesses an objective format that allows it to be formally communicated, replicated, verified, critically examined and updated. It is relevant to the unitary approach; and personal knowledge; based upon direct experience, not easily codified and analysed. This type is more relevant to individualistic planning and thus more appropriate at the local project stage.

One important possibility in helping to overcome the difficulties identified in this paper would be to try and integrate these two types of knowledge and their associated approaches and perhaps use the processed knowledge of network planning to define network needs and aims, and the personal knowledge of local planning to assess the effect of each network plan upon local individuals. Clearly this fits well into

the framework proposed earlier of assessing the consequences of implementing differing combinations of local schemes so that maximum networkwide effects are achieved. By optimising the range of local alternatives (based upon personal knowledge) and then selecting the optimal combination (based upon processed knowledge), then the potential exists to integrate the two planning concepts to at least some extent. Obviously, this proposal does not imply a strict split in knowledge information or technical use according to the planning aim, but hopes to combine the two through a mix where this would be appropriate. Thus the output from a traffic model might be used to give an indication of future delay at a site where no specifically localised technique is available.

It is widely recognised that current transport planning methods tend either to be network orientated (Department of Transport; Structure Plans, etc.), which fail to recognise the local nature of transport improvements and that individuals are unable, often, to comprehend network improvements on the strategic scale, but can only appreciate them locally, or locally orientated (T.P.P. process; District Council planning, etc.) whereby only local issues are evaluated and overall network effects including the combined effects of local improvements are ignored. These problems are given added emphasis by the fact that planning agencies are theoretically working together to achieve the integration of strategic and local transport objectives. At present, depending upon the agency, different concepts are applied and a particular problem is the translation of strategic planning issues, formulated in the Structure Plan, to local transport implementation through the T.P.P. County Councils continue to evaluate projects in isolation, despite their origins, which are often in strategic objectives.

TAXONOMETRIC EVALUATION

The issue of reconciling problem identification and policy-making at the strategic level with evaluation and project selection at the

local level has been widely recognised, although few attempts have been made to overcome these problems. One attempt was made by Gilbert and Jessop (1978), who also discussed the need to appreciate the role of uncertainty in the planning process. They emphasised two major problems:-

(1)   There is rarely any consideration of risk or uncertainty in prediction;

(2)   There is a failure to use a sensible and numerate approach which could provide a mechanism to link the design and evaluation stages.

The authors considered the difficulties of reconciliation that have been noted earlier and discussed the relationship between the specification of alternative solutions, the forecasting process and the evaluation procedure used. Whilst this relationship is acknowledged in many models of the evaluation process, in practice it is largely ignored. Solutions tend to be designed using an 'unspecified' method in which a great deal of professional judgement is involved. The results are then tested using an evaluation model whose reason for being and design may be quite different from that "in the mind of the planners when designing the solution".

The specification of alternatives is a fairly impenetrable stage of the process, with the result that relatively few emerge. Gilbert and Jessop felt that it was particularly important to distinguish between a type of solution and an example. Too often the two are regarded as the same thing. Whilst exhaustive specification and evaluation of alternatives is both time consuming and costly, some movement towards better project generation is possible.

Especially important is the poor link (feedback) from evaluation results to design, largely because conventional evaluation techniques
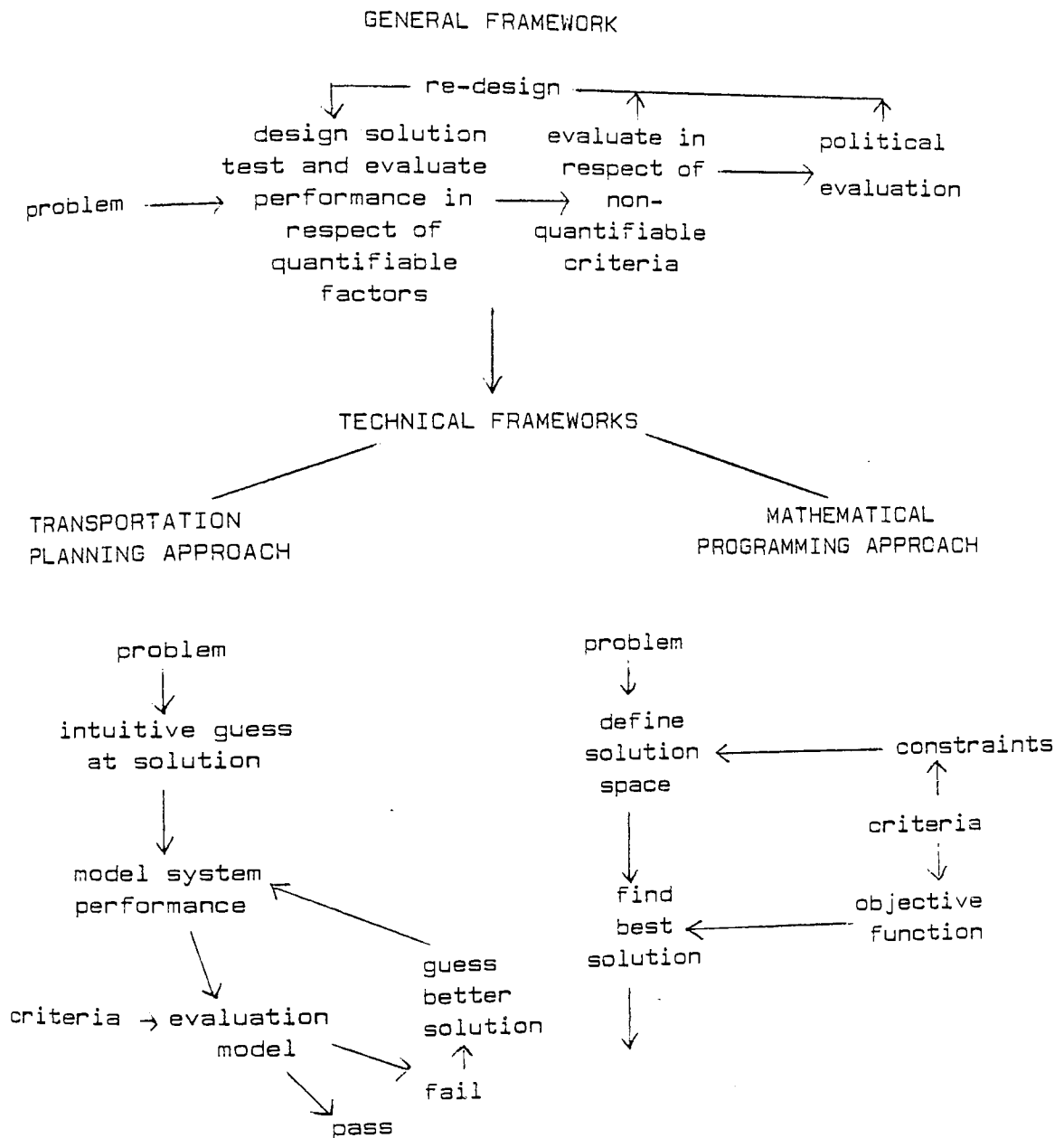
have poor diagnostic powers (Figure A24). Contrast this with mathematical programming wherein evaluation is an integral part of the design process first in constructing a set of feasible solutions, and second in choosing from that set the best solution according to the quantified criteria embodied in the objective function. Non-quantified evaluation follows. Mathematical programming seems sensible, comprehensive and efficient. So can it be applied to transport planning?

Returning to the issue of uncertainty in planning they emphasise that probabilistic forecasts must be used for predictive purposes - and that this must result in distributions rather than single point values. Differing probability distribution functions (p.d.f.) will result for different projects and discrimination between them will be very difficult due to the range of values that exist. However, it can be seen to be analogous to testing for significant differences between sample means. In the transport planning case, it would be to see if one project was significantly better than any other in terms of the evaluation criteria. If no such discrimination is possible, then a group is formed of the two indistinguishable projects. Given a whole range of projects, this process would proceed by a sequence of pairwise amalgamations until further ones are impossible. Then it would be possible to say that projects within Group X or within Group Y are homogeneous and 'sensibly' indistinguishable, whilst this is not the case between them.

This is very different from finding a best solution which is incompatible anyway, with using probabilistic forecasts - although it does remain possible that the most favoured group has only one project in it. Instead it finds that group of projects which are indistinguishable, but which overall are better, in terms of the favoured strategy, than any other. It thus forms a strategic approach to project selection, yet retaining the optimal combination of individual projects whilst so doing. Current evaluation methods are not redundant, but arithmetic ratios and

FIGURE A24 - ALTERNATIVE DESIGN/EVALUATION

FRAMEWORKS SHOWING FORMAL LINKS BETWEEN ELEMENTS

GENERAL FRAMEWORK

```
                       ┌───── re-design ─────────┐        ┌
                       ↓              ↑           ↑
              design solution    evaluate in    political
              test and evaluate  respect of ──→ evaluation
problem ──→   performance in ──→ non-
              respect of         quantifiable
              quantifiable       criteria
              factors
```

```
                              │
                              ↓
```

TECHNICAL FRAMEWORKS

```
          ╱                              ╲
```

TRANSPORTATION   MATHEMATICAL
PLANNING APPROACH   PROGRAMMING APPROACH

```
        problem                           problem
          │                                 │
          ↓                                 ↓
   intuitive guess                        define
     at solution                         solution  ←──────── constraints
                                         space                  ↑
          │                                 │                 criteria
          ↓                                 ↓                   │
    model system                          find                  ↓
    performance  ↖                        best  ←──────── objective
                   ╲                      solution          function
          │      guess                      │
          ↓      better                      ↓
  criteria → evaluation  solution
             model    ╲    ↑
                       ╲  fail
                        ↘
                        pass
```

differences must be replaced by grouping and discrimination. Distributions contain more information than point estimates and, consequently more elaborate calculations and processes are needed.

SOME APPROACHES

The major problem lies in deciding how to achieve groupings in a rigorous way. The problem really is to decide how to quantifiably describe how alike/unalike projects are. The basis for this has to be criterion values (for example N.P.V.). It is clear that criterion A = 100, B = 110, are more alike than if B = 110 and C 2 160, but by how much more, and is it significant? Again, it is similar to comparing differences between sample means. However, in the transport planner's case, he is asking the question:-

'Given the uncertainty with which I can estimate the performance

of schemes A and B, am I really justified in recommending one in

preference to the other?'

This question emphasises the need to treat p.d.f.'s as expressions of credibility about preferences and not as a statistical sampling issue. It is a subjective credibility measure. Even if we are trying to distinguish between groups of projects, where the groups are samples in effect, p.d.f's will be attached to the performance of each member of the group and these will be based upon subjective estimates of the credibility of constituent forecasts and the p.d.f. of the sample will be some combination of the p.d.f's of its constituent scheme's performances.

Let us now consider Gilbert and Jessop's suggestions for a single criterion taxonomy approach to project grouping and selection. Take two projects, A and B:-

Project	Criterion Mean Value	SD(σ^2)
A	100	20
B	130	10

If we take the means (expected values) of the two criteria, B is preferred to A since it produces a benefit of 30.   However:-

$$D \text{ (Difference)} = \bar{x}_A - \bar{x}_B$$

and

$$\sigma^2{}_D = \sigma^2{}_{\bar{x}_A} + \sigma^2{}_{\bar{x}_B}$$

This gives a standard deviation of our normally distributed estimate of the difference in expected values of 22.4.   Taking the difference in the means, plus and minus 1 standard deviation, one can say that a sensible estimate of the benefit of B over A is in the range 7.6 - 52.4.   Since this does not include zero, it appears to be reasonable to conclude that A and B are sensibly different and that B is preferable to A.   However, if the range had included zero, then this would not have been the case, and one could not have said definitely that a sensible difference existed.   The two projects would then be grouped together as one class of projects with a new mean and SD of:-

$$M = 0.5 \ (\bar{x}_A + \bar{x}_B)$$

$$SD \ (\sigma^2 M) = 0.25 \ (\sigma^2{}_{\bar{x}_A} + \sigma^2{}_{\bar{x}_B})$$

This method includes a subjective/personal choice for judging the likeness of A and B by leaving the choice of range, in this case $\pm$ 1 SD to the user.   The range used here is not particularly rigorous, but reflects the quality of data that is available.

