DRIVE II PROJECT V2016 : PRIMAVERA

**Priority Management for Vehicle Efficiency,
Environment and Road Safety on Arterials**

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A BEST PRACTICE MANUAL FOR INNOVATIVE UTC SCHEMES

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FOREWORD

While it is hoped that this manual will be of immediate use to practitioners, it is nevertheless acknowledged that it deals with a fast developing subject, and that new procedures, techniques and strategies are continuously being developed. It is therefore intended that the manual will be regularly revised. In order to help us keep the manual as up-to-date as possible, we welcome your comments and contributions. These should be sent to the address below.

Best Practice Manual for Innovative UTC Schemes	Comments: (Use extra sheets if needed)
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EXECUTIVE SUMMARY

This manual aims to put forward current accepted principles of best practice concerning the development, implementation and evaluation of innovative Urban Traffic Control (UTC) schemes, particularly those involving the application of Advanced Transport Telematics (ATT) systems. The manual does not prescribe specific strategies, but rather indicates the process to be carried out in order to identify, sift, model, evaluate and choose the best strategy for a given location.

It is envisaged that the main users of the manual will be transport practitioners working in local authorities, central government, consultants, plus transport researchers and academics.

The examples in the manual are based on urban arterials, but the general principles can be applied more widely.

After an introduction defining the context within which the manual applies, Chapter 2 outlines systematic procedures for locating and ranking those parts of the road network where traffic conditions are unacceptable, and which could potentially benefit from innovative UTC strategies. Chapter 3 covers the process of strategy development, involving a review of the existing state of the art, supplemented by 'brainstorming' and the use of local knowledge.

Chapter 4 describes how a preliminary screening of an initially large list of strategies can be carried out using a 'Delphi' style approach.

Chapters 5, 6 & 7 describe how to:

a) test individual strategies in isolation;
b) construct integrated strategies from individual strategy elements;
c) evaluate the integrated strategies, including the use of multi-criteria analysis as well as more traditional cost-benefit analysis.

Chapter 8 contains advice on aspects of implementation based on the experience of the PRIMAVERA project members.

Finally, post-implementation evaluation is discussed in Chapter 9, with reference to the CORD/ERTICO evaluation guidelines

1. INTRODUCTION

1.1 Background

1.1.1 Innovative Urban Traffic Control (UTC) Systems

Traffic signals in a network may be coordinated either by using fixed time plans, developed off-line, or by using real time adaptive systems. The aim of these systems is to calculate signal plans that minimise a cost function where delays and stops to private traffic and public transport are taken into account.

Real time adaptive systems can be classified into two groups. The first of these (including the widely used UK SCOOT and the Australian SCATS), look at the network as a whole optimising cycle times, green splits and offsets between the intersections [1,2,3]. The second group (including the Italian SPOT, the French PRODYN and the US OPAC, all of which have been developed over the last few years), uses a decentralised approach dividing the network problem into sub-problems resolved at the intersection level [4,5,6,7]. Common features of systems belonging to this group are the use of the "rolling horizon" concept and switching optimisation.

Current systems are far from perfect, in particular in the management of oversaturated conditions, and new algorithms and improvements to their model of the network are continually being made.

For each of the main areas of concern of traffic control (queue management, public transport priority and traffic calming) a wide range of techniques can be found in the literature [8,9,10]. Historically however these techniques have in general been applied in an isolated manner, without regard to the fact that objectives and effects of different techniques are often conflicting.

In recent years a more comprehensive approach to urban traffic control has been advocated, taking safety and environmental aspects into greater consideration. This has necessitated the development of measures with the overall aim of reducing queues, increasing public transport efficiency and limiting excessive speeds within urban areas. In the DRIVE II programme, and in particular in the PRIMAVERA project, attention has been focused on this problem.

1.1.2 DRIVE II Project V2016: PRIMAVERA

PRIMAVERA focused on integrated traffic control on urban arterial corridors. It has developed and appraised methods for managing queues of traffic, giving priority to public transport, protecting the environment and improving safety through traffic calming measures. Particular attention was paid to the integration of queue management and public transport priority strategies in saturated and oversaturated conditions. Given that these techniques are potentially conflicting in their effects, the project has developed means of integrating the individual control measures to ensure that they complement one another and that an acceptable balance is obtained between potentially conflicting objectives. It has been demonstrated not only that this balance can be obtained but also that synergies can be found.

Strategies have been implemented in two different UTC systems, the Italian SPOT and the UK SCOOT. After developing an evaluation framework following the DRIVE guidelines, a comprehensive assessment of the strategies tested was carried out, first through an off-line evaluation procedure and then through extensive field trials on two urban arterials in Leeds (UK) and Torino (Italy) [11].

1.1.3 The Need for this Manual

The last ten years has seen a great increase in the number and variety of techniques available for urban traffic management. Some of these new measures utilise traditional concepts and/or materials in a new way, such as the 'axes rouges' of Paris, and physical traffic calming. Other measures however utilise recent developments in computing and communications technology applied to transport (Advanced Transport Telematics; ATT), such as those developed by projects in Area 3 of the DRIVE II programme.

Design guidelines already exist for the more established techniques, and have recently been developed for some of the more innovative ones. These however tend to treat each technique in isolation, without reference to the interaction with other techniques being used in the same area, or to the environment in which they operate. In other words there are currently no consistent guidelines available on the design and evaluation of integrated strategies. This is a serious shortcoming, especially in view of the renewed emphasis in recent years on the use of an integrated approach to transport planning.

1.2 Overall Approach

A clear statement of objectives is needed in order to identify the problems to be overcome by the selected strategies; to evaluate the relative performance of alternative candidate strategies; and to assess the performance of the selected strategy when implemented in the field. The use of objectives in this way follows the principles of Systems Analysis, as summarised in Figure 1.1.

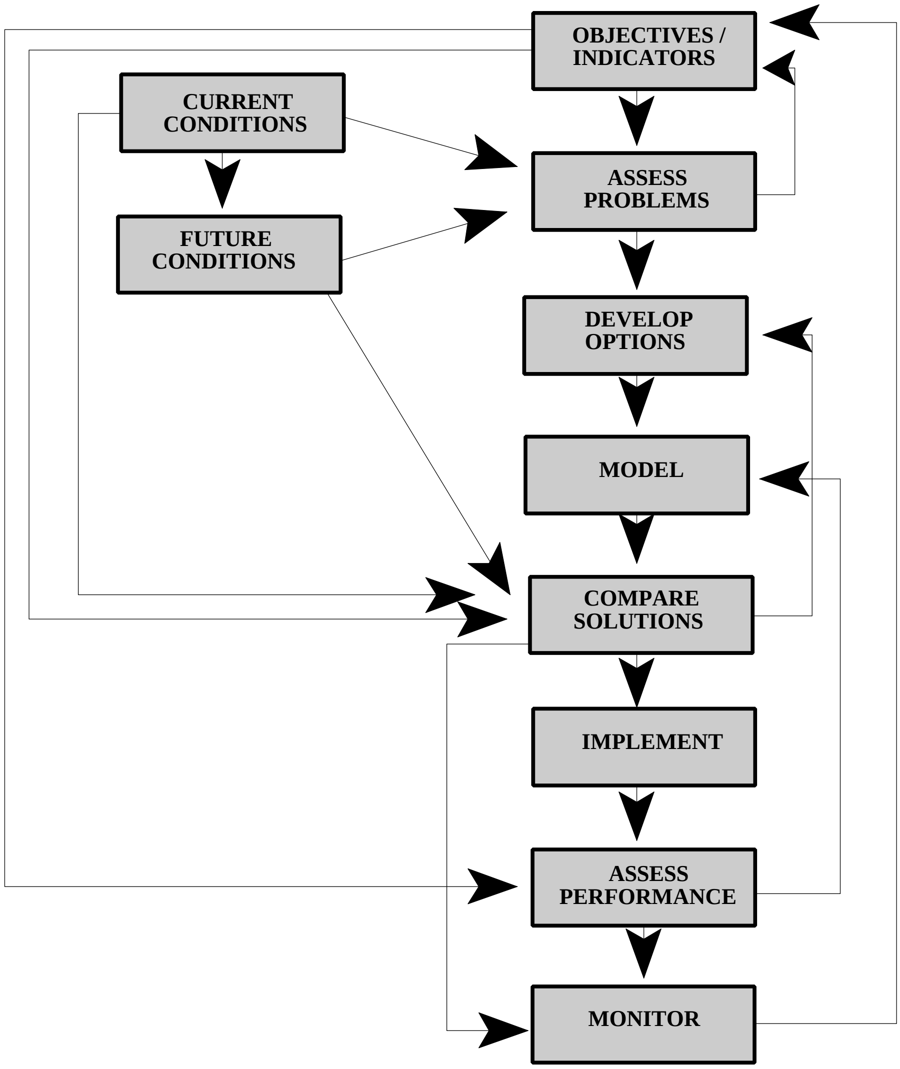

Figure 1.1: An objectives led structure for strategy formulation

Objectives are defined and used to specify more detailed indicators of performance. These are then used initially, with data for the existing situation, to identify current problems, defined as indicators for which objectives are not currently being met. It is also possible, at this stage, to predict future conditions, and hence future problems. In practice in PRIMAVERA the assessment was based solely on current conditions.