This agglomeration procedure can be summarised as follows:-

(i) Calculate lower bands of credible intervals for the difference in criterion values between all pairs of projects.

(ii) If no lower bands are negative - stop. Do not combine any projects. They should be ranked by mean. If some are, go on to (iii).

(iii) Choose the pair of projects having the most negative lower band and amalgamate them calculating the new mean criterion value and the SD as described. Henceforth, the combined projects will be treated as one. Go to (i).

Figure A25 provides an example of this process.

Multiple criteria taxonomy

This occurs where a number of criteria are used to select between projects. Scheme performance is, therefore, listed under a number of headings.

If scheme A is better than scheme B on all counts, then the situation is simple. However, usually this is not the case. For example:-

	Criteria		
	$\underline{x}$	$\underline{y}$	$\underline{z}$
Scheme A	20 (10)	15 (2)	40 (15)
B	30 (10)	20 (4)	30 (5)

We can, as before, calculate the credible interval for the difference between A's performance and B's to give:-

$\underline{x}$	$\underline{y}$	$\underline{z}$
- 24.1, 4.1	- 9.5, - 0.5	- 5.8, 25.8

Only upon criterion Y can the schemes be sensibly distinguished (both $<$ 0), and here B out performs A. In total, therefore, B is better than A since the others show no sensible difference. This feature the authors call 'probabilistic dominance' of B over A and it can be used

273

as a basis for amalgamation similar to the single criterion case, joining pairs of schemes when no dominance exists between them at all, either because all credible intervals for criterion differences contain zero, or because A out performs B on some criteria, and B out performs A on others.

DESIGN

Transport planners tend to talk in strategies but what they have to evaluate and implement are particular schemes which are examples of one or more strategy. Given that it is convenient and/or necessary for the designer to consider alternative strategies in the early stages of the design process, we need to think about how we might most appropriately progress from strategy comparison to scheme selection.

Normally, one example of each strategy is designed and then subjected to the forecasting and evaluation stages. This implies either that a sample size of one is adequate, or that only one example exists, of each strategy. Neither would appear to be the true case.

We would compare all possibilities, but this is both costly and time consuming. So the most sensible answer would appear to be to sample those projects available. But how do we choose a sampling frame?

Each evaluation model possesses a number of scheme performance characteristics considered important (e.g. time saved). One could rank these in importance subjectively, having firstly decided upon constraints (usually financial) which limit the number of schemes chosen. If the subjectively most important factor is the strategies' attitude to public transport, strategies can be chosen, some favouring public transport and some not. Samples consisting of schemes exemplifying each category can be chosen and tested and by combining the results, appropriate p.d.f's obtained showing the likely performance from each category. Then using the taxonometric method outlined earlier, we can pick a preference - or

assess that there is not one. In the former case, the second most important factor (e.g. accidents) can be used to stratify schemes belonging to the group preferred following consideration of the most important criterion. In the latter, no subsequent distinction is made according to that criterion which did not allow a differentiation between strategies/ schemes to be made. The process continues until evaluation criteria are exhausted, at which point a preferred group of schemes is identified.

A different sample of schemes is drawn at each stage and as a result, considerably more schemes than normal are tested.

This taxonometric approach to reconciling local/design stages with the network/evaluation stages of transport planning achieves a balanced programme of projects which together should move effectively towards the achievement of a favoured strategy. Thus the optimum combination of projects in terms of that strategy are selected, and in particular it is assumed that projects which conflict substantially in their objectives are not recommended.

However, it is possible to envisage a situation where the implementation of say three schemes, A, B and C, would not be recommended by the taxonometric method because scheme A is a public transport scheme with a small environmental disbenefit, whereas schemes B and C are environmental schemes with a small public transport disbenefit. If the favoured strategy of the planning agency was that of public transport, then it is most likely that scheme A would be favoured over B and C. However, it is possible that the environmental benefits of B and C would be so great that they vastly outweigh those of scheme A in terms of public transport - and thus would be more beneficial community wide. The taxonometric method, as outlined above, would, as a result, not select that combination of projects most beneficial to the areas as a whole, since it fails to evaluate all potential groupings and their

combined benefit to the community. This does not mean that schemes favouring the strategy with highest priority would not achieve greater emphasis – this could be included by weighting them appropriately, but that not only those schemes would progress to the highest ranked group.

NETWORK TAXONOMETRIC METHOD

This section outlines an approach to project group selection which takes the taxonometric method as a basis but proceeds to combine its more beneficial characteristics with the demands of a network and local project based system. By so doing, it helps to ensure that the combination of projects chosen are both individually robust and also in combination with all others that are recommended.

The method outlined here is designed to interface specifically with the approaches to evaluation currently advocated within West Midlands County Council. However, with some slight modification, it would be appropriate for application to any project evaluation authority.

Stage 1. Following problem identification and the preliminary design stages, the County transport model is used to produce future ranges of information for the 'do minimum' option and for each project group combination. Each project group will be made up of designed solutions, preferably a number of options for each problem spot, which total in cost approximately the amount of finance that will be available. Each represents, therefore, a potential programme of schemes. Predictions of future financial solutions ought normally to be available for planning purposes. It is of utmost importance that predicted levels of flow, accident rates, etc., are available in ranges, and not single points so that predicted costs and benefits will also be in the same form.

Stage 2. Calculate the mean difference over the whole network between the 'do minimum' and each project within each group of project alternatives for each criterion, and the associated standard deviations:-

Project Group		Criteria		
		x	y	z
1	A	20 - 40 (10)	- 4 - 15 (7)	15 - 25 (10)
	C	30 - 40 (5)	10 - 15 (7)	20 - 35 (4)
	D	10 - 20 (4)	9 - 12 (1)	12 - 17 (5)
2	A	25 - 35 (10)	20 - 30 (12)	15 - 25 (12)
	E	20 - 30 (10)	12 - 15 (4)	15 - 20 (10)
3	F	15 - 20 (9)	30 - 45 (3)	- 5 - 15 (15)
	G	5 - 25 (10)	5 - 10 (2)	5 - 20 (10)

Stage 3.   Combine the means of these ranges and SD's for each project criterion within each project group to give a project group criterion score:-

Project Group	Criteria		
	x	y	z
A C D	26.66 (4)		
AE	27.5	etc.	
FG	16.75		

Stage 4.   Then compare each group of projects with each other using the multiple criteria taxonomy outlined earlier, by comparing the difference in the means and their standard deviations.   Where no sensible difference is discernible, then amalgamate, thus forming groups like A.C.D./ A.E.   Where there is a discernible difference, select the preferred and reject the other.   Then compare the preferred group with the next, continuing with the amalgamation process until all groups have been compared. The group which remains favoured at the end of the process is that most favourable combination.
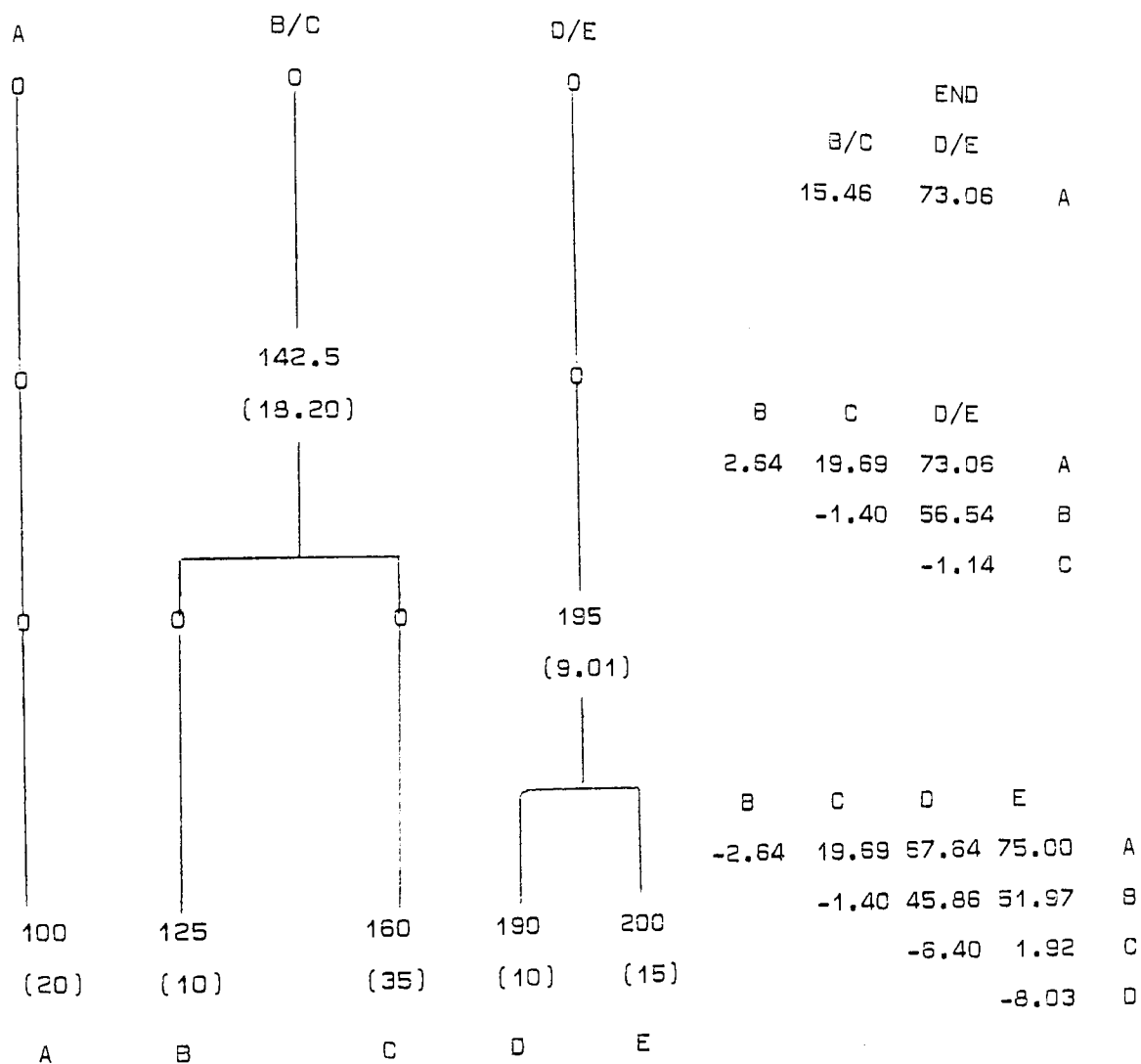
The method outlined here is only one possible approach using the taxonometric methods developed by Gilbert and Jessop. However, it could provide information upon the most desirable combination of individual projects, which together act to the best for the network as a whole.

CONCLUSIONS

Some tentative conclusions can be reached:-

(i) The practical application of the technique proposed by Gilbert and Jessop, and the modifications also outlined here, rely upon the use of ranges of values for criteria. Such ranges are currently rarely used in the transport planning process and consequently some fundamental changes in data collection, prediction and technique will need to be made.

(ii) There are also problems associated with the inevitable generalisations that result from use of a traffic model. The accuracy of prediction from such a model, even if expressed in range form, as yet cannot be particularly good. Using such information as a basis for selecting between projects has to be viewed with that in mind.

(iii) Substantial quantities of computer time, and therefore money, will be needed to run the traffic model the number of times needed to compare all potential situations. This may prove prohibitive, even though the financial benefits in terms of the improvements in project selection and programming might prove enormous.

(iv) Certain problems associated with combining values from differing criteria are at least partially overcome, since projects are compared solely on the basis of differences between equivalent criteria. The need to 'add' delay to noise levels, for instance, no longer exists. However, this does mean that the magnitude of

FIGURE A25 - NETWORK TAXONOMETRIC EVALUATION

A   B/C   D/E

	END	
	B/C	D/E
	15.46	73.06	A

142.5

(18.20)

B	C	D/E	
2.64	19.69	73.06	A
	-1.40	56.54	B
		-1.14	C

195

(9.01)

B	C	D	E	
-2.64	19.69	57.64	75.00	A
	-1.40	45.86	51.97	B
		-6.40	1.92	C
			-8.03	D

100	125	160	190	200
(20)	(10)	(35)	(10)	(15)
A	B	C	D	E

START

Legend:
$\bar{x}$
(σ^2) $\bar{x}$ = mean project
      σ^2 worth

Table of
lower bounds
of credible
interval for
difference.

difference between criteria is only partly recognised. Thus a
moderate benefit in delay for Project A over Project B might lead
to A's selection, even though Project B might possess an enormous
benefit for the environment over A. The trade off between
criteria is not made fully explicit.

(v) It would seem that there are substantial opportunities for research
into this area. The need to achieve a balanced and optimal combin-
ation of projects, as well as selecting individually worthwhile
projects, is both obvious and vital. Yet techniques which can
achieve this are few and unproven. The methods suggested here
are only some which could be used, but hopefully they indicate the
potential that exists.

REFERENCES

ACKOFF, R.L. (1962). <u>Scientific Method; optimising applied research decisions</u>. Wiley, New York.

A.C.T.R.A. <u>Report of the Advisory Committee on Trunk Road Assessment</u>. H.M.S.O., 1977.

ARNOTT, C. (1979). <u>Liverpool Inner Ring Road Feasibility study; economic impact study</u>. Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

ARROW, K.J. and LIND, R. (1970). "Uncertainty and the evaluation of public investment decisions". <u>American Economic Review</u>, 60 (3), 364 - 378.

BALL, R.R. (1976). 'The T.P.P. Assessing priorities', <u>Chartered Municipal Engineer</u>, 103, (12/76), 226 - 232.

BALL, R.R. (1977). <u>'Priority ranking of schemes within the T.P.P.'</u> Paper presented at the P.T.R.C. Summer Annual Meeting, University of Warwick.

BARRELL, D.W.F. and HILLS, P.J. (1972). 'The application of cost benefit analysis to transport investment projects in Great Britain'. <u>Transportation</u>, 1, 29 - 54.

BAUMGARTNER, J.P. (1977). 'Choice of investment priorities. Theoretical aspects'. <u>7th International Symposium on Theory and Practice in Transport Economics</u>. London.

BAYLISS, D. (1974). <u>'Transport policies and programmes'</u>. R.T.P.I. Summer School.

BAYLISS, D. (1975). 'T.P.P's and Structure Plans'. <u>The Planner</u>, November, 1975.

BEESLEY, M.E. and WALTERS, A.A. (1970).   'Some problems in the evalu-
ation of urban transport investment'.   Applied
Economics, 1 (4), 241 - 259.

BELENSEN, S.M. and KAPUR, K.C. (1973).   'An algorithm for solving
multi-criterion linear programming problems with
examples'.   Operations Research Quarterly, 24 (1),
65 - 78.

BENEVOLO, L. (1967).   Origins of modern town planning.   Routledge and
Kegan Paul, London.

BETTISON, G. (1979).   'Total programme analysis for the justification
and budgetting of capital investment in transport'.
Session 7.   Australian Transport Research Forum,
Sydney, Australia.

BOHN, P. (1972).   'Estimating demand for public goods'.   European
Economic Review, 3.

BOTHAM, R. (1979).   The regional development effects of road investment.
Paper presented at P.T.R.C. Summer Annual Meeting,
University of Warwick.

BOVAIRD, A.G. (ed.) (1980).   Evaluation in the T.P.P. process.   Joint
Unit for Research on the Urban Environment, University
of Aston in Birmingham.

BRAYBROOKE, D. and LINDBLOM, C. (1963).   Strategy of Decision.   Free
Press, New York.

BROADBENT, T.A. and MACKINDER, I.H. (1973).   'Transport planning and
structure planning'.   Traffic Engineering and Control,
14, 536 - 537.

BURRIDGE, P. (1979). 'Non-normality in parametric statistical analysis', _Area_, 11, 132 - 134.

BUTTON, K.J. (1980). 'Some comments on Starkie's Method of allocating inter-urban road and rail investment'. _Regional Studies_, 14, 333 - 335.

CHADWICK, G. (1971). _A systems view of planning_. Pergamon, Oxford.

CHAN, Y. and ELLIS, R.H. (1978). 'An analysis of internal transit systems requirements for central cities'. _Transportation Planning and Technology_, 5, 1 - 11.

CHAPMAN, R.J. (1980). _'Traffic management - the allocation of scarce resources'_. Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

CHATFIELD, C. and COLLINS, A.J. (1980). _Introduction to Multivariate analysis_. Chapman & Hall, London.

CHEUNG, Y.H. (1977). _An appraisal of the points-rating system_. Unpublished Note. Greater London Council.

CLARK, D. (1973). 'Normality, transformation and the principal components solution; an empirical note'. _Area_, 5, 110 - 113.

CLARKE, D. and RIVETT, B.H.P. (1978). 'A structural mapping approach to complex decision making'. _Journal of the Operational Research Society_, 29 (2), 113 - 128.

COMMISSION ON THE THIRD LONDON AIRPORT (1971). _Report_. H.M.S.O., London.

COOPER, G. (1980). _Is economic evaluation objective?_

COWLEY, J.A. (1981). 'The evaluation of highway maintenance' in A.G. Bovaird (ed.) (1980) "Evaluation in the T.P.P. process" University of Aston in Birmingham.

DALVI, M.Q. (1973). Distributional aspects of investment in urban transport. Institute for Transport Studies, University of Leeds, Working Paper WP.26.

DALVI, M.Q. and MARTIN, K. (1976). Urban transport evaluation procedures; a review. Institute for Transport Studies, University of Leeds, Working Paper WP.23.

DALVI, M.Q. and NASH, C.A. (1977). 'The redistributive impact of road investment' in Bonsall, P.W., Dalvi, M.Q. and Hills, P.J. (eds.) Urban Transport Planning. Abacus, Tunbridge Wells.

DAVIES, P.W. and WORSLEY, T. (1979). 'What price standards?' Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

DEPARTMENT OF THE ENVIRONMENT (1972). C.O.B.A., H.M.S.O.

DEPARTMENT OF THE ENVIRONMENT (1973A). Local Transport Grants. Circular 104/73.

DEPARTMENT OF THE ENVIRONMENT (1973B). Assessment of Schemes valued between £50,000 and £500,000. Circular Roads, 502.

DEPARTMENT OF THE ENVIRONMENT (1974). Transport Supplementary Grant. More Details of the New System. Circular 27/74.

DEPARTMENT OF THE ENVIRONMENT (1975A). Transport Supplementary Grant. Submissions for 1976/7. Circular 43/75.

DEPARTMENT OF THE ENVIRONMENT (1975B). Transport Supplementary Grant. Submissions for 1977/78. Circular 125/75.

DEPARTMENT OF TRANSPORT (1977). Transport Supplementary Grant. Submissions for 1978/79. Circular 1/77.

DEPARTMENT OF TRANSPORT (1978A). Transport Supplementary Grant. Submissions for 1979/80. Circular 3/78.

DEPARTMENT OF TRANSPORT (1978B). Policy for Roads. White Paper, H.M.S.O.

DEPARTMENT OF TRANSPORT (1978C). National Traffic Forecasts. Interim Forecasts. H.M.S.O.

DEPARTMENT OF TRANSPORT (1979). Transport Policies and Programme Submissions for the 1980/81 T.S.G. Settlement. Circular 4/79.

DODGSON, J.S. (1973). 'External effects and secondary benefits in road transport appraisal'. Journal of Transport Economics and Policy, 7, 169-185.

DORFMAN, R., SAMUELSON, P.A. and SOLOW, R.M. (1958). Linear programming and economic analysis. McGraw-Hill, New York.

ECKENRODE, R.T. (1965). 'Weighting multiple criteria'. Management Science, 12 (3), 180 - 192.

EDDISON, T. (1975). Local government: management and corporate planning, Leonard Hill, Leighton Buzzard.

EILON, S. (1972). 'Goals and constraints in decision-making'. Operational Research Quarterly, 23 (1), 3 - 15.

ENGLISH, J.M. (1968). Cost effectiveness. John Wiley, New York.

EVANS, A. and HOLDER, A. (1978). 'Another look at Leitch'. Surveyor, 18/5/1978.

FALUDI, A. (1971). 'Problems with problem solving'. Journal of the Royal Town Planning Institute, 57, 415.

FARBEY, B.A. and MURCHLAND, J.D. (1967). 'Towards an evaluation of road system designs'. Regional Studies, 1, 27 - 37.

FELLS, P.J. and TWEEDALE, D. (1977). 'Monitoring transport policies and objectives'. Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

FRIEND, J.K. and JESSOP, W.N. (1969). Local government and strategic choice. Pergamon, Oxford.

FRUCHTER, B. (1954). Introduction to factor analysis. D. Van Nostrand Co. Inc., New Jersey.

GANE, D., ROGERS, K., HOLT, B. and JONES, J. (1979). The highway review evaluation. Transport Planning Group, Department of County Engineer, Greater Manchester Council, T.P.G. Note 49.

GILBERT, D. and JESSOP A. (1978). Taxonometric evaluation. Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick; also published in Transportation 7/2, 147 - 166.

GLEASON, J.M. and BARNUM, D.T. (1982). 'Toward valid measures of public sector productivity; performance measures in urban transit'. Management Science, 28 (4), 379 - 386.

GOWER, J.E. (1977). A highway scheme appraisal method. Greater London Council, Department of Planning and Transportation. Branch Background Paper No. 59.

GREATER LONDON COUNCIL (1977). Factors affecting the location of industry. Freight Unit Report, G.L.C.

GRIGG, A.O. (1978). A review of techniques for scaling subjective judgements. Transport and Road Research Laboratory, Report SR.379.UC.

GRIGG, A.O. (1981). Rating scales - measures of central tendency and sample size. Transport and Road Research Laboratory, Report SR.647.

GUIGOU, J.L. (1971). 'On French location models for production units.' Regional and Urban Economics, 1 (2), 107 - 138, and 1 (3), 289 - 316.

GWILLIAM, K.M. (1970). 'The indirect effects of highway investment'. Regional Studies, 4 (2), 167 - 176.

GWILLIAM, K.M. and MACKIE, P.J. (1975). Economics and transport policy. George Allen and Unwin, London.

HAGGETT, P. and CHORLEY, R.J. (1969). Network analysis in geography. Methuen, London.

HALL, A.D. (1962). A methodology for systems engineering. D. van Nostrand Inc., New Jersey.

HAMILTON, T.D. (1980). Evaluation of public transport strategies in the T.P.P. Paper presented at conference upon Evaluation in the T.P.P. process. University of Aston in Birmingham.

HAMPSHIRE COUNTY COUNCIL (1980). _Transport Policies and Programme_.

HARMAN, H. (1960). _Modern factor analysis_. University of Chicago Press, Chicago.

HARRISON, A.J. and HOLTERMAN, S.E. (1973). _Economic appraisal of transport projects and urban planning objectives_. Centre for Environmental Studies, Urban Economics Conference, University of Keele.

HARVEY, D. (1969). _Explanation in geography_. Edward Arnold, London.

HARVEY, D. (1973). _Social justice and the city_. Edward Arnold, London.

HAVEMAN, R. (1977). 'The economic evaluation of long run uncertainties'. _Futures_, 95 (5), 365 - 374.

HEADICAR, P. (1979). _Priority assessment in the T.P.P._ Paper presented at T.P.P. Evaluation Meeting, University of Aston in Birmingham.

HOACHLANDER, E.G. (1979). _Equity issues in the development of Bay Area Rapid Transit; who pays and who benefits?_ Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

HODGINS, H. (1976). _The evaluation of environmental quality; a method of predicting the environmental effects of urban traffic_. PhD Thesis, University of Aston in Birmingham.

HOUGHTON, T. (1974). _Some theoretical aspects of evaluation and their application to plan-making_. Paper presented at Land-Use and Built Form Studies Conference, University of Reading.

HUBBARD, R. (1978). 'The probable consequences of violating the
normality assumption in parametric statistical analysis.
Area, 10, 393 - 398.

HULL, J.C., MOORE, P.G. and THOMAS, H. (1973). 'Utility and its
measurement'. Journal of the Royal Statistical
Society, Series A, 136 (2), 226 - 247.