The identified problems are then used as a basis for devising possible solutions. This process is described in Chapter 3. The long list of possible solutions generated in this way may then, as in PRIMAVERA, be screened to identify a suitable shortlist for further analysis. This is done, as described in Chapter 4, by reference to the objectives and indicators. Further assessment of the shortlisted solutions, and combinations of those solutions into integrated strategies, is performed by simulation, as described in Chapters 5, 6 and 7. The simulation process provides, as output, measures of performance against each of the objectives and indicators.

Finally, selected strategies are implemented either as field trials (as in PRIMAVERA) or as final schemes. For field trials, it is clear that a "before and after" evaluation is needed, as described in Chapter 9. Even with final schemes, such an evaluation is desirable, both for fine-tuning of the implementation and to provide experience of the performance both of the measures and of the accuracy of the simulation. A full Systems Analysis approach would then complete the cycle by regular monitoring of conditions to identify any new problems which required further treatment. Once again, the before and after tests and monitoring are based on the defined objectives, measured in terms of the specified indicators.

2. FORMULATION OF OBJECTIVES

2.1 Context

The formulation of objectives is usually the responsibility of the local or central government body responsible for the road network in question. They can be specified very generally in the form of an overall vision for the area, of the kind now being specified in many cities' transport strategies. Such statements of vision provide a context for evaluation, but are too abstract to be used directly. They can be specified broadly as higher level transport policy objectives, such as efficiency, accessibility and safety. These are helpful in indicating the directions in which strategies should be developed, and the relative performance of alternative solutions. They do not, however, demonstrate whether a particular solution is adequate in its impact. To do this more specific, quantified objectives are needed. These are typically expressed in terms of thresholds, such as the avoidance of delays of over 60 sec at individual junctions. These can then be used directly to identify problems as objectives for which these thresholds are currently exceeded.

2.2 High Level Transport Objectives

Quantified objectives, or indicators, are needed for evaluation purposes, but must be specified in the light of local requirements. The higher level transport objectives are, however, more generally applicable, and are outlined in Table 2.1. It should be emphasised that this is a suggested list of possible objectives; it will be for politicians or government officials to decide which are relevant in a particular situation.

Table 2.1: High Level Transport Objectives

- **Economic efficiency**

The efficiency objective is concerned with maximising the net benefits, in resource terms, of the provision of transport. This in turn involves maximising the difference between the consumer surplus of travellers and the resource costs of the provision, operation and maintenance of transport facilities. Consumer surplus can be thought of as the difference between the maximum which an individual traveller is prepared to pay to travel and the actual cost of that journey. Consumer surplus is therefore increased when travel time, operating costs and direct payments such as fares are reduced, and also when more travellers are able to travel as a result of reductions in those costs.

Efficiency defined in this way is central to the principles of social cost-benefit analysis, and a higher net present value from a cost-benefit assessment represents a more efficient outcome. However, it is based directly on the values which individuals assign to their journeys, and there has been some concern recently that the resulting emphasis on increases in the amount of travel, and in speed of travel, may not be wholly consistent with the needs of society.

- **Environmental protection**

The environmental protection objective involves reducing the impact of transport facilities, and their use, on the environment of both users and non-users. Traditionally [12], the environmental impacts of concern include noise, atmospheric pollution of differing kinds, vibration, visual intrusion, severance, fear and intimidation, and the loss of intrinsically valuable objects, such as flora and fauna, ancient monuments and historic buildings through the consumption of land.

While some of these can be readily quantified, others such as danger and severance are much more difficult to define and analyse. Attempts have been made, with impacts such as noise and pollution, to place money values on them, and hence to include them in a wider cost benefit analysis, but it is generally accepted that it will be some time before this can be done reliably even for those impacts which can be readily quantified.

- **Safety**

The safety objective is concerned straightforwardly with reducing the loss of life, injuries and damage to property resulting from transport accidents. The objective is thus closely associated with the concerns over fear and intimidation listed under environmental protection above, and these concerns could as readily be covered under either heading.

Although there are marked differences in detail between member states of the EU, it is common practice to place money values on casualties and accidents of differing severity, and to include these within a social cost benefit analysis. These values may include the direct costs of accidents, such as loss of output, hospital, police and insurance costs, and replacement of property and, more controversially, an allowance for the pain, grief and suffering incurred. To this extent, the safety objective has been subsumed within the efficiency objective. However, there are some misgivings about some elements of the valuation of accidents, and it is probably therefore helpful to estimate accident numbers directly as well.

- **Accessibility**

Accessibility can be defined as "ease of reaching", and the accessibility objective is concerned with increasing the ability with which people in different locations, and with differing availability of transport, can reach different types of facility. In most cases accessibility is considered from the point of view of the resident, and assessed for access to activities such as employment, shopping and leisure. By considering accessibility separately for those with and without cars available, or for journeys by car and by public transport, the shortcomings of the existing transport system can be readily identified. It is possible also to consider accessibility from the standpoint of the employer or retail outlet, wanting to obtain as large a catchment as possible in terms of potential employees or customers. In either case, access can be measured simply in terms of the time spent travelling or, using the concept of generalised cost, in terms of a combination of time and money costs.

- **Sustainability**

The sustainability objective was defined by the Brundtland Commission [13] in 1987 as being the pursuit of 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. It can therefore be thought of in transport terms as a higher level objective which considers the trade-off between efficiency and accessibility on the one hand and environment and safety on the other. A strategy which achieves improvements in efficiency and accessibility without degrading the environment or increasing the accident toll is clearly more sustainable.

However, the definition of sustainability also includes considerations of the impact on the wider global environment and on the environment of future generations. Issues to be considered under this heading include the reduction of carbon dioxide emissions, which are a major contributor to the process of global warming, controlling the rate of consumption of fossil fuels, which are non-renewable, and limiting also the use of other non-renewable resources used in the construction of transport infrastructure and vehicles.

- **Economic regeneration**

The economic regeneration objective can be defined in a number of ways, depending on the needs of the local area. At its most general it involves reinforcing the land use plans of the area. If these foresee a growth in industry in the inner city, new residential areas or a revitalised shopping centre, then these are the developments which the transport strategy should be supporting. At its simplest it can do so by providing the new infrastructure and services required for areas of new development. But transport can also contribute to the encouragement of new activity by improving accessibility to an area, by enhancing its environment and, potentially, by improving the image of the area. The economic regeneration objective therefore relates directly to those of accessibility and environmental protection.

- **Equity**

While all of the above objectives can be considered for an urban area as a whole, they also affect different groups of people in society in differing ways. The equity objective is concerned with ensuring that the benefits of transport strategies are reasonably equally distributed, or are focused particularly on those with special needs. Among the latter may be included lower income residents, those without cars available, elderly and disabled people, and those living in deprived areas. The equity objective will also be concerned with avoiding worsening accessibility, the environment or safety for any of these groups.

- **Finance**

Financial considerations act primarily as constraints on the design of a strategy. In particular, they are a major barrier to investment in new infrastructure, or to measures which impose a continuing demand on the revenue account, such as low fares. In a few cases, the ability to raise revenue may be seen as an objective in its own right, and it is clearly the dominant objective for private sector participants in a transport strategy. The finance objective can therefore be variously defined as minimising the financial outlay (both capital and revenue) for a strategy or as maximising revenue.

- **Practicability**

The other major constraints on strategy design and implementation are practical ones. Issues under this heading include the availability of legislation; the feasibility of new technology; the ability to acquire land; and the simplicity of administration and enforcement of regulatory and fiscal measures. Public acceptability can also be considered under this heading. Flexibility of design and operation, to deal with uncertainties in future demands or operating circumstances, may also be important. The practicability objective can therefore be defined as ensuring that policies are technically, legally and politically feasible, and adaptable to changing circumstances.

Checklist of Practicability Issues

(a) Degree of Control - is the policy or proposal directly under the control of the local authority, or does it require influencing other decision-takers?
(b) Feasibility - what is the likelihood of the decision being implemented?
(c) Scale of Resources - what is the scale of resources, such as land or finance required?
(d) Enforcement - does the proposal require other, supporting enforcement measures to ensure that it is effective?
(e) Complexity ('depth' of decision) - does the policy or proposal involve numerous factors? Most transport policy decisions are, of course, complex but the extent varies.
(f) Time-scale - what is the time-scale for the implementation and of the effects of that policy or proposal?
(g) Flexibility - is the decision "final" or merely a preliminary one that can be revised later?
(h) Phasing - what is the trade-off between making at least some kind of decision at an early stage (even though it may be revised later), as against postponing it?
(i) Dependence - how many and what types of other decisions will be affected, and is the policy or proposal dependent on or supportive of others?
(j) Complementarity - are the proposals complementary, such as light rail and park and ride facilities, or are they independent?
(k) Conflicts - does the policy or proposal conflict with others that have been or are likely to be made?
(l) Partitioning - can the policy or proposal be broken down into a series of simpler, discrete components?
(m) Political Nature or Policies and Proposals - how should the policy or proposal relate to the way that political choices are made, and in what form should information about it be communicated to decision-makers?