HUTCHINSON, B.G. (1970). 'Structuring urban transportation planning
decisions; available social science constructs'.
Environment and Planning, 2, 251 - 265.

HUTCHINSON, B.G. (1974). Principles of urban transport systems planning.
McCraw-Hill, Maidenhead.

JANSEN, G.R.M. and BOVY, P.H.L. (1982). The effect of network aggreg-
ation on shortest route predictions in urban road net-
works: some empirical results. Paper presented at
3rd European Colloquim on Theoretical and Quantitative
Geography, Augsburg.

JENSEN, O.H. (1976). Evaluation of public transportation. Institute
of Mathematical Statistics and Operational Research,
Technical University, Denmark.

JOHNSON, M. (1978). Preparing the T.P.P. The next step. Unpublished
note, University of Aston in Birmingham.

JOINT UNIT FOR RESEARCH ON THE URBAN ENVIRONMENT (1975). Lorry route
proposals: some local planning examples. J.U.R.U.E.,
University of Aston in Birmingham.

JOINT UNIT FOR RESEARCH ON THE URBAN ENVIRONMENT (1976). Environmental
policy and the Heavy Goods Vehicle: a study on behalf
of the Department of the Environment. J.U.R.U.E.,

University of Aston in Birmingham.

JOINT UNIT FOR RESEARCH ON THE URBAN ENVIRONMENT (1976). Conceptual frameworks for environmental evaluation and research. J.U.R.U.E., University of Aston in Birmingham.

JOINT UNIT FOR RESEARCH ON THE URBAN ENVIRONMENT (1977). The Environmental impact of transport in the West Midlands Metropolitan Counties, Volume 1 - A Survey. J.U.R.U.E., University of Aston in Birmingham.

KAIN, J.F. and QUIGLEY, J.M. (1970). 'Evaluating the quality of the residential environment'. Environment and Planning, 2, 23 - 32.

KAPLAN, A. (1964). The conduct of inquiry. Chandler, San Francisco.

KEENEY, R. and RAIFFA, H. (1976). Decisions with multiple objectives; preferences and value trade offs. Wiley, New York.

KITCHEN, T. (1972). 'The general and coarse evaluation of alternatives in regional planning'. Journal of Royal Town Planning Institute, 58 (1), 8 - 12.

KNIGHT, F.H. (1921). Risk, uncertainty and profit. University of Chicago Press, Chicago.

KOZLOWSKI, J. (1968). 'Threshold theory and the sub-regional plan'. Town Planning Review, 39, 99 - 116.

KOZLOWSKI, J. (1970). 'Optimisation method - a case for research'. Journal of Royal Town Planning Institute, 56, 134 - 137.

KOZLOWSKI, J. and HUGHES, J.T. (1967). 'Urban threshold theory and analysis'. Journal of Royal Town Planning Institute, 53 (2), 55 - 60.

KOZLOWSKI, J. and HUGHES, J.T. (1971). Threshold analysis; theoretical
background, evaluation, development. Planning
Research Unit, Department of Urban Design and Regional
Planning, University of Edinburgh.

LAIDLAW, C.D. (1972). Linear programming for urban plan evaluation.
Praegar; New York.

LAWLEY, D.N. and MAXWELL, A.E. (1963). Factor analysis as a statistical
method. Butterworths; London.

LAYARD, R. (ed.) (1974). Cost-benefit analysis. Penguin Modern
Economics, London.

LEATHERS, N.J. (1967). 'Residential location and mode of transportation
to work; a model of choice'. Transportation Research,
1, 129 - 155.

LEES, A.M. (1978). 'Relationship of road strategy to economic develop-
ments and industry in Merseyside'. The Highway
Engineer, 25, 8 - 9.

LICHFIELD, N. (1970). 'Evaluation methodology of urban and regional
plans; a review'. Regional Studies, 4, 151 - 165.

LICHFIELD, N., KETTLE, P. and WHITBREAD, M. (1975). Evaluation in the
planning process. Pergamon, Oxford.

LIN, S. (1975). 'Heuristic programming as an aid to network design'.
Networks, 5, 33 - 43.

LIN, F.B. and HOEL, L.A. (1977). 'Structure of utility based evalua-
tion approaches'. A.S.C.E. Transportation Journal,
103, 307 - 320.

LITTLE, I.M.D. (1958). A critique of welfare economics. Oxford

University Press, Oxford.

LONDON TRANSPORTATION SURVEY (1962). Report, London County Council, London.

MACKIE, P.J. and GARTON, P.M. (1979). The financing of local transport. Institute of Transportation, University of Leeds.

MACKIE, S. and KING, A. (1974). 'Managing uncertainty in plan evaluation'. The Planner, 898 - 900.

MACKINDER, I.H. (1979). The predictive accuracy of British transport studies - a feasibility study. Transport & Road Research Laboratory, Report SR.483, Crowthorne, Berkshire.

MACKINDER, I.H. and EVANS, S.E. (1981). The predictive accuracy of British transport studies in urban areas. Transport and Road Research Laboratory, Report SR.699, Crowthorne, Berkshire.

MACKINNON, R.D. and HODGSON, M.J. (1970). 'Optimal transportation networks; a case study of highway systems'. Environment and Planning, 2, 267 - 284.

M.A.R.C.H. (1977). M.A.R.C.H. Highway Maintenance System. Engineering Manual. The M.A.R.C.H. Group.

MARTIN, B.V. (1977). An introduction to the West Yorkshire Transportation Study. Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

MASSAM, B.H. (1978). 'The search for the best alternative using multiple criteria; Singapore Transit Study'. Economic Geography, 54, 245 - 253.

MASSAM, B.H. (1980). Spatial search. Application to planning problems in the public sector. Pergamon, Oxford.

MATHER, P.M. (1971). 'Varimax and generality'. Area, 3, 252 - 259.

MEAD, K.C. (1973). Resource allocation and the system planning process. Highway Research Record, No. 467. Transportation Systems Planning and Resource Allocation, Highway Research Board, 38 - 51.

MEYERSON, M. and BANFIELD, E.C. (1955). Politics planning and the public interest. Free Press, Glencoe, Illinois.

MISHAN, E.J. (1960). 'Survey of welfare economics, 1939 - 1959'. Economic Journal, 70, 197 - 265.

MISHAN, E.J. (1971). Cost-benefit analysis. An informal introduction. Allen and Unwin, London.

MISHAN, E.J. (1982). 'The new controversy about the rationale of economic evaluation'. Journal of Economic Issues, XVI(I), 29 - 47.

MORRISON, D.G. (1967). Multivariate statistical methods. McGraw-Hill, New York.

MOSER, C.A. and SCOTT, W. (1961). British towns. Oliver and Boyd, Edinburgh.

MOSS, G.J. (1979). Developing techniques for urban transport project evaluation. Paper presented at conference upon Transport Evaluation Planning, Adelaide, Australia.

NEEDHAM, B. (1971). 'Concrete problems, not abstract goals'. Journal of Royal Town Planning Institute, 57, 317 - 319.

NEFZGER, M.D. and DRASGOW, J. (1957). 'The needless assumption of
normality in Pearson's R'. American Psychologist,
12, 623 - 625.

NEWTON, J.K. (1981). 'Computer modelling for project evaluation'.
Omega, 9 (3), 281 - 286.

NIE, N.H., BENT, D.H. and HULL, C.H. (1970). Statistical Package for
the Social Sciences. McGraw Hill, New York.

NIJKAMP, P. (1975). 'A multi-criteria analysis for project evaluation'.
Papers of the Regional Science Association, 35,
87 - 111.

NIJKAMP, P. (1977). 'Stochastic quantitative and qualitative multi-
criteria analysis for environmental design. Papers
of the Regional Science Association, 39, 175 - 199.

NIJKAMP, P. (1979). Multi-dimensional spatial data and decision
analysis. John Wiley, Chichester.

NIJKAMP, P. (1980). 'Energy problems and regional development.
Editorial note'. Regional Science and Urban Economics,
10, 299 - 301.

NIJKAMP, P. (1982). 'Soft econometric models; an analysis of regional
income determinants'. Regional Studies, 16,
121 - 128.

NUNALLY, J.C. (1967). Psychometric theory. McGraw Hill, New York.

NYSDOT (1980). Surcts Highway Condition Analysis Methodology. New
York State Department of Transportation.

OCHOJNA, S. (1979). The appraisal of capital investment proposals; the Greater Glasgow P.T.E. experience. Paper presented at Meeting of the P.T.E. Evaluation and Forecasting Group, University of Aston in Birmingham.

O'FLAHERTY, C.A. (1974). Highways. Edward Arnold, Leeds. 2nd ed.

OLDER, S.J. and SHIPPEY, J. (eds.) (1980). Proceedings of the 2nd International Traffic Conflicts Technique Workshop. Transport and Road Research Laboratory, Report SR.557, Crowthorne, Berkshire.

O'LEARY, T. (1979). 'The cost/benefit analysis. It can be a misleading tool for transportation planners'. Transportation Planning and Technology, 5, 189 - 193.

PAELINCK, J.H.P. and NIJKAMP, P. (1976). Operational theory and method in regional economics. Saxon House, Farnborough.

PARKER, M. (1978). 'Structure planning - its future role'. The Surveyor, 2/2/1978, 153.

PARKINSON, M. (1981). The effect of road investment on economic development in the U.K. Government Economic Service Working Paper No. 43. Department of Transport.

PATTERSON, N.S. and MAY, A.D. (1980). The impact of transport problems on inner city firms - results of a pilot study. Paper presented at U.T.S.G. Conference, University of Newcastle upon Tyne.

PEARMAN, A.D. (1979). Comparing road and rail investment using a multiple criteria investment. Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

PERRATON, J. (1974). The process of evaluation. Paper presented at the Land Use and Built Form Studies Conference, University of Reading.

PERRETT, K. (1977). The T.R.A.M.S. Methodology used in Merseyside and its extension to other United Kingdom local authorities. Paper presented at 6th European Urban Data Management Symposium, Liege, Belgium.

PHILLIPS, G. (1979). Efficiency and accuracy of traffic sampling procedures. Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

PIGOU, A.C. (1932). The economics of welfare. Macmillan, London.

POOLE, M.A. and O'FARRELL, P.N. (1974). 'The assumptions of the linear regression model'. Transactions of the Institute of British Geographers, 52, 145 - 158.

POULIQUEN, L.Y. (1970). Risk analysis in project appraisal. World Bank Staff Occasional Paper No. 11.

PREST, A.R. and TURVEY, R. (1965). 'Cost-benefit analysis - a review'. Economic Journal, 75, 685 - 705.

PRESTON, V. (1982). 'A multidimensional scaling analysis of individual differences in residential area evaluation'. Geografiska Annaler, 64 (1), 17 - 26.

QUARMBY, D.A. (1977). The contribution of economic research to transport policy decisions. Topic 3. Choice of investment priorities. Practical aspects. Paper presented at the 7th International symposium on Theory and Practice in Transport Economics, London.

RAIFFA, H. (1970). _Preferences for multi-attributed alternatives._ Memo. Rm-5868-DOTRC, Rand Corporation, Santa Monica, Calif.

REUTLINGER, S. (1970). _Techniques for project appraisal under uncertainty._ World Bank Staff Occasional Paper No. 10.

RICHMOND, T. (1982). _Assessing priorities; the Nottinghamshire approach._ Paper presented at conference on 'Evaluation in the T.P.P. process'. University of Aston in Birmingham.

RIVETT, B.H.P. (1977). 'Multidimension scaling for multi-objective policies'. _Omega_, 5 (4), 367 - 379.

RIVETT, B.H.P. (1978). 'Structural mapping applied to single value policies'. _Omega_, 6 (5), 407 - 417.

RIVETT, B.H.P. (1980). 'Indifference mapping for multiple criteria decisions'. _Omega_, 8 (1), 81 - 93.

ROBINSON, C. (1978). _A comparison of actual and predicted traffic flows from the W.M.T.S._ Unpublished paper. Joint Unit for Research on the Urban Environment, University of Aston in Birmingham.

ROE, M.S. (1978). _The efficiency of automatic traffic counters - an example of Camden._ Unpublished Note. Greater London Council.

ROE, M.S. (1979). _Pilot Studies of the Use of factors to extrapolate traffic data._ Unpublished Note. West Midlands County Council.

ROE, M.S. (1980A). _Problem identification and Priority Ranking in the_

West Midlands.   J.U.R.U.E. Research Note 12, University

of Aston in Birmingham.

ROE, M.S. (1980B).   The Greater London Council Highway Scheme Appraisal

Methodology.   Unpublished Note.   J.U.R.U.E.,

University of Aston in Birmingham.

ROE, M.S. (1980C).   'Priority evaluation in T.P.P's - Methodology'.

Joint Unit for Research on the Urban Environment,

University of Aston in Birmingham.

ROE, M.S. (1981).   'A Review of current plan evaluation techniques used

for T.P.P. preparation purposes'.   Joint Unit for

Research on the Urban Environment, University of Aston

in Birmingham.

ROE, M.S. and JOHNSON, M. (1979).   Multi-criteria approaches to plan

evaluation.   Unpublished Note.   J.U.R.U.E., University

of Aston in Birmingham.

ROFF, A. (1977).   'The importance of being normal'.   Area, 9, 195 - 198.

ROY, B. (1972)   'Decisions avec criteres multiples'.   Metra, 11 (2),

121 - 151.

ROY, B. and HUGONNARD, J.C. (1982).   'Ranking of suburban line exten-

sion projects on the Paris Metro System by a multi-

criteria method'.   Transportation Research A, 164 (4),

301 - 312.

RUMMEL, R.J. (1967).   'Understanding factor analysis'.   Journal of

Conflict Resolution, XI (4), 444 - 480.

RUMMEL, R.J. (1970).   Applied Factor analysis.   Northwestern University

Press, Evanston.

RUNCIMAN, W.G. (1966). _Relative deprivation and social justice._
Routledge and Keegan Paul, London.

SAATY, T.L. (1977A). 'Scenarios and priorities in transport planning;
application to the Sudan'. _Transportation Research,_
11, 343 - 350.

SAATY, T.L. (1977B). 'A scaling method for priorities in hierarchical
structures'. _Journal of Mathematical Psychology,_ 15,
234 - 281.

S.A.C.T.R.A. (1979). _Trunk road appraisal - a comprehensive framework
for appraisal._ H.M.S.O., London.

SAGNER, J.S. and BARRINGER, R.L. (1978). 'Toward criteria in the
development of urban transportation systems'.
Transportation, 7, 87 - 96.

SALTER, R.J. (1976). _Highway traffic analysis and design._ Macmillan,
London.

SCHIMPELER, C.C. and GRECCO, W.L. (1968). _The community systems evalua-
tion. An approach based upon community structures and
values._ Highway Research Record 238. Highway Research
Board, Washington D.C., 123 - 152.

SCHLAGER, K. (1968). _The rank based expected value method of plan
evaluation._ Highway Research Record 238. Highway
Research Board, Washington D.C.

SELF, P. (1975) _Econocrats in the policy process; the politics and
philosophy of cost-benefit analysis._ Macmillan,
London.

SHALAL, L.A.Y. and KHAN, A.M. (1982). 'A decision theoretic framework for urban transport design and investment decisions'. Transportation Quarterly, XXXVI (2), 283 - 299.

SIMPSON, B. (1977). 'Some theoretical developments on threshold analysis and testing'. Urban Studies, 14, 79 - 88.

SINGLETON, D.S. (1981). 'Monitoring and evaluating road safety programmes in the T.P.P. process', in A.G. Bovaird (1981) 'Evaluation in the T.P.P. process'. University of Aston in Birmingham.

SKEWIS, W.I. (1979). Transport and regional development. Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

SKINNER, R.J. (1980). 'Bus planning methods. 1 : project evaluation'. Traffic Engineering and Control, 21, 415 - 419.

SMITH, C. (1982). Assessing priorities; the Bedfordshire approach. Paper presented at conference on 'Evaluations in the T.P.P. process', University of Aston in Birmingham.

SOUTH YORKSHIRE COUNTY COUNCIL (1980). Transport policies and programme.

STANLEY, J.K. (1974). 'A cardinal utility approach for project evaluation'. Socio-economic Planning Sciences, 8 (6), 329 - 338.

STARKIE, D.N.M. (1976). Transportation planning policy and analysis. Pergamon, Oxford.

STARKIE, D.N.M. (1979). 'Allocation of investment to inter-urban road and rail'. Regional Studies, 13, 323 - 336.

STEVENS, S.S. (1959). 'Measurement, psychophysics and utility', in

    Churchman, C.W. and Ratoosh, P. (eds.).

STEWART, T.J. (1981). 'A descriptive approach to multiple-criteria

    decision-making'. Journal of the Operational Research

    Society, 32, 47 - 53.

STUART, D.G. (1974). 'Interactive sensitivity analysis in transport-

    ation plan evaluation'. Transportation, 3, 289 - 310.

SYRNICK, J.R. and HARVEY, T.N. (1977). 'Assessing the distribution of

    user benefits from proposed transportation investments'.

    Transportation Engineering, 29 - 36.

TEITZ, M.B. (1968). 'Cost effectiveness; a systems approach to

    analysis of urban services'. Journal of the American

    Institute of Planners, XXXIV, 303 - 310.

THEIL, H. (1967). Economics and information theory. North Holland

    Publishing Company, Amsterdam.

THOMSON, J.M. (1967). 'Speeds and flows of traffic in central London'.

    Traffic Engineering and Control, 8, 721 - 725.

THOMPSON, W.R. (1965). Preface to urban economics. John Hopkins

    University Press, Baltimore.

TORGERSEN, W.R. (1963). Theory and methods of scaling. Wiley, New

    York.

TREDDENICK, J.M. (1979). 'Cost effectiveness in defence expenditure'.

    Omega, 7 (5), 459 - 469.

VAN DELFT, A. and NIJKAMP, P. (1976). 'A multi objective decision model

    for regional development, environmental quality con-

    trol and industrial land use'. Papers and proceedings

of the Regional Science Association, 36, 15 - 37.

WALLER, R.A. (1973). Evaluation of the impact of new roads. Paper
presented at the P.T.R.C. Seminar on Urban Traffic
Model Research, London.

WARDROP, J.G. (1968). 'Journey speeds and flow in central urban areas'.
Traffic Engineering and Control, 9, 528 - 532.

WATERS II, W.G., VYERO, D.H. and KEAST, T.G. (1982). 'Evaluation of
railroad operation and financing'. Omega, 10 (3),
279 - 291.

WEISBROD, B.A. (1968). Income redistribution effects and benefit-cost
analysis, in S.B. Chase (ed.) 'Problems in public
expenditure analysis'. Brockings Institution,
177 - 209.

WEST MIDLANDS COUNTY COUNCIL (1979). Transport policies and programme,
W.M.C.C.

WEST MIDLANDS COUNTY COUNCIL (1980). Transport policies and programme.
W.M.C.C.

WEST MIDLANDS MINOR WORKS TEAM (1980). The evaluation of highway main-
tenance requirements. Unpublished Note.

WEST SUSSEX COUNTY COUNCIL (1981). The evaluation of highway improve-
ments. Unpublished Note.

WILLIAMS, P.K. (1977). The T.R.A.M.S. report. Working Paper.
C.S.I.R.U., Planning Department, West Midlands County
Council.

WILSON, A.G., BAYLISS, D., BLACKBURN, A.J. and HUTCHINSON, B.G. (1969).
New directions in strategic transportation planning.
Centre for Environmental Studies, Working Paper

CES.WP.36, London.

WOOTTON JEFFREYS (1979).   T.R.A.M.P.   Wootton Jeffreys, Farnborough.

WYTCONSULT (1976).   Issues, objectives, measures, standards.   West

Yorkshire Transportation Study, Document 104.   West

Yorkshire County Council, Wakefield.

ZELENY, M. (1974).Linear, multi-objective programming.   Springer

Verlag, Berlin.

ADDITIONAL REFERENCES

ABELSON, P. (1979).   Cost-benefit analysis and environmental problems.

Saxon House, Farnborough.

ACKOFF, R.L. and VERGARA, E. (1981).   'Creativity in problem solving and

planning; a review'.   European Journal of Operational

Research, 7, 1 - 13.

ADLER, H.A. (1971).   Economic appraisal of transport projects.

University of Indiana Press, Bloomington.

ALONSO, W. (1968).   'Predicting best with imperfect data'.   Journal of

the American Institute of Planners, XXXIV, 248 - 255.

ALTSHULER, A. (1965).   'The goals of comprehensive planning'.   Journal

of the American Institute of Planners, XXXI, 186 - 195.

ANDERSON, C.M.B. (1971).   The measurement of attitude to noise and

noises.   National Physical Laboratory Acoustics

Report, AC.52, London.

APPLEYARD, D. and LINTELL, M. (1970).   Environmental quality of city

streets.   Working Paper 142.   University of

Berkeley, California.

APT, C.C. (ed.) (1976).   The evaluation of social programs.   Sage,

California.

ARROW, K.J. (1951).   Social choice and individual values.   Wiley, New

York.

BAMFORD, T.J.G. and WIGAN, M.R. (1974). The effects on transport benefit calculation of user misconception of costs. Transport and Road Research Laboratory, Report SR23UC. Crowthorne, Berkshire.

BANKS, R.L. and KOTZ, A. (1966). 'The program budget and the interest rate for public investment'. Public Administration Review, 26, 283 - 292.

BARRAS, R. (1977). Local authority resource allocation: analysis and and modelling. P.R.A.G. Technical Paper, TP17. Centre for Environmental Studies, London.

BARRAS, R. and BROADBENT, T.A. (1973). The development of an activity-commodity representation of urban systems as a potential framework for evaluation. Centre for Environmental Studies. Research Paper RP2, London.

BARRELL, D. (1970). Cost-benefit analysis in transportation planning. Oxford Polytechnic, Oxford.

BARTLETT, C.J., HERMANN, E. and RETTIG, S. (1960). 'A comparison of six different scaling techniques'. Journal of Social Psychology, 51, 343 - 348.

BATEY, P. and BROWN, P. (1980). Multi-objective planning. Unpublished report. Department of Civic Design, University of Liverpool.

BAYLISS, D. (1974). T.P.P's in Metropolitan planning. Paper presented at P.T.R.C. Summer Annual Meeting, University of Warwick.

BEESLEY, M.E. (1973). Urban transport: studies in economic policy. Butterworth, London.

BEESLEY, M.E. and KAIN, J.F. (1964). 'Urban form, car ownership and
public policy; an appraisal of "Traffic in Towns".
Urban Studies, 1 (2), 174 - 203.

BEETHAM, A. (1976). 'T.P.P's - review and prospect from a public
transport viewpoint'. Transport, 37 (7), 190.

BELL, D.E., KEENEY, R.L. and RAIFFA, H. (1977). Conflicting objectives
in decisions. Wiley, New York.

BELLMAN, R.E. and ZADEH, L.A. (1970). 'Decision-making in a fuzzy
environment'. Management Science, 17 (4), 141 - 164.

BEN-SHAHAR, H., MAZOR, A. and PINES, D. (1969). 'Town planning and
welfare maximisation; a methodological approach'.
Regional Studies, 3, 105 - 113.

BERRY, B.J.L. (1971). 'The logic and limitations of comparative
factorial ecology'. Economic Geography, 47 (2),
209 - 219.

BETTISON, G. (1979). Total programme analysis for the justification
and budgetting of capital investment in transport.
Paper presented at Session 7, Australian Transport
Research Forum, Sydney.

BISHOP, D. (1976). Forum on T.P.P. indicators - an introduction to a
discussion of transport indicators'. Paper presented
at Session III, 9th Symposium, on the Future of Con-
urbation Transport, London.

BONSALL, P.W., DALVI, M.Q. and HILLS, P.J. (eds.) (1977). Urban
transportation planning. Abacus, Tunbridge Wells.

BORINS, S.F. (1981). 'The effect of pricing policy on the optimal

timing of investments in transport facilities'.

Journal of Transport Economics and Policy, 15, 121 - 183.