In practice, the DRIVE programme, of which PRIMAVERA was part, had specified objectives of efficiency, safety and environment, and the evaluation process was therefore focused solely on these. However, equity issues were considered by identifying impacts separately for different groups, and financial and practicability issues were central to scheme design.

2.3 Development of Specific Indicators

As noted above, it is not appropriate to specify general indicators and thresholds to be applied uniformly, since requirements and the potential for improvement will be different for different sites. However, Table 2.2 suggests a number of indicators which might be used for each of the objectives listed in Table 2.1 except practicability.

Table 2.2: Suggested Indicators for Different Policy Objectives

Objective (see Table 2.1)	Indicators
Economic efficiency	Delays for vehicles (by type) at junctions Delays for pedestrians at road crossings Time and money costs of journeys actually undertaken Variability in journey time (by type of journey) Costs of operating different transport services Change in numbers of journeys in total and by vehicles
Environmental protection	Noise levels Vibration Levels of different local pollutants (CO, HCs, NO_X, particles) Visual intrusion Townscape quality (subjective) Fear and intimidation Severance (subjective)
Safety	Personal injury accidents by user type per unit exposure (for links, junction, networks) Insecurity (subjective)
Accessibility	Activities (by type) within a given time and money costs for a specified origin and mode Weighted average time and money cost to all activities of a given type from a specified option by a specified mode
Sustainability	Environmental, safety and accessibility indicators as above CO_2 emissions for the area as a whole Fuel consumption for the area as a whole
Economic regeneration	Environmental and accessibility indicators as above, by area and economic sector
Finance	Operating costs and reviews for different modes Costs and revenues for parking and other facilities Tax revenue from vehicle use
Equity	Indicators as above, considered separately for different impact groups

In the PRIMAVERA project, the indicators were generated by considering first the expected benefits from an integrated strategy. These are listed, for each of the three DRIVE objectives, in Table 2.3. Some of these, such as stress, are not readily measurable, and have to be inferred from other information or assessed by professional judgement. The remainder can be measured, and Table 2.4 indicates the impact groups for which each was measured in PRIMAVERA. This disaggregate treatment enables the equity objective to be considered.

Table 2.3: Expected Benefits from Integrated Strategy

Objective	Impact Variable	Expected Benefit
Efficiency	Journey Time	Reduction in overall journey time or maintained journey time with reduced variability.
	Vehicle Operating Cost and Fuel Consumption	Reduced operating costs and fuel consumption gained from fewer oversaturated junctions and reduced number of stops.
	Operational Impacts	Increased reliability of bus journey times.
	Traffic Flows	Traffic flows may be seen to increase overall as more vehicles move more efficiently through the system. However this should not occur at the cost of other impact variables such as journey time.
	Vehicle Occupancy (No of people in vehicle)	Whilst little or no change may be expected in car occupancy, bus occupancy may be expected to increase as a benefit of PT/ATT measures.
Environment	Comfort	Increased comfort as reflected in fewer (unscheduled) stops and benefits from reduced congestion.
	Air and Noise Pollution	Reduced estimated pollution levels as a benefit of reduced congestion, fewer unscheduled stops and controlled speeds through the system.
	Crossing delay Visual Intrusion Severance	Reduced levels in each of these impact variables as a benefit of reduced congestion, lower and more controlled vehicle speeds. Reduced pedestrian crossing delays.
	Stress	Reduced driver stress as a benefit of levels of congestion and more controlled speeds. Reduced resident stress as a benefit of reduced and controlled speeds, reduced estimated noise/pollution and reduced pedestrian crossing delays.
Safety	Safety	Increased safety levels as a benefit of lower and more controlled speeds of vehicles.
	Speed	Safety benefits expected from lower and more controlled speeds.

Table 2.4: Impact Groups Relevant to Different Indicators

VARIABLE	DISAGGREGATE IMPACT GROUP
Journey Time	Vehicle Category (total 5) - cyclist, car, bus, light commercial, heavy commercial
Vehicle Operating Cost	Vehicle Category (excluding cyclist) - car, bus, light commercial, heavy commercial
Traffic Flows	Vehicle category
Vehicle Occupancy	Cars/Buses
Comfort	Vehicle Category
Air Pollution	Residents, Pedestrian, Cyclist Groups
Crossing Delay	Pedestrians
Stress	Residents, Pedestrians Drivers: vehicle category
Safety	Severity - slight/serious/fatal
Speed	Vehicle Category (total 5) - cyclist, car, bus, light commercial, heavy commercial
Scheme Cost	

At this stage it is necessary to decide how such indicators are to be measured in the field and in the simulation. Table 2.5 indicates the way in which this was done for the field trial data collection in PRIMAVERA. It identifies, for each quantifiable indicator, a set of criteria to be used, the spatial and temporal disaggregation involved, the data collection methods and the statistical tests employed in identifying significant changes.

2.4 Problem Identification and Monitoring

Having defined a set of indicators for the specified objectives (as in Tables 2.3 and 2.4) and a measurement process (as in Table 2.5), it is a relatively straightforward process to identify problems and regularly to monitor trends in those problems.

Ideally, this is done by specifying a threshold for each indicator, above which it is judged that conditions are unsatisfactory. Such thresholds need to be defined with care. Too high a threshold will imply that conditions which are a problem for some people will not be identified as such; conversely too low a threshold may impose unnecessary costs in treatment. For some indicators, such as noise, people have a wide range of tolerances, and a level which is unacceptable for one person will not be noticed by another. In these circumstances, a single threshold may be inappropriate. An alternative is to specify a range of two or three thresholds, of which the lowest would be the maximum desirable level, and the highest the level which should not be exceeded.

Data is then collected, for each of the locations, times of day and impact groups specified (as in Table 2.5), and checked to ascertain whether any of the thresholds has been exceeded. The severity of the problem can then be judged by the level of threshold exceeded and, when the highest threshold has been exceeded, the extent by which it has.

Monitoring is carried out in a similar vein by collecting the same information on a regular cycle, typically annually at "normal" times of the year, and establishing trends in the nature and severity of problems. It would be expected, of course, that problems would be reduced significantly once a new strategy had been introduced. However, secular trends in traffic levels or diversion of traffic to the now improved route may well serve to undermine the initial benefits over time. The monitoring programme will enable such effects to be identified and further remedial measures designed.

In a wider sense, a monitoring programme could include a survey of users' attitudes to the conditions. This may help, as indicated in Figure 1.1, to reassess the underlying objectives and their relative importance.

Table 2.5: Definition of Criteria of Effectiveness and Response

IMPACT	CRITERIA OF EFFECTIVENESS	CRITERIA OF RESPONSE	DATA COLLECTION	PROPOSED STATISTICAL TEST
Journey Time (JT)	Reduced JT for route/link	Mean JT for route/link: Peak/interpeak	Number plate matching/floating observer	z or t for difference in means
	Reduced variance in JT for route/link	Variance (JT) for route/link: Peak/interpeak		F for difference in variance
Vehicle Operating Cost (OC) and Fuel Consumption (FC)	Reduced OC and FC for vehicles for whole route	Mean FC for buses for whole route	Data from bus operators	z or t for difference in means
	Reduced congestion for vehicles route/link	Total number of stops for vehicles, route/link: peak/interpeak	Manually in field	Contingency for no. of stops
Operational	Improvement in bus journey time reliability.	Variance in buses journey time peak/interpeak	Manually in field	F for difference in variance
Traffic Flows	Reduced or no change in traffic flow for whole route	Mean traffic flow for whole route: peak/interpeak	Loop detectors	z or t for difference in means
Vehicle Occupancy	Increased bus occupancy. No change in other vehicle occupancy	Mean vehicle occupancy for whole route: peak/interpeak	Manually in field	z or t for difference in means
Comfort	Increased comfort for drivers/passengers	Mean no. of stops for vehicles route/link: peak/interpeak	Manually in field	Contingency for no. of stops
Crossing delay/ Uncertainty/ Visual intrusion	Reduced or no change in crossing delay	Mean crossing delay for link	Manually in field	z or t for difference in means
	Reduced queue lengths at junctions	Mean queue length for link: peak/interpeak	Manually in field	
	Reduced mean traffic flow (TF) for link	Mean TF for link: peak/interpeak	Loop detectors	
	Reduced mean speed at crossing point	Mean speed at crossing point: peak/interpeak	Loop detectors	
Stress	Reduced stress for drivers & passengers for whole route	Mean no. of stops and queue lengths for whole route: peak/interpeak	Manually/floating car	z or t for difference in means
Safety	Increased safety for cars/pedestrians for route/link	Accident rate for route	Police accident records	
		Conflict study for junctions	Manually in field	
Speed	Reduced speed for route/link	Mean speed for route/link: Peak/interpeak	Number plate matching/ floating observer	z or t for difference in means
	Reduced variance in speed for route/link	Variance (speed) for route/link: Peak/interpeak	Loop Detectors	F for difference in variance
	Fewer "speeding" vehicles for route/link	Proportion of vehicles exceeding certain speed for route/link: Peak/interpeak		z or t for difference in proportions

3. DEVELOPING A LIST OF POTENTIAL STRATEGIES

Strategy development involves the application of creative thinking to devise ways of using existing and innovative technology to solve the problems identified in Chapter 2. The traditional starting point for such a process is a review of the existing state of the art, as described in 3.1. This review can then be used as a starting point for the generation of new ideas. However novelty is a rare commodity, and cannot be produced to order. Neverless techniques have been devised which, by creating favourable conditions, encourage its generation. Such a technique is brainstorming (3.2) which if properly applied, can produce an explosion of novel ideas. The fact that most of the ideas generated here will later be rejected should not be used as an excuse for cutting down on this work area. This would be analogous to asking medical researchers to find a cure for cancer using existing drugs only.

3.1 State of Art Reviews

Firstly, the author(s) of a state of the art review should be experts in the field. It may be necessary to split the review into parts in order to accomplish this. (The PRIMAVERA project produced three separate reviews [8][9][10], each by different authors.) It is obviously important that the review is as up to date as possible. The pace of change in ATT means that even experts can find it difficult to keep abreast of all the latest developments. Hence it is considered essential to carry out a comprehensive literature search. Traditionally such searches have involved the use of library card-index catalogues supplemented by a key-word search of a computerised database, the latter being carried out by the library staff. Within recent months however, there have been a number of significant developments in access to bibliographic databases via the internet, which enable a substantial improvement in the speed and effectiveness of searches. Three examples of these developments are the on-line public access catalogue (OPAC) of mainly university libraries; the TRANSPORT database and the CARL database.

OPAC. Most university libraries (and several outside the university system such as the World Bank) have been progressively converting their card index catalogues to computerised systems. Initially these computerised catalogues were searchable only from terminals within the library, but with the advances in PC networking in recent years, it is now the norm for catalogues to be searchable from any PC in the university which is attached to the LAN. Furthermore, with the growth of the internet, it is now normal to be able to search almost any OPAC from the PC on one's own desk. One should be aware when searching an OPAC that it will not necessarily be comprehensive as not all of the original card-index catalogue may have been transferred.

The TRANSPORT database. This database is supplied on CD-ROM by Silver Platter, and is an amalgam of three previously separate databases: Transportation Research Information Service (TRIS) produced by the US TRB; International Road Research Documentation (IRRD) produced by the OECD; and TRANSDOC, produced by the European Conference of Ministers of Transport (ECMT). This database covers a wide spectrum of transport, and includes conference papers as well as books and journal papers. Subscribers (such as University libraries) are supplied with an updated CD-ROM quarterly, and normally the database licence allows access by bona-fide members of staff and students of the university for teaching and personal research. Commercial use of the system may incur a fee.

CARL. This is a commercial service formed by a consortium of several US university libraries, and is available to anyone with access to the internet. Several databases are accessible, but probably the most useful from the point of view of a literature review, is the UnCover service. This is a very large database of journal titles and contents pages, and can be searched in a number of ways. If articles of interest are not available in one's own local library, they can be faxed by the UnCover service at a cost of approx US$15.

3.2 Brainstorming

The physiology of the human brain is very imperfectly understood, but one aspect which seems to be well accepted (and based on empirical evidence) is that different parts specialise in different tasks. Moreover, with regard to higher brain functions, those concerned with logical, straight-line thinking tend to be carried out by the left side, whereas those concerned with intuitive, holistic, lateral thinking tend to be carried out by the right side. In most humans the left brain functions dominate and suppress those of the right (possibly due to the extreme importance in human culture of speech, which is located on the left side). Among scientists and engineers the dominance of the left brain is even greater than among (say) artists, as the former are trained to develop their left brain functions (such as analysis, criticism) at the expense of right brain functions (such as synthesis, ingenuity, invention). This can mean that the generation of new ideas may be quite difficult, unless specific steps are taken to lessen the dominance of the left brain over the right. A brainstorming session is one such technique.

As many participants as possible are gathered together, and the ethos of brainstorming explained to them. They are then split into groups of around 4 with each group being as heterogenous as possible with regard to the backgrounds/occupations of its members. The essential aspect of the session is that participants must not criticise the suggestions of other group members, no matter how silly, illogical or impractical they may seem. The idea is to deliberately suppress these left brain faculties and thereby allow the right brain functions to surface. One member of each group should be appointed to keep a list of all suggestions. Successful sessions can be very enjoyable, and will generate large numbers of ideas. At a later stage these can be critically examined, and doubtless many will be discarded, but it is usually the case that a sufficient number of useful ideas are generated to make the exercise worthwhile.

4. SCREENING THE INITIAL LIST OF STRATEGIES

The process described in the previous section may produce quite a large number of potential strategies: the PRIMAVERA project produced 40 possible individual strategy components at this stage (see Table 4.1).

It would be impractical to evaluate all of these in detail, thus it is necessary to carry out a preliminary screening to eliminate those strategies which seem obviously inappropriate. This section describes how this can be done using a 'Delphi' style approach as recommended by the SECFO and EVA projects of DRIVE 1 [14][15].

It is however recognised that such an approach may not be appropriate to certain cultures or particular situations. Also discussed in this chapter are the criteria of rejection of the strategies at this stage. These could range from institutional constraints to considerations about whether a given technique is fit for the intended purpose.

4.1 The strategic assessment

The first step subsequent to the listing of the potential strategies to be applied is a strategic assessment in order to make a first screening, or even only a ranking, of the initial list. This can be done using a 'Delphi' style approach.

A team of experts carries out this assessment. The task of the panel is to estimate the effect that each strategy will have in terms of a number of impacts, such as the impacts on delays or safety issues or pollution. The types of impact selected for the strategic assessment may not be exactly the same as those that will be used in the field evaluation but should include all the indicators whose changes can be perceived and foreseen by the experts.

In addition to estimating the effects of different strategies, the experts are asked to provide weights for each impact reflecting the importance that they feel each indicator should have in the decision process. Thus it is important that the panel represents different views of traffic management including, for example, UTC operators as well as car users, local authority officials, bus passengers and operators and safety experts.

The sum of the impacts multiplied by their weights gives a score for each strategy which provides for comparison between alternative techniques. Sensitivity analysis should be used to estimate how sensitive the result is to the different experts' judgements.

This method affords the opportunity for the experts to revise their judgement in the light of the judgements of the other experts.

In PRIMAVERA the initial list of strategy components (Table 4.1) was considered by a panel of experts who gave a score of between ±2 for each impact variable for each strategy component. The impact variables used are based on those identified in Section 2.3. They are shown in Table 4.2 along with the set of weights which the experts decided would show the relative importance of these impact variables.

Strategy	Description	Score	Appropriate for	
			Leeds	Turin
Queue Management				
Telematics	Auto-Gating Family (Four types)	8.12	✓	✓
Telematics	Double Cycle Times At Critical Junctions	6.48	✓	✓
Telematics	Starting and Stopping Waves and Signal Control	6.24	✓	✓
Telematics	Horizontal Queue Model	6.24	✓	✓
Telematics	External Metering	4.91	✓	✓
Telematics	Variable Message Signs	4.12	✓	✓
Telematics	Shorter Cycle Times for Congestion Recovery	2.24		
Telematics	Identification of Links for Queue Storage	0.42		
Telematics	Restrict Turning Into Congested Arterial	-3.39		
Telematics	Queue Storage	-3.82		
Telematics	Tidal Flow	n/a		
Telematics	Flared Green Times in Networks	n/a		
Physical	Separate Stage (Phase) for Turning Traffic	6.91	✓	✓
Physical	Maximise Signalised Junction Capacity	5.76	✓	✓
Physical	Turn Bans	4.73	✓	✓
Physical	Separate Turning Lanes At Critical Junctions	3.27	✓	✓
Public Transport				
Telematics	Co-Ordinate Signals for Buses	2.97	✓	✓
Telematics	Priority to Buses At Signals	2.73	✓	✓
Physical	Increase Bus Stop Spacing	7.64	✓	✓
Physical	Reduce Time At Bus Stops	7.33	✓	✓
Physical	Create Bus Laybys	6.36	✓	✓
Physical	Bus Stops Upstream/Downstream From Junctions	4.97	✓	✓
Physical	With Flow Bus Lanes	2.06	✓	
Physical	Information At Bus Stops	1.64	✓	
Physical	Bus Lane Width	0.61	✓	
Physical	Zero Bus Lane Set Back	-6.61	✓	
Physical	Form Bus Convoys	n/a		
Traffic Calming				
Telematics	Linked Traffic Signals	2.85	✓	✓
Telematics	Forcing Speeds to Best Values for Platoons	1.33	✓	✓
Telematics	Signalised Pedestrian Crossings	-2.18	✓	
Physical	Bicycle Routes	2.61	✓	
Physical	Preventing Rat-Runs Off the Arterial	0.91	✓	
Physical	Planting	0.73	✓	
Physical	Medians	0.42	✓	
Physical	Parking Bays	-0.91	✓	
Physical	Service Roads	n/a		
Physical	Cushions At Pedestrian Crossings	n/a		

Table 4.1: The initial list of individual strategy components considered by PRIMAVERA

The strategies with n/a in the score column were considered to be not applicable in either Leeds or Turin, therefore they were not considered in the Delphi assessment.