BOYCE, D.E., DAY, N.D. and McDONALD, C. (1972).   Metropolitan plan

making; an analysis of experience with the preparation

and evaluation of alternative land use and transport-

ation plans.   Philadelphia Regional Science Research

Institute, Monograph Series No. 4.   University of

Pennsylvania.

BRANCH, M.C. and ROBINSON, I.M. (1967).   'Goals and objectives in civil

comprehensive planning'.   Town Planning Review, 38,

261 - 274.

BREEN, F.L. and COVAULT, D.O. (1976).   'Priority analysis and ranking

of highway improvement projects'.   Traffic

Quarterly, 30, 615 - 632.

BRIDLE, R.J. (1977).   'The cash value of traffic changes upon the

environment'.   The Highway Engineer, XXIV (6), 18 - 24.

BRIERLEY, R.F. and COPLEY, G. (1981).   'Traffic modelling for highway

appraisal; the A27 Worthing/Lancing study'.

Traffic Engineering and Control, 22, 622 - 628.

BROADBENT, T.A. (1970).   'An activity analysis framework for urban

planning'.   Centre for Environmental Studies Working

Paper WP.61.   London.

BROADBENT, T.A. (1973).   'Activity analysis of spatial allocation

models.'   Environment and Planning, 5 (6).

BRUSER, A. (1979).   Difficulties encountered in the economic evaluation

of road projects in developing countries and outline

of practicable solutions. Paper presented at P.T.R.C.
Summer Annual Meeting, University of Warwick.

BRUTON, M.J. (1975). An introduction to transportation planning.
Hutchinson, London. 2nd ed.

BUCHANAN, J. (1971). 'Evaluation of housing stock and its environment'.
Journal of the Royal Town Planning Institute, 57 (8),
372 - 375.

BURT, C. (1953). 'Scale analysis and factor analysis'. British Journal
of Statistical Psychology, VI (1), 5 - 21.

BUTT, R.B. (1972). 'Planning, programming, budgetting systems and
transportation'. Journal of the Institution of
Highway Engineers, XIX, 21 - 26.

CAPRON, W.M. (1966). 'P.P.B. and state budgetting'. Public Adminis-
tration Review, 26, 155 - 159.

CARLEY, M. (1980). Rational techniques in policy analysis. Heinemann,
London.

CARO, F.G. (1969). 'Approaches to evaluative research; a review'.
Human Organisation, 28 (2), 87 - 98.

CARTER, E.C., HALL, J.W. and HAEFNER, L.E. (1973). Incorporating
environmental impacts in the transportation system
evaluation process. Highway Research Record No. 467.
Transportation Research Board, Washington D.C.

CATTELL, R.B. (1952). Factor analysis. Greenwood Press, Westport,
Conn.

CATTELL, R.B. (1965). 'Factor analysis; an introduction to essentials'. Biometrics, 21, 190 - 215.

CHARLESWORTH, G. and PAISLEY, J.L. (1959). 'The economic assessment of the returns from road works'. Procs. of the Institution of Civil Engineers, 14, 229 - 254.

CHARLTON, J.R.H. (1977). Evaluation and ranking of highway schemes. Greater London Council, Department of Planning and Transportation. Technical Studies Note TSN.164.

CHEESMAN, R. (1974). The place for evaluation in the planning design process. Paper presented at the Land Use and Built Form Studies Conference, Reading.

CHILD, D. (1970). The essentials of factor analysis. Holt, Rinehart and Winston, London.

CHMARA, E. and LANGLEY, P.E. (1973). Evaluation matrices for structure plans. Department of the Environment, London.

CHURCHMAN, W.C. and ACKOFF, R.L. (1954). 'An approximate measure of value'. Journal of the Operational Research Society of America, 2 (2).

CHURCHMAN, W.C. and SCHAINBLATT, (1969). 'P.P.B.; how can it be implemented?' Public Administration Review, 26, 178 - 189.

C.I.P.F.A. (1976). T.P.P's - the new planning approach. Chartered Institute of Public Finance and Accountancy. Occasional Paper 5/76.

C.I.P.F.A. (1979).   Assessment of priorities.   Chartered Institute of
        Public Finance and Accountancy.   Occasional Paper 1/79.

CLARK, R.F. (1979).   'The proverbs of evaluation; perspectives from
        C.S.A's experience'.   Public Administration Review,
        36, 562 - 566.

COCHRANE, J.L. and ZELENY, M. (eds.) (1973).   Multiple criteria
        decision-making.   Univeristy of South Carolina Press,
        Columbia.

COHON, J.L. and MARKS, D.H. (1975).   'A review and evaluation of
        multi-objective programming techniques'.   Water
        Resources Research, 11 (2), 208 - 220.

COLEMAN, J.S. (1957).   'Multidimensional scale analysis'.   American
        Journal of Sociology, LXIII (3), 253 - 263.

COLLINS, M.S. (1962).   'Determining the merits of road improvements'.
        Traffic Engineering and Control, 3, 208 - 211.

COOLEY, W.W. and LOHNES, P.R. (1964).   Multivariate procedures for the
        behavioral sciences.
        New York.

COOPER, J.B. (1973).   Transport policies and programmes; a local
        authority viewpoint.   Paper presented at P.T.R.C.
        Summer Annual Meeting, University of Warwick.

DAHL, R.A. and LINDBLOM, C.E. (1976).   Politics, economics and welfare.
          University of Chicago Press, Chicago.

DAS, M. (1978).   The collection and dissemination of transport inform-
          ation in a local authority.   Transport and Road
          Research Laboratory, Report LR.815.   Crowthorne,
          Berkshire.

DAVIDOFF, P. and REINER, T.A. (1962).   'A choice theory of planning'.
          Journal of the American Institute of Planners, XXVII,
          103 - 115.

DAWSON, R.F.F. (1968).   The economic assessment of road improvement
          schemes.   Road Research Technical Paper No. 75.
          Ministry of Transport, London.

DEARLOVE, J. (1973).   Political policy in local government.   Cambridge
          University Press, Cambridge.

DICKEY, J.W. (1975).   Metropolitan transportation planning.   McGraw-
          Hill, Washington D.C.

DODGSON, J.S. (1974).   'Motorway investment and sub-regional growth; a
          case study of the M62'.   Regional Studies, 8, 75 - 90.

DONNELLY, E.P., HOWE, S.M. and DESCHAMPS, J.A. (1976).   Trade off
          analysis; theory and applications to transportation
          policy planning.   Planning Research Unit, New York
          State Department of Transportation.   Preliminary
          Research Report 103.

DOWALL, D.E. and JUHASZ, J.B. (1978).   'Trade off surveys in planning;
          theory and application'.   Environment and Planning A,
          10, 125 - 136.

DROR, Y. (1968). Public policy making re-examined. Chandler, Scranton.

DROR, Y. (1971). Design for policy sciences. Elsevier, New York.

DROR, Y. (1971). Ventures in policy sciences; concepts and appli-

cations. Elsevier, New York.

DULANSEY, M.L. (ed.) (1978). Approaches to appropriate evaluation.

American Council of Voluntary Agencies for Foreign

Service Inc., New York.

DYER, J.S. (1972). 'Interactive goal programming'. Management

Sciences, 19 (1), 62 - 70.

EDWARDS, W. (1954). 'The theory of decision-making'. Psychological

Bulletin, 51 (4), 380 - 417.

EINHORN, H.J. and McCOACH, W. (1977). 'A simple multivariate procedure

for evaluation'. Behavioural Science, 22, 270 - 282.

EVANS, H.K. (1968). 'Economic studies for highways'. Traffic

Quarterly, 22 (4), 479 - 495.

FELDSTEIN, M.S. (1970). 'Health sector planning in developing

countries'. Economica, 37 (146), 139 - 163.

FERREIRA, L.J.A., STANWAY, R.A. and GREEN, M.J. (1980). 'Strategic planning in the Johannesberg Metropolitan (JOMET) Area'. Traffic Engineering and Control, 21, 377 - 383.

FILLEY, A.C. (1975). Interpersonal conflict resolution. Scott, Foresman and Co., Glenview, Illinois.

FISHBURN, P.C. (1967). 'Methods of estimating additative utilities'. Management Science, 13 (7), 435 - 453.

FISCHOFF, B. (1977). 'Cost-benefit analysis and the art of motor-cycle maintenance'. Policy Sciences, 8, 177 - 202.

FOSTER, C.D. and BEESLEY, M.E. (1963). 'Estimating the social benefit of constructing an underground railway in London'. Journal of the Royal Statistical Society, 126 (1), 46 - 92.

FRANKLIN, W.D. (1968). 'Benefit-cost analysis in transportation; the economic rationale of resource allocation'. Traffic Quarterly, 22 (1), 69 - 76.

FRIEDMANN, J. (1965). 'Comprehensive planning as a process'. Journal of the American Institute of Planners, 31, 195 - 197.

FRIEDMANN, J. (1967). 'A conceptual model for the analysis of planning behaviour'. Administrative Science Quarterly, 12, 225 - 252.

FRIEND, J.K. and JESSOP, W.N. (1969). Local government and strategic choice. Pergamon, Oxford.

GALLAGHER, W.E. (1981). Recent developments in trunk road assessments
and the preparation of the Traffic Appraisal Manual.
Paper presented at P.T.R.C. Summer Annual Meeting,
University of Warwick.

GAMBLE, H.B. (1974). Adverse and beneficial effects of highways on
residential property values. Transportation Research
Record 508. Transportation Research Board,
Washington D.C.

GEARY, K. (1977). Local authority resource allocation with multiple
objectives. An education example. P.R.A.G. Technical
Paper TP.21, London.

GLASS, G.V. (ed.) (1976). Evaluation studies review annual, Volume 1.
Sage, Beverley Hills.

GODDARD, J. and KIRBY, A. (1976). An introduction to factor analysis.
Concepts and techniques in modern geography. No. 7.
Study Group in Quantitative Methods of the Institute
of British Geographers, London.

GORDON, P. and NEIDERCOM, J.H. (1978). 'A procedure for fully evalua-
ting the anticipated impacts of selected public system
innovations on various environments using citizen
generated information inputs'. Socio-econ. Plan.
Sci., 12, 77 - 83.

GOULD, P.R. (1967). 'On the geographical interpretation of Eigenvalues'.
Transactions of the Institute of British Geographers,
42, 53 - 86.

GREENHOUSE, S.M. (1966). 'The planning, programming, budgetting system.
Rationale, language and idea-relationships'. Public

Administration Review, 26, 271 - 277.

GREGG, P.M. and BANKS, A.S. (1965).   'Dimensions of political systems;

　　　　factor analysis of a cross-policy survey'.   American

　　　　Political Science Review, 59, 602 - 614.

GROSS, B.M. (1969).   'The new systems budgetting'.   Public Adminis-

　　　　tration Review, 29, 113 - 137.

GULBRANDSEN, O. (1967).   'Optimal priority rating of resources -

　　　　allocation by dynamic programming'.   Transportation

　　　　Science, 1 (4), 251 - 260.

GUTTMAN, L. (1953).   'A note on Sir Cyril Burt's "Factorial analysis

　　　　of qualitative data"'.   British Journal of

　　　　Statistical Psychology, VI (1), 1 - 4.

GWILLIAM, K.M. (1972).   'Economic evaluation of urban transportation

　　　　projects - the state of the art'.   Transportation

　　　　Planning and Technology, 1.

GWILLIAM, K.M. (1976).   'Appraising local transport policy;   the new

　　　　regime'.   Town Planning Review, 47 (1), 26 - 42.

GWILLIAM, K.M. and NASH, C.A. (1972).   'Evaluation of urban road

　　　　investments - a comment'.   Applied Economics, 4,

　　　　307 - 315.

GWILLIAM, K.M. and NASH, C.A. (1972).   'The evaluation of urban road

　　　　investments - a rejoinder'.   Applied Economics, 4, 321.

GWILLIAM, K.M., PETRICCIONE, S., VOIGT, F. and ZIGHERA, J.A. (1973).

　　　　Coordination of investments in transport infrastruc-

　　　　tures.   Commission of the European Communities.

　　　　Transport Series No. 3, Brussels.

HAFKAMP, W. and NIJKAMP, P. (1981). 'Multi-objective modelling for economic-environmental policies'. Environment and Planning A, 13, 7 - 18.