Impact Variables	Relative Weight
Travel time for persons and goods	2.00
Travel time for commercial vehicles	1.33
Fuel consumption / air pollution / noise pollution	2.00
Vehicle operating costs	1.33
Driver comfort / stress	0.67
Pedestrian / bicyclist comfort / stress	0.67
Safety	1.33
Mode Choice	0.67

Table 4.2: The Impact Variables used for the PRIMAVERA Delphi Screening

Summing the average scores multiplied by the relative weights gives a total score for each strategy component. An example for the Auto-Gating strategy component is shown in Table 4.3. The total scores for all the strategy components are shown in the third column of Table 4.1.

Auto-Gating Strategy Component Impact Variables	Average Score	Relative Weight	Weighted Score
Travel time for persons and goods	1.05	2.00	2.10
Travel time for commercial vehicles	0.98	1.33	1.31
Fuel consumption / air pollution / noise pollution	1.00	2.00	2.00
Vehicle operating costs	0.90	1.33	1.20
Driver comfort / stress	0.75	0.67	0.50
Pedestrian / bicyclist comfort / stress	0.45	0.67	0.30
Safety	0.53	1.33	0.71
Mode Choice	0.00	0.67	0.00
Total Score			8.12

Table 4.3: An example of the calculations used to produce a score for a strategy component

This approach is essentially a multi-criteria analysis based on expert forecasts rather than measured values of the impact indicators.

4.2 Criteria for rejection

4.2.1 Institutional and general constraints

Certain strategies have to be rejected at the beginning of the selection procedure due to national or local authority policy or the characteristics of the city or area where the system will work. For example the implementation of an AVL system for buses would be problematical in the UK as the operators would not be willing to let another organisation have access to commercially sensitive information. It is also possible, that some of the strategies will be outside the terms of reference of the project. In the case of DRIVE II projects only telematics based approaches could be considered. This resulted in a significant reduction in the number of strategy components which could be considered by PRIMAVERA, as can be seen in Table 4.1.

Some strategies that would otherwise be acceptable may have to be rejected because of incompatibility with the existing UTC systems.

4.2.2 Local Knowledge

A characteristic feature of the study of Transport is that, unlike the physical sciences, its laws are not universal. Thus whereas we can emphatically assert that the freezing point of water is the same in London as in Athens, we cannot say this about (say) the critical gap for drivers entering a stream of traffic in those cities.

Even the "hard" aspects of transport such as ATT, are heavily influenced by "soft" aspects such as driver and pedestrian behaviour, institutional constraints and other cultural influences. For example, the success of a route guidance system will depend not only on whether its technical operation is satisfactory, but also on whether the drivers believe the information; are willing to divert from their normal route; can use the in-car units without compromising safety; and so on.

When considering the implementation of ATT or any other transport measures therefore, it is important to bear in mind the peculiarities of the locality. As well as the behavioural issues already mentioned, institutional issues must also be considered, such as local traffic laws and regulations; local practice in (eg) traffic signal control; lines of communication within and between the relevant roads authorities, police and transport operators, at local and national levels.

If local factors are ignored it is unlikely that a scheme will have the expected effects. It is therefore considered most important to make use of local knowledge in the design process. This local knowledge is unlikely to be found within consultants or universities, (even if locally based) as their staff tend often to come from a wider area, and are usually more concerned with broader issues. In order to obtain a good knowledge of local conditions therefore, it is suggested that representatives of the local authority, police and operators are consulted. In the PRIMAVERA project this was done at an early stage of the project, by involving all interested parties in the Delphi process. Moreover, throughout the project local knowledge was provided by the local authority partners from the two cities involved.

For PRIMAVERA the strategy components which were considered applicable at each of the two sites are indicated in Table 4.1.

5. EVALUATING & SELECTING INDIVIDUAL STRATEGIES

5.1 The Role of Simulations

Off-line evaluation by simulation of the selected strategies is an essential part of the selection procedure. Evaluation by simulation has a number of advantages over direct implementation in the field:

- it is usually faster, cheaper and easier to develop a computer simulation model of a network
- it allows different strategies to be tested in response to repeatable and controlled traffic conditions. (With on-street trials it is often very difficult to ascertain whether measured changes are due to the strategy being implemented or just due to variability in the traffic conditions)
- it is easy to develop, tune and assess the different strategies both individually and integrated together
- it is easier to collect data from a computer model than from the street
- computer models allow schemes to be developed and tuned in safety

The use of a simulator does have some disadvantages, that can depend on the nature of the simulator itself and on the particular simulator used. In particular:

- some things are difficult to model, such as safety implications or the effects of the weather or the likely user reactions to the new systems
- limits on computing power and data storage may require simplifications to be made
- a lot of data has to be collected about the proposed implementation site in order to specify the network and calibrate and validate the model
- some of the data required for the model may be difficult to acquire, such as the frequency of incidents or the day-to-day variability in flows

However, usually the advantages of using a simulation package outweigh the disadvantages.

For PRIMAVERA it was decided to use the NEMIS [16] micro-simulation package to assess the performance of the strategies being considered. When models of the trial networks were developed some simplifications had to be made to ensure that the package ran fast enough. These included a simplification of the network by ignoring a number of minor roads. Further simplifications were made to the stage sequences of some junctions. As the NEMIS simulator did not provide the information that is used on-street to manage optional stages (initiated by microwave detectors on the side roads, or by pedestrian buttons) the cycle and the stage lengths were modified at some intersections of the Leeds test site. For example at junctions where a pedestrian optional stage is provided, the simulated network was coded with a pedestrian stage every cycle, but with a reduced length according to the observed frequency of the pedestrian demands. Other limits were related to behavioural aspects. For example the compliance to speed advice was assumed to be obeyed by a fixed percentage of drivers and not individually decided according to a more sophisticated behavioural model. The use of the simulation architecture described in Section 5.3 also uncovered a problem with repeatability of the results. It proved impossible to precisely synchronise the UTC system and the simulation package at the start of each run. This resulted in slight differences in the starting conditions which led to different results being obtained each time a simulation run was made. This problem was overcome by repeating several runs of the same simulation and taking an average value of the various indicators. All of these simplifications and problems were minor and did not affect the overall conclusions being made about the relative effectiveness of the strategies being tested. Using simulation it was possible to test and evaluate a large number of strategies over a period of a few months. This would have been impossible if only field trials were available.

5.2 The simulation procedure

The objectives of the off-line evaluation are thus to:

- conduct an operational analysis of the performance of the strategy
- allow a first tuning of the parameters of the strategies (weighting factors, thresholds, etc.)
- allow a comparison of different strategies in repeatable and known traffic conditions

The simulation procedure should follow the flow diagram as depicted in Figure 5.1.

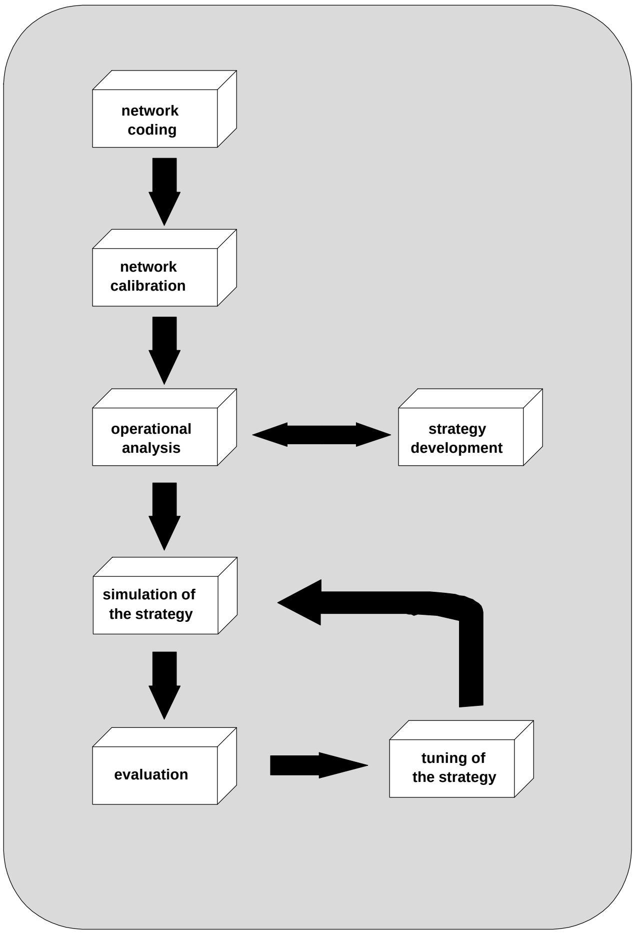

Figure 5.1: The Simulation Process

5.3 Functional architecture

The soundness of the simulation results can be increased by interfacing the actual UTC system to be used with the software package which simulates vehicle movements in the network. In detail the simulator must receive from the UTC system the commands that would drive the traffic signals and send back to the UTC system the information that is usually collected by the detectors. In this way, realistic responsive reactions between the UTC system and network can be produced.

PRIMAVERA tested two different UTC systems (SPOT and SCOOT) using a similar architecture for the off-line evaluation. The physical connection between the simulator and the UTC system is made through a frontend computer that manages the low-level communication tasks and translates, when needed, the information coming from the UTC system or the simulator into a format suitable for the destination system. The architecture is thus made of three systems described below.

5.3.1 The Simulator

The requirements for the simulator are:

- it must be able to provide the UTC system with all the information that would be measured on site. In the case of PRIMAVERA this information included loop occupancy, loop counts and detection of buses by simulating the presence of special detectors.
- it must be able to receive from the UTC system the switching commands for the simulated traffic signals
- it must be able to produce the outputs needed for the evaluation of the strategies

It is clear that the level of detail of the information needed by UTC systems (loop occupancy or counts) makes the use of a micro-simulator essential.

The main features of micro-simulators are:

- microscopic model of the network with discrete simulation time steps
- car-following rule used for the movement of vehicles
- lane changing rules
- intersections controlled by traffic signals or give-way rules
- simulation of a variety of types of private and public transport vehicle to represent a variable mix of traffic conditions

The same time variant O-D matrix should be used for the different simulations to present to the UTC system the same typical traffic demand (AM peak, off-peak, PM peak) as measured from site surveys. These surveys are also usually needed to collect data (journey times, spot flows) used for the calibration of the network loaded in the simulator.

The NEMIS software used by PRIMAVERA ran on a OS/2 PC and was able to simulate a network of 50 nodes faster than real time. The interface with the Frontend was carried out using serial communications.

5.3.2 The Frontend

The Frontend computer sits between the simulator and the UTC system and manages the communication tasks between them. At a higher level it also translates the incoming data into a suitable format for the destination system.

The PRIMAVERA application used software already available for the interface between NEMIS and SPOT while new software was developed to interface NEMIS with the SCOOT system.

The requirements for the Frontend system are to:

- manage different communication protocols at the same time in order to exchange data with the simulator and the UTC
- maintain the synchronisation of the systems
- translate or change the format of the data exchanged

The PRIMAVERA Frontend software ran on a MS-DOS PC equipped with a suitable number of serial ports. Communications with both the simulator and the UTC system were based on serial links.

5.3.3 The UTC System

The UTC system receives from the simulator the expected inputs and calculates the signal plans as if it were working on the real network. Instead of driving a traffic signal controller it sends the switching commands to the Frontend to force the desired stage in the simulator.

The frequency of update of the inputs and outputs is strictly dependent on the UTC system being used.

PRIMAVERA tested the SCOOT and SPOT UTC systems, modified in order to incorporate different strategies. Although the architecture of the two UTC systems is different (centralised in SCOOT and decentralised in SPOT) the same concept has been used for the connection with the simulator.

In the SPOT trials, carried out on two different networks, the network of SPOT controllers was controlling up to 10 intersections. One SPOT unit was used for each controlled intersection. Point to point communication links between adjacent units and two/three links between the frontend and the controller networks were provided. Every three seconds each SPOT unit sent to the simulator the signal settings for the intersection under its control and received back the loop counts. Bus detection was simulated through event messages generated by the simulator when a simulated bus passed over a special detector.

Figure 5.2 shows the conceptual diagram of this application.

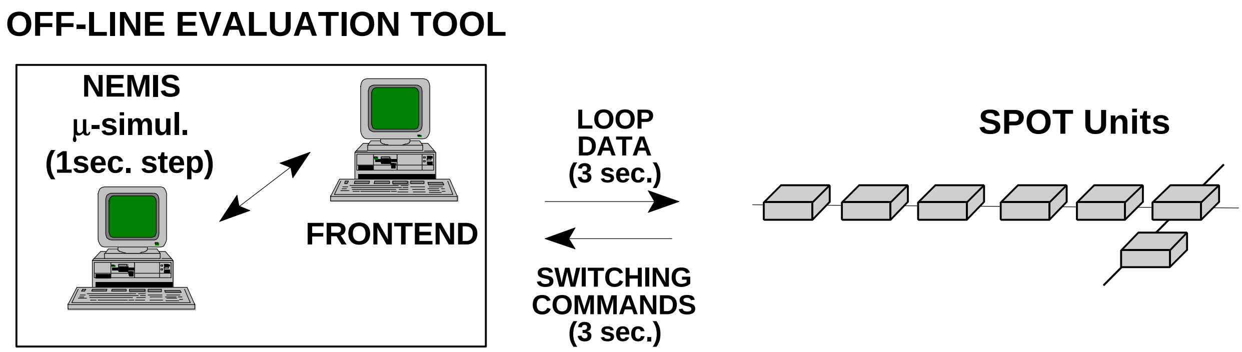

Figure 5.2: Functional architecture of the off-line evaluation of the SPOT system

In the SCOOT trials the mainframe where the modified software was running saw the simulated network as a region. The control commands were sent on unique serial links (able to control up to 9 outstations), translated by the Frontend into stage commands for the simulated traffic signals being controlled and were transmitted to the simulator. The information received back from the simulator was the loop occupancy for the last second with a resolution of 4 samples per second. Bus detection was passed to the UTC as a bit in the reply word built by the Frontend. Information in the two directions was exchanged with a frequency of one message per second for each intersection. Figure 5.3 shows the conceptual diagram of this application.

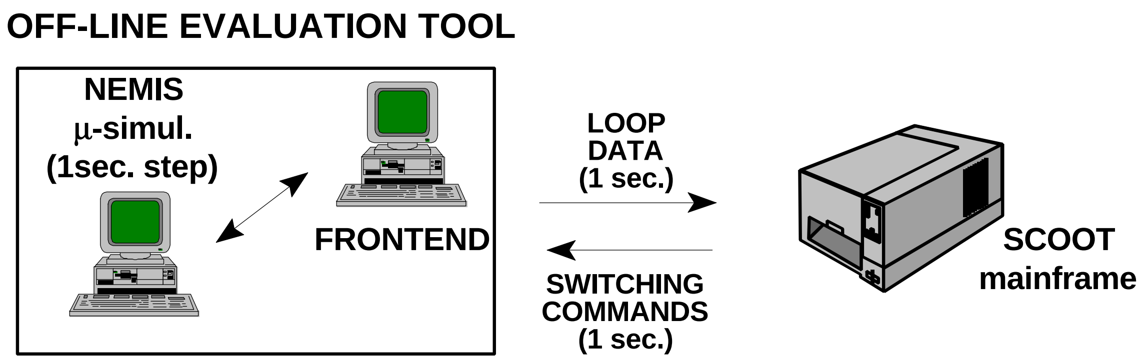

Figure 5.3: Functional architecture of the off-line evaluation of the SCOOT system

5.4 Data Collected

The use of a simulator allows a great amount of data to be collected without carrying out expensive field surveys.

Data is collected on all the simulated vehicles so there are no problems with using small data samples, as is often the case with field trial data collection. However the use of a simulator also implies limitations on some types of data that could be collected on site but cannot be modelled by a simulator. For example, PRIMAVERA found problems modelling the safety indicators chosen for the evaluation. As the main safety indicators (pedestrian - vehicle conflicts, vehicle - vehicle conflicts) greatly depend on the non-observance of driving rules or traffic signal regulations, they cannot be modelled by a simulator and so cannot be observed with an off-line evaluation. PRIMAVERA partly overcame this problem by using indirect indicators for the assessment of the safety aspects. (For example an incident prediction model was used based on the average speed on the links or the percentage of time spent by vehicles at a speed higher than a threshold.) However it was deemed necessary to supplement this information with conflict studies for the field trials.

On the other hand the simulator proved very useful for the assessment of environmental impact: the availability of a detailed modal emission model based on the knowledge of the speed and acceleration of all the vehicles in the network gave results that could not have been collected during field trials.

Based on the impact variables identified in Section 2.3 the data collected in the simulations were as follows:

- network/link travel time
- network/link delay
- individual travel time and delay for each public vehicle
- incoming and outgoing flow on each link
- number of stops of each link, used a a proxy for stress and comfort
- speed profile on each link, used to indicate changes in safety
- network/link HC, NOx, CO emission rate
- network/link fuel consumption rate, used to indicate vehicle operating costs

5.5 Selection of Candidates for Simulation

The processes described in Sections 3 and 4 will have identified the most promising strategy components for the chosen sites. As many of these as possible, given time and resource constraints, should be simulated using models of the appropriate sites.

For PRIMAVERA, the best seven queue management, two public transport priority and two traffic calming components were simulated. These are shown in Table 5.1.

Strategy	Description
Queue Management	Auto-Gating Family (Four types) Double Cycle Times At Critical Junctions Starting and Stopping Waves and Signal Control Horizontal Queue Model
Public Transport	Co-ordinate Signals for Buses Priority to Buses At Signals
Traffic Calming	Linked Traffic Signals Forcing Speeds to Best Values for Platoons

Table 5.1: The individual strategy components simulated by PRIMAVERA

5.6 Evaluating the individual strategies; Cost Benefit and Multi-Criteria Analysis

The evaluation of individual and integrated strategies as well as the field trials can be carried out using both a Cost Benefit Analysis (CBA) and a Multi Criteria Analysis (MCA).