HALLOWS, D. (1975). 'T.P.P's present and future'. Municipal and Public Services Journal, 17/1/75.

HARRIS, B. (1968). 'Problems in regional science'. Papers and Proceedings of the Regional Science Association, 21, 7 - 18.

HARRIS JNR., C.C. (1974). Regional economic effects of alternative highway systems. Ballinger, Cambridge, Massachusetts.

HARRISON, A.J. (1974). The economics of transport appraisal. Croom Helm, London.

HARSANYI, J.C. (1955). 'Cardinal welfare, individualistic ethics and interpersonal comparison'. Journal of Political Economics, 63, 309 - 321.

HASTINGS, T.R. and TAPLIN, J.H.E. (1978). Transport investment in South Australia. A ten year view. University of Adelaide, Department of Economics, Occasional Paper.

HERENDEN, J.H. (1978). 'Role of economic analysis in plan selection'. American Society of Civil Engineers Transportation Journal, 104 (TE1), 55 - 68.

HILL, M. (1968). 'A goals achievement matrix in evaluating urban plans'. Journal of the American Institute of Planners, XXXIV (2), 19 - 29.

HILL, M. (1973). Planning for multiple objectives. R.S.R.I. Monograph Series 5, Philadelphia.

HILL, M.O. (1974). 'Correspondence analysis; a neglected multi-
variate method'. Applied Statistics, 23 (3),
340 - 354.

HODGE, G. (1963). 'Use and misuse of measurement scales in city plan-
ning'. Journal of the Americal Institute of Planners,
XXIX, 112 - 121.

HOINVILLE, G. (1971). 'Evaluating community preferences'. Environ-
ment and Planning, 3, 33 - 50.

HOLLOWAY, C. and KING, W.R. (1979). 'Evaluating alternative approaches
to strategic planning'. Long Range Planning, 12 (4),
74 - 78.

HOLMES, J.C. (1972). 'An ordinal method of evaluation'. Urban
Studies, 4, 179 - 191.

HOLMES, J.W. (1977). 'Traffic and the environment - cash values'.
The Highway Engineer, XXIV, 17 - 23.

HUGHES, J.T. and KOZLOWSKI, J. (1968). 'Threshold analysis - an
economic tool for town and regional planning'.
Urban Studies, 5, 132 - 143.

HUTCHINSON, B.G. (1966). 'A planning morphology for transportation
systems'. Traffic Quarterly, XX (3), 347 - 360.

HUTCHINSON, B.G. (1969). 'Structuring urban transportation decision-
making; the use of statistical decision theory'.
Environment and Planning, 1, 209 - 220.

HYDE, A.C. and SHAFRITZ, J.M. (eds.) (1979). Program evaluation in the
public sector. Praegar, New York.

ISHII, T. and TSUKIO, Y. (1979). 'A method of deciding the optimal

specification of transit systems'. Journal of

Advanced Transportation, 13 (2), 19 - 43.

JARA-DIAZ, S.R. and FRIESZ, T.L. (1982). 'Measuring the benefits

derived from a transport investment'. Transportation

Research B, 168 (1), 57 - 77.

JENKINS, P.M. (1972). 'An approach to planning in the public sector'.

Management Decision, 10, 155 - 168.

JENKINS, P.M. and ROBSON, A. (1974). 'An application of linear program-

ming methodology for regional strategy-making'.

Regional Studies, 8, 267 - 279.

JESSIMAN, W., BRAND, D., TUMMINIA, A. and BRUSSEC, C.R. (1967). A

rational decision-making technique for transportation

planning. Highway Research Record 180. Highway

Research Board, Washington D.C.

JOHNSTON, R.J. (1971). 'Some limitations of factorial ecologies and

social area analysis'. Economic Geography, 47 (2),

314 - 323.

JONES, I.S. (1977). Urban transport appraisal. Macmillan, London.

JOWETT, G.H. (1958). 'Factor analysis'. Applied Statistics, 7,

114 - 125.

KALDOR, N. (1939). 'Welfare comparisons of economics and inter-

personal comparisons of utility'. Economic Journal,

49.

KAPUR, K.C. (1970).   'Mathematical methods of optimisation for multi-

objective transportation systems'.   Socio-econ.

Planning Sci., 4, 451 - 467.

KETTLE, P. (1972).   A comparison of the planning balance sheet and the

goals achievement matrix methods of evaluation.

Planning Methodology Research Unit, Working Paper 7.

School of Environmental Studies, University College

London.

KETTLE, P. and WHITBREAD, M. (1973).   'An ordinal method of evaluation.

A comment'.   Urban Studies, 10 (1), 95 - 99.

KOELMAN, F.H.J. (1972).   'Transportation planning integrated in the

overall planning process'.   Traffic Quarterly,

XXVI (1), 55 - 70.

KOZLOWSKI, J. and HUGHES, J.T. (1972).   Threshold analysis.   A

quantitative planning method.   Architectural Press,

London.

KRAUSE, M.S. (1966).   'Ordinal scale construction for convergent

validity, object discrimination and resolving power'.

Multivariate Behavioural Research, 1, 379 - 385.

KREDITOR, A. (1967).   Industrial development and the development plan.

An Foras Forbartha, Dublin.

KRUSKALL, J.B. (1964).   'Multidimensional scaling by optimising goodness

of fit to a non-metric hypothesis'.   Psychometrika,

29, 1 - 28.

KUMM, K.I. and SODERBAUM, P. (1979).   Positional analysis in road

planning - case studies of highway E4 in the province

of Västermorrland.   Report 154.   Swedish University

LANE, J.S., GRENZEBACK, L.R. and KINGHAM, R.I. (1980).   The role of the
            do-nothing alternative in the evaluation of transport-
            ation projects.   Paper presented at P.T.R.C. Summer
            Annual Meeting, University of Warwick.

LANSING, J.B. and MARANS, R.W. (1969).   'Evaluation of neighbourhood
            quality'.   Journal of the American Institute of
            Planners, 35, 195 - 199.

LASSIERE, A. (1976).   Environmental evaluation of roads and traffic.
            Department of the Environment, London.

LEAKE, G.R. and DIX, M. (1979).   'Weighting transport objectives using
            the method of pair comparisons'.   Traffic Engineering
            and Control, 20, 246 - 252.

LEAN, W. (1969).   'An economist's note on the validity of urban threshold
            theory'.   Journal of the Royal Town Planning Institute,
            55, 311.

LEE, S.M. and MOORE, L.J. (1977).   'Multi-criteria school bussing models'.
            Management Science, 23 (7), 703 - 715.

LEMER, A.C. (1979).   Analysis in planning and programming non-urban
            highway investment.   U.S. and U.K. experience.   Paper
            presented at P.T.R.C. Summer Annual Meeting, University
            of Warwick.

L.G.O.R.U. (1973).   Better plan evaluation.   Local Government
            Operational Research Unit.

L.G.O.R.U. (1974).   Hierarchical activity allocation model.   Local
            Government Operational Research Unit, Report D.17.

L.G.O.R.U. (1975).   Which by-pass for Faringdon?   Local Government

Operational Research Unit.

L.G.O.R.U. (1976).   Development plan evaluation and robustness.

Department of the Environment Research Report 5, London.

LICHFIELD, N. (1956).   Economics of planned development.   Estates

Gazette Ltd., London.

LICHFIELD, N. (1960).   'Cost-benefit analysis in city planning'.

Journal of the American Institute of Planners, XXVI,

273 - 279.

LICHFIELD, N. (1964).   'Cost-benefit analysis in plan evaluation'.

Town Planning Review, 35, 159 - 169.

LICHFIELD, N. (1966).   'Cost-benefit analysis in urban redevelopment.

A case study - Swanley'.   Urban Studies, 3,

215 - 249.

LICHFIELD, N. (1967).   'The evaluation of capital investment projects

in town centre redevelopment'.   Public Administration,

45, 132 - 134.

LICHFIELD, N. (1968).   'Economics in town planning.   A basis for

decision-making'.   Town Planning Review, 39, 13 - 15.

LICHFIELD, N. (1969).   'Cost-benefit analysis in urban expansion.   A

case study of Peterborough'.   Regional Studies, 3,

123 - 155.

LICHFIELD, N. and CHAPMAN, H. (1968).   'Cost-benefit analysis and road

proposals for a shopping centre - a case study;

Edgware'.   Journal of Transport Economics and Policy,

2, 280 - 320.

LICHFIELD, N. and MARGOLIS, J. (1963).   Benefit-cost analysis as a

    tool in urban government decision-making.   In H.G.

    Schaller (ed.) 'Public expenditure decisions in the

    urban community'.   118 - 146.

LINDBLOM, C.E. (1959).   'The science of muddling through'.   Public

    Administration Review, 19, 79 - 88.

LINDBLOM, C.E. (1979).   'Still muddling; not yet through'.   Public

    Administration Review, 39, 517.

LOCKWOOD, S. (1974).   'Transportation planning in a changing environ-

    ment'.   Traffic Quarterly, XXVIII (4), 521 - 536.

LYDEN, F.J. and MILLER, E.G. (eds.) (1972).   Planning, programming,

    budgetting systems.   Markham, Chicago.   2nd ed.

MALISZ, B. (1969). 'Implications of threshold theory for urban and regional planning'. Journal of the Royal Town Planning Institute, 55, 108 - 110.

MAO, J.C.T. (1966). 'Efficiency in public transport urban renewal expenditure through benefit-cost analysis'. Journal of the American Institute of Planners, 32, 95 - 107.

MARGOLIS, J. (1957). 'Secondary benefits, external economies and the justification of public investment'. Review of Economics and Statistics, 39, 284 - 291.

MASSAM, B.H. and ASKEW, I.D. (1982). 'Methods for comparing policies using multiple criteria; an urban example'. Omega, 10 (2), 195 - 204.

MATALAS, N.C. and REIHER, B.J. (1967). 'Some comments on the use of factor analyses'. Water Resources Research, 3 (1), 213 - 223.

MAXWELL-STEWART, C.D. (1974). 'Environmental management. Some techniques for defining, measuring and comparing costs and benefits'. Traffic Engineering and Control, 15, 824 - 827.

McALLISTER, D.M. (1980). Evaluation in environmental planning. Massachusetts Institute of Technology Press, Cambridge.

McAUSLAN, J.P.W.B. and BEVAN, G.R. (1977). 'The influence of officers and councillors on procedures in planning - a case study'. Local Government Studies, July 1977, 7 - 21.

McBRIDE, G.A. (1970). 'Policy matters in investment decision-making'. _Regional Studies_, 4, 241 - 253.

McGUIRE, M.C. and GARN, H.A. (1969). 'The integration of equity and efficiency criteria in public project selection'. _Economic Journal_, 79, 882 - 893.

McINTOSH, P.T. and QUARMBY, D.A. (1970). _Generalised costs and the estimation of movement costs and benefits in transport planning_. Mathematics Advisory Unit Note MAU.179. Department of the Environment, London.

McLOUGHLIN, J.B. (1970). _Urban and regional planning; a systems approach_. Faber and Faber, London.

MEAD, K.C. (1973). _Resource allocation and the system planning process_. Highway Research Record 467. Transportation Systems Planning and Resource Allocation. Highway Research Board, 38 - 51.

MELINEK, S.J. (1974). 'A method of evaluating human life for economics purposes'. _Accident Analysis and Prevention_, 6, 103 - 114.

MILLS, G. (1977). 'Economic appraisal and reappraisal of an inter-urban road in Great Britain'. _Journal of Transport Economics and Policy_, 11 (1), 3 - 23.

MINAS, J.S. and ACKOFF, R.L. (1964). _Individual and collective value judgements_. John Wiley, New York.

MISHAN, E.J. (1974). 'Flexibility and consistency in project evaluation'. _Economica_, 41, 81 - 96.

MITCHELL, H.R. (1975). 'Citizen participation in transportation

decision-making'. Traffic Engineering, August 1975,
7 - 11.

MOORE, P.G. and THOMAS, H. (1976). The anatomy of decisions.
Penguin, London.

MOSHER, F.C. (1969). 'Limitations and the problems of P.P.B.S. in the
States'. Public Administration Review, March/April,
160 - 167.