For a CBA monetary values have to be given to each of the impact variables. Assigning monetary values to indicators allows a direct monetary comparison to be made between the strategies. This is only possible with a subset of the impact variables identified in Section 2.3 as it is very difficult to assign monetary values to some variables such as comfort or stress. The rates and impact variables used in PRIMAVERA were those given by the EVA manual as shown in Table 5.2.

Impact	Cost Rate
Travel Time (UK)	14.26 ECU / person hour
Travel Time (Italy)	18.28 ECU / person hour
Fuel Consumption	0.36 ECU / l
CO Emissions	3 ECU / ton
NOx Emissions	443 ECU / ton
Hydrocarbon Emissions	348 ECU / ton
Fatal Casualty	744177 ECU
Serious Casualty	105593 ECU
Slight Casualty	7080 ECU

Table 5.2: The cost of each impact used in the CBA

In PRIMAVERA the capital costs of implementing each strategy would be very similar so they were ignored in the analysis. Obviously if the schemes being compared cost different amounts to be implemented then this should also be considered in the CBA.

Analysis of the PRIMAVERA results suggests that the monetary values available bias the assessment towards the efficiency indicators. This approach is therefore useful if the main objective of the assessment is to evaluate the economic impacts derived from the strategies but is a poor indicator if the aim is a comprehensive assessment of the different schemes. For this reason a Multi-Criteria Analysis was also carried out. MCA gives a more structural analysis of gains and losses from the strategies. More impact variables can be used since it is not necessary to limit the range to costable variables. In addition different weightings of the variables can be employed with different sets of weights reflecting various groups' opinions of the values of the impact. These weights do not have to be related to monetary values. Whilst the final result of the analysis is a value of an overall performance indicator, the strategy scores from the contributory variables give useful and important insights into the scheme performance. The weights and impact variables used by PRIMAVERA are shown in Table 5.3. The MCA was carried out using the MASCOT computer program [17]. This program comes with three built-in sets of weights, which correspond to the opinions of "Official", "Environmental" and "Commercial" groups. It also allows sensitivity analyses to be carried out to see how big the changes in the weights or scores have to be to change the strategy rankings. Such an analysis is highly recommended.

Impact	Units	Target % change	Official	Environmental
Efficiency				
Car travel time saving	K veh s	-15	5.5455	3.0248
Bus travel time saving	K veh s	-5	138.6388	106.645
Travel time sd reduction	K veh s	-15	2.7728	1.5124
Bus time sd reduction	K veh s	-10	69.3194	53.3225
Stops	K	-10	0	100
Speed sd	m/s	-1	0	-0.3
Environment				
Fuel consumption saving	K litres	-5	360	3600
NOx emissions	kg	-10	-0.443	-4.43
HC emissions	kg	-10	-0.348	-3.48
CO emissions	kg	-10	-0.003	-0.03
Visual intrusion by queues	veh	-10	10	15
Safety				
Mean speed	m/s	0	0	-10
Excessive speed time	K s	-5	0	50
Fatal casualty reduction	-	-5	744177	1284910
Serious casualty reduction	-	-5	105593	211186
Slight casualty reduction	-	-5	7080	12390

Table 5.3 : The weights and targets used for the MCA

6. DEVELOPING INTEGRATED STRATEGIES

6.1 Overall Approach

The process described in Chapter 5 enables the best performing of the individual measures to be identified. The next task is to combine these in ways which are likely to maximise the performance against each of the underlying objectives. Two issues are of importance here.

The first is that any adverse impacts of a particular measure should where possible be counteracted by the addition of a second measure. For example, if a capacity increasing measure encourages faster speeds and potentially more accidents, it can be combined with a measure likely to enhance safety. These combinations can be identified readily from the simulations, by highlighting the adverse impacts, or poor performances, of individual measures, and selecting as complementary measures those which perform best in terms of these attributes.

The second is to attempt to achieve synergy between the individual elements. Synergy can be defined as achieving more from the combination of measures than from the sum of their individual contributions. It is difficult to achieve, and potential synergy is even harder to identify. The most appropriate approach is to assess, through professional judgement and simulation results, those measures which are likely to complement one another, where synergy is most likely, and to test these in preference to those which are likely to duplicate or conflict with one another.

One difficulty with the process of specifying integrated strategies is the large number of potential combinations. A set of eight measures which might be used one or two at a time provides a total of 36 combinations. If they can be used one, two or three at a time the number of combinations increases to 92. The process of focusing on complementarity and potential synergy, as described above, should help to reduce the number of tests required, but there will almost certainly be too many to be tested in total.

Further shortlisting can be aided by identifying measures which should preferably be included. In PRIMAVERA this was done for speed advice which, given the importance of safety, was included in all strategies. This approach does, however, run the risk that better combinations excluding this measure will be overlooked.

An alternative, more systematic approach has been developed in the related area of urban transport strategies [18]. This approach specifies an objective function, which could, in the case of PRIMAVERA, be a multi-criteria-based combination of efficiency, environment and safety, and conducts a first set of tests of selected strategies. These are used to formulate a relationship between the descriptors of the constituent measures and the objective function. This is done by multiple regression, with the objective function as dependent variable. This relationship is then used to predict an optimum specification of the strategy, which is then tested, together with selected combinations which appear to be close to the optimum. The regression is then repeated, a new optimum predicted and further tests conducted. This process is repeated until the predicted optimum performs closely enough to the performance predicted by the regression.

This approach was not used in PRIMAVERA, since it was still under development. It should, however, offer a means of significantly reducing the number of combinations to be tested, and of getting more information from each test conducted.

6.2 The Approach Adopted in PRIMAVERA

To develop integrated strategies, ideally every possible strategy combination should be simulated, however, time constraints meant that this was not possible. The queue management integrated strategy components would be implemented using either the SPOT or SCOOT UTC systems. There were a manageable number of possibilities for the SPOT based integrated strategies. The only reduction made was to reject the autogating strategy components as they performed poorly as individual strategies. All the remaining possible combinations were tested by simulation. This resulted in four integrated strategies in Leeds and six integrated strategies in Turin. For the SCOOT based strategies there were a larger number of strategy components and time did not permit every possible combination to be tested. The strategy combinations were reduced in a number of ways. Simulation runs were performed to determine which of the family of autogating strategies performed best, so that only this winning autogating strategy component would be used in further combinations. The SPOT runs had indicated that including bus priority was synergistic so this component was included in all the integrated strategies. Finally, speed advice was also included in all the integrated strategies to improve safety as the high number of accidents on the Dewsbury Road is a major concern. All the remaining eight strategy combinations were tested.

7. EVALUATING INTEGRATED STRATEGIES

Once the integrated strategies have been developed and implemented in the UTC system and their operational functionality tested through the simulations, off-line evaluation is used to provide a global assessment of the performance of the strategies. As described in the evaluation methodology section the assessment was made using two different types of analysis: a Multi Criteria Analysis and a Cost-Benefit Analysis.

7.1 Presentation of Results

When several performance indicators are involved (see MCA in Section 5.6) for several elements to be assessed, effective presentation of results can be very important. A clear and simple representation must be used in order to describe to the decision makers the performance of the strategies on the disaggregated impact goals as well as on a unique performance indicator.

To clearly represent the performance of the strategies according to the MCA PRIMAVERA has used a simple graphic representation that also shows easily the effect of the integration of different components.

As there are three goal indicators, three values can be associated with each strategy, one for each indicator; thus in PRIMAVERA each strategy was represented as a point in a three-dimensional space (evaluation space) where the axes correspond to the goals (safety, efficiency, environment) and the goals indicators act as coordinates of the point. The following figures show an example of this representation showing the distribution of points for the set of strategies tested in simulation in Torino.

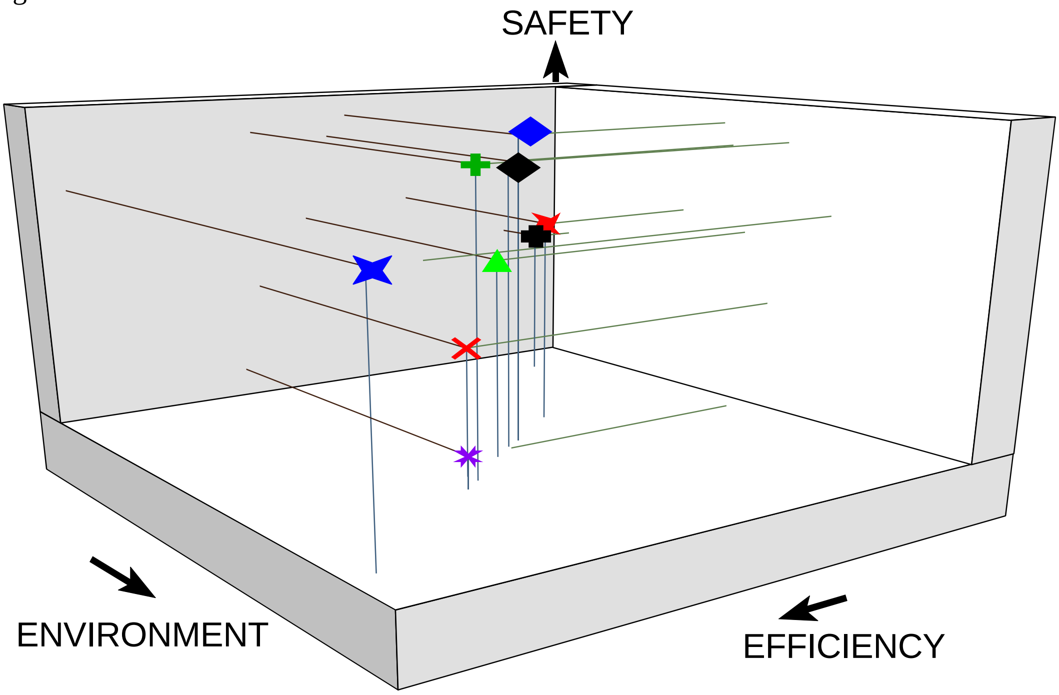

Figure 7.1: The Evaluation Space

From the example figure it is easy to see which strategy performs best in all three goals.