MUSHKIN, S.J. (1969). 'P.P.B. in cities'. Public Administration
Review, March/April, 167 - 178.

MUSTOW, S.N. (1977). 'Value for money in public service'.
Chartered Municipal Engineer, 104, 103 - 106.

NASH, C.A. (1979). 'The use of economic appraisal in transportation
analysis'. Omega, 7 (5), 441 - 451.

NASH, C.A. (1981). 'The allocation of investment to inter-urban road
and rail - a comment'. Regional Studies, 15 (2),
143 - 144.

NASH, C.A., PEARCE, D. and STANLEY, J. (1975). 'Criteria for evalua-
ting project evaluation techniques'. Journal of
the American Institute of Planners, XLI (2), 83 - 89.

NEUBERGER, H. (1971). 'User benefit in the evaluation of transport
and land use plans'. Journal of Transport Economics
and Policy, 5, 52 - 75.

NEUBERGER, H. and WILCOX, J. (1973). Methods of evaluating land use
and transport plans. Department of the Environment,
Economics and Statistics Note, London.

DE NEUFVILLE, R. and KENNEY, R.L. (1973). 'Multi-attribute preference

analysis for transportation systems evaluation'.

Transportation Research, 7, 63 - 76.

NICHOLSON, T.H. (1971). 'Steps towards planned programme budgetting'.

Journal of the Institution of Municipal Engineers, 98,

328 - 333.

NIJKAMP, P. and RIETVELD, P. (1976). 'Multi-objective programming

models'. Regional Science and Urban Economics, 6,

253 - 274.

NIJKAMP, P. and SPRONK, J. (1981). Interactive learning models for

integrated planning. Centre for Research in Business

Economics. Department of Business Finance and Port-

folio Investment, Erasmus University of Rotterdam,

Report 8118/A.

NIJKAMP, P. and VOOGD, H. (1979). 'The use of psychometric techniques

in evaluation procedures; methodology and application'.

Papers and Proceedings of the Regional Science Assoc-

iation, 42, 119 - 138.

NOWLAN, D.M. (1975). 'The use of criteria weights in rank ordering

techniques of project evaluation'. Urban Studies,

12, 169 - 176.

O'FLAHERTY, C.A. (1974). Highways. Edward Arnold, London.

OGLESBY, C.H., BISHOP, B. and WILLEKE, G.E. (1970). <u>A method for</u>
<u>deciding among freeway locations alternatives based</u>
<u>on user and community consequences</u>. Highway
Research Record 305. Highway Research Board,
Washington D.C.

OPENSHAW, S. and WHITEHEAD, P.T. (1977). 'Decision-making in local
plans'. <u>Town Planning Review</u>, 48, 29 - 41.

ORR, W., HARTZ, M. and COSLEY, B. (1974). 'An exploratory study in
strategic monitoring'. <u>Progress in Planning</u>, 5 (2),
51.

PATTON, M.Q. (1978). <u>Utilization-focussed evaluation</u>. Sage,
Beverley Hills.

PEARCE, D.W. (1978). <u>The valuation of social cost</u>. George Allen
and Unwin, London.

PEARMAN, A.D. (1977). 'A weighted maximin and maximax approach to
multiple criteria decision-making'. <u>Operational</u>
<u>Research Quarterly</u>, 28, 584 - 587.

POPPER, K. (1965). <u>The logic of scientific discovery</u>. Harper
Torchbooks, New York.

PRESTWOOD-SMITH, P. and MAY, A.D. (1977). <u>The assessment of transport</u>
<u>programme options</u>. Paper presented at P.T.R.C.
Summer Annual Meeting, University of Warwick.

RABETT, J.D. and HEGERTY, R. (1977). 'A system for the rapid review of highway schemes'. Journal of the Institution of Highway Engineers, XXIV, 24 - 26.

RAHMAN, W.M. and DAVIDSON, K.B. (1968). 'A model for the analysis and evaluation of urban transport'. Proceedings of the Australian Road Research Board, 4 (1), 135 - 152.

REES, P.H. (1971). 'Factorial ecology; an extended definition, survey and critique of the field'. Economic Geography, 47 (2), 220 - 233.

REYNOLDS, D.J. (1960). The assessment of priorities for road improvements. Department of Science and Industrial Research. Road Research Technical Paper 48, London.

RIVETT, B.H.P. (1977). 'Policy selection by structural mapping'. Proceedings of the Royal Society of London, Series A, 354, 407 - 423.

ROSSI, P.H. and WRIGHT, S.R. (1977). 'Evaluation research - an assessment of theory, practice and policies'. Evaluation Quarterly, 1 (1).

ROTHENBERG, J. (1961). The measurement of social welfare. Prentice Hall, Englewood Cliffs, New Jersey.

ROWE, M.D. and PIERCE, B.L. (1982). 'Some tests of analytical multi-objective decision-making methods'. Socio-econ. Planning Sciences, 16 (3), 133 - 140.

ROY, B. (1971). 'Problems and methods with multi-objective functions'. Mathematical Programming, 1, 239 - 266.

ROY, B. and VINCKE, P. (1981). 'Multicriteria analysis; survey and

new directions'.   European Journal of Operational
Research, 8, 207 - 218.

ROY, G.G. (1974).   'A multiple criteria approach to regional planning
problems'.   Environment and Planning, 8, 313 - 320.

RUEFLI, T.W. (1974).   'Analytic models of resource allocation in
hierarchical multi-level systems'.   Socio-econ.
Planning Sciences, 8, 353 - 363.

RUSSETT, S.M. (1966).   'Discovering voting groups in the U.N.'.
American Political Science Review, 60, 327 - 339.

RUTMAN, L. (ed.) (1977).   Evaluation research methods; a basic guide.
Sage, Beverley Hills.

SAGER, T. (1981).   'Evaluation methods in local participatory planning'.
Town Planning Review, 52 (4), 417 - 432.

SCHICK, A. (1966).   'The road to P.P.B.; the stages of budget reform'.
Public Administration Review, 26, 243 - 258.

SCHICK, A. (1969).   'Systems politics and systems budgetting'.   Public
Administration Review, 29, 137 - 151.

SCHOFER, J.L. and STUART, D.G. (1974).   'Evaluating regional plans
and community impacts'.   American Society of Civil
Engineers.   Journal of the Urban Planning Division,
100, 99 - 109.

SCHUESSLER, K.F. and DRIVER, H. (1956).   'A factor analysis of sixteen
primitive societies'.   American Sociological Review,
21, 493 - 499.

SCOTTISH DEVELOPMENT DEPARTMENT (1973).   Treshold analysis manual.

    S.D.D., Edinburgh.

SEO, F. and SAKAWA, M. (1979).   'An evaluation method for environmental

    systems planning'.   Environment and Planning A, 11,

    149 - 168.

SHARP, C.H. (1979).   'The environmental impact of transport and the

    public interest'.   Journal of Transport Economics

    and Policy, 13, 88 - 101.

SILCOCK, D.T. and WALKER, R.T. (1982).   'A method for comparative

    evaluation of accident counter-measures for appli-

    cation in residential areas'.   Traffic Engineering

    and Control, 23 (9), 430 - 437.

SINGHVI, S.S. (1980).   'Risk analysis'.   Long Range Planning, 13 (1),

    12 - 19.

SMITH, J.F. (1970).   'The design of a transportation study with regard

    to the evaluation of its output'.   Regional Studies,

    4 (2), 193 - 204.

SNACK, R.B. and WILLIAMS, R.G. (1979).   'Structure plans and road

    building; recognising the conflict'.   Paper pre-

    sented at P.T.R.C. Summer Annual Meeting, University

    of Warwick.

SODERBAUM, P. (1981).   Institutional economics in relation to public

    decision-making.   Department of Economics and

    Statistics, Swedish University of Agricultural Sciences,

    Uppsala.

SODERBAUM, P. (1982). _An application of positional analysis to public_
        decision-making. Paper presented to the European
        Working Group on Operational Research in Government
        and in the Public Sector; Lausanne.

SPEARING, D. and HINCKLEY, E.P. (1970). 'Investment appraisal in the
        comparative evaluation of highway improvements'.
        Journal of the Institution of Highway Engineers, XVII,
        11 - 17.

STARKIE, D.N.M. (1973). _Transportation planning and public policy._
        Pergamon, Oxford.

STARKIE, D.N.M. (1981). 'Rejoinder to C.A. Nash'. _Regional Studies_,
        15 (2), 145 - 146.

STEPHENSON, C. (1975). _Transport policies and programmes._ Paper
        presented at London Students Society (East Anglia
        Section) Meeting of C.I.P.F.A., Session 1974 - 1975,
        No. 7.

STEWART, J.D. (1971). _Management in local government._ Charles
        Knight, London.

STOCKS, N. and GLEAVE, G. (1971). 'Financial analysis and town centre
        development'. _Urban Studies_, 8, 255 - 269.

STOPHER, P.A. and MEYBURY, A.H. (1977). 'Transportation systems
        evaluation'. _Transportation_, 6 (2), 212.

SUGDEN, R. and WILLIAMS, A. (1978). _The principles of practical cost-_
        benefit analysis. Oxford University Press, Oxford.

TARDIFF, T.J. (1977). 'Causal inferences involving transportation attitudes and behaviour'. Transportation Research, 11, 397 - 404.

T.E.C. COMMITTEE 643 (1975). 'Land use and transportation system evaluation; a conceptual framework'. Traffic Engineering, October, 22 - 32.

THIRIEZ, H. and ZIONTS, S. (eds.) (1975). Multiple-criteria decision-making. Springer Verlag, Berlin.

THOMAS, E.N. and SCHOFER, J.L. (1970). Strategies for the evaluation of alternative transportation plans. National Cooperative Highway Research Program Report 96, Highway Research Board, Washington D.C.

THOMAS, R. (1967). A method for the evaluation of alternative forms of urban growth by means of a comparison of access. Paper presented at the Urban Studies Conference, Oxford.

THURSTONE, L.L. (1959). The measurement of values. University of Chicago, Chicago.

TORGERSEN, W.R. (1963). Theory and methods of scaling. Wiley, New York.

TURNER, R.K. (1979). 'Cost-benefit analysis - a critique'. Omega, 7 (5), 411 - 421.

VAN DELFT, A. and NIJKAMP, P. (1977). Multi-criteria analysis and regional decision-making. Martinus Nijhoff, Leiden.

WACHS, M., HUDSON, B.M. and SCHOFER, J.L. (1974). 'Integrating localised and systemwide objectives in transportation planning'. Traffic Quarterly, 28, 159 - 184.

WAGON, D.J. and HILL, G.J. (1970). The economic evaluation technique and methodology used in the SELNEC study. Mathematical Advisory Unit, M.A.U. Note 186, Ministry of Transport.

WANNOP, U.A. (1972). 'An objective strategy. The Coventry-Solihull-Warwickshire Sub Regional Study'. Journal of the Royal Town Planning Institute, 58 (4), 159 - 166.

WENDT, P.F. (1967). 'Large-scale community development'. Journal of Finance, 22, 220 - 239.

WHITBREAD, M. (1972). Evaluation in the planning process. Working Paper No. 3. Planning Methodology Research Unit, School of Environmental Studies, University College, London.

WHITBREAD, M. (1973). Measurement in evaluation. Working Paper No. 6. Planning Methodology Research Unit, School of Environmental Studies, University College, London.

WHITE, P.R. (1978). 'Allocation of funds to public transport investment and operating support'. Transportation, 7, 225 - 242.

WICKELGREN, W.A. (1974). How to solve problems. W.H. Freeman and Co., San Francisco.

WILDAVSKY, A. (1966). 'The political economics of efficiency; cost benefit analysis and program budgetting'. Public Administration Review, 26, 292 - 310.

YASS, I. (1979).   'The Leitch Report and after'.   The Highway Engineer,

     26 (6), 34 - 37.

YOUNG, W. (1972).   Planning - a linear programming model.   Greater

     London Council Intelligence Unit Bulletin 19, London.

ZIONTS, S. (1981).   'A multiple-criteria method for choosing among

     discrete alternatives'.   European Journal of

     Operational Research, 7, 143 - 147.