Such a figure can also aid understanding of the effects of integration of strategy components on the goal indicators.

The figure below shows an example again from the simulation results of Torino. Results are shown in the Efficiency-Safety view but are similar also in the Environment-Safety view.

If we start from the individual strategy B (bus priority) and we integrate a queue management technique (Q) we can see improvements in all the performance indicators. A further integration of a traffic calming component (S) leads to even better performance, while adding another traffic calming component (T) worsens all the indicators.

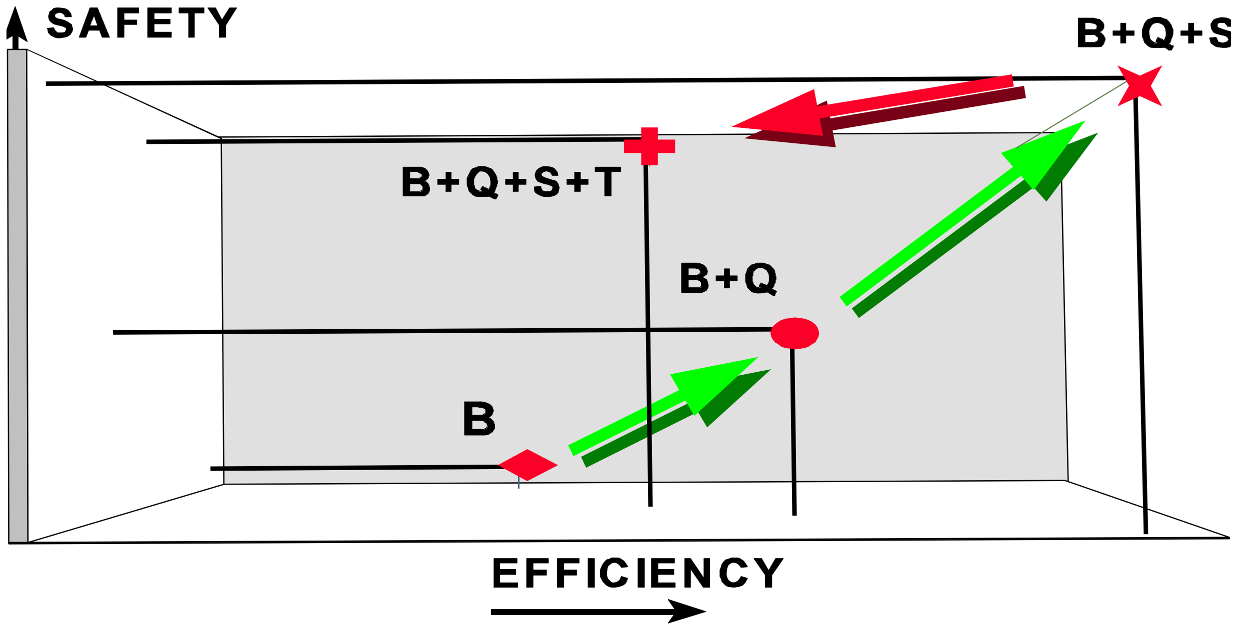

Figure 7.2: The Evaluation Space, effects of the integration of components

8. FIELD IMPLEMENTATION

8.1 Introduction

No matter how much advance planning and simulation has been carried out, the implementation of new techniques on-street will always produce some unforeseen problems. There are various reasons for this, including:

- failure to carry out a realistic risk assessment exercise [19] (the PRIMAVERA team found such an exercise very worthwhile);

- equipment may perform differently in the harsh on-street environment compared to the controlled conditions in the test lab;

- a simulation is never a perfect copy of real life, and there is always the possibility that some important aspect has been omitted;

- the realisation that on-street trials involve real vehicles and real people, tends to concentrate the mind in a way that can probably never be achieved with simulations. (Simulated traffic does not complain about long delays).

This chapter draws on the experience of the PRIMAVERA project members involved with the implementation of the Leeds field trials with respect to the following areas:

- the selective vehicle detection system
- the speed controlled variable message sign system
- the interface between the SPOT computers and UK signal controllers
- the data transmission system

For each area, the implementation of the system is described, together with details of the problems that arose and the lessons to be learned.

8.2 The selective vehicle detection system

Implementation

The SVD system adopted was a radio based system [20]. The aerial was in the form of a loop of wire buried in the road surface, with a transponder mounted underneath the vehicle.

This system is ideally suited to outdoor environments, being extremely robust and unaffected by temperature fluctuations, dirt, rain or snow. Because the transponder has no battery, it requires no maintenance. The system was found to work well in practice, with 100% of those buses known to be equipped with transponders being successfully detected and decoded in tests. The only recorded failures in such tests were where buses were found not to be equipped with transponders.

The transponder (tag) is held within a plastic housing bracket and attached to the underside of the bus. The aerial consists of a single turn of cable in the shape of a rectangle, buried within a slot cut into the road surface, in the same way as for conventional vehicle detection employed at traffic signals. The size of the rectangle is a function of the road width, and the distance of the reader from the loop. The reader is contained within a weather proof housing, mounted on a short pole within 5 metres of the loop at all sites.

At one of the four reader sites, the equipment had the capability of down-loading the serial numbers of tags detected and the time of detection. This information could be down loaded to a portable PC and was used to monitor the error rate of the system.

Problems

One of the problems related to the restriction on the maximum acceptable distance between the aerial loop and the receiver (5 metres). At a minority of sites, the inability to easily reposition the loop without moving the entire reader installation, meant that a non-ideal loop position had to be accepted.

A more serious problem related to the "non-detection" of certain buses which, on investigation, were shown to be buses not fitted with transponders. Despite assurances by the bus operators that this would not occur, operational requirements to move buses onto different routes meant that in practice it did.

Lessons

The SVD equipment proved to be highly reliable in terms of detecting buses which were equipped with transponders. A solution to the problem of non-equipped buses could be to provide a portable aerial/receiver unit so that buses could be tested at the depots. Alternatively, permanent systems could have been installed at the exit of depots to provide an indication (e.g. visual) of the correct operation of the transponder.

8.3 The speed controlled variable message sign system

Implementation

The type of VMS chosen was a fibre optic sign, the normal state of which is a blank screen. This was selected because of the following factors:

- It had proven reliability.
- The visibility was good in various weather conditions
- It was easily maintained (e.g. by a third party).
- Spare parts were readily available.
- It was already approved by the UK Department of Transport.
- The cost was acceptable

The form of speed detection used was a Microwave Vehicle Detector (MVD) unit, which was used in preference to a detector loop or piezo based system. MVDs are proven technology, they have low maintenance cost, ease of installation and a readily alterable speed threshold limit.

The sign location was selected after consideration of the following points:

- The provision of good visibility (i.e. adequate sight lines).
- The need for visual impact (depends mainly on height and size of sign)
- The need for easy access to the sign for maintenance vehicles.
- The requirement to eliminate legend 'ghosting' due to the low winter sun.

Clearly the speed at which the variable threshold MVD is set is critical, the philosophy being that the VMS sign should be triggered at slightly less speed than that at which the Speed Violation Camera is set. In the UK, however, Speed Violation Cameras' speed thresholds are set solely at the discretion of the police, although they base their settings on the following formula: speed limit (64 km/h) + 10% + 4.8 km/h. On this basis the MVD was set to the lower value of: speed limit (64 km/h) + 4.8 km/h.

Problems

Some initial problems were experienced with the MVD detector not responding to both lanes of the (two-lane) carriageway. This was corrected by horizontal adjustment of the MVD, and thereafter the system operated satisfactorily.

Lessons

The decision to use a VMS sign with integral speed detector (MVD) proved satisfactory once the initial adjustment problems were overcome. However, had the speeds been more variable between lanes, or the carriageway wider (i.e. more than two lanes), it would have been necessary to install speed detection on a lane-by-lane basis.

8.4 The interface between SPOT computers & signal controllers

Implementation

The interface system was built around an industrial specification PC/AT . Each SPOT unit was housed in its own cabinet adjacent to the traffic signal control cabinet which also housed the SCOOT type OTU. Cables were run between the two cabinets so that all relevant signals into and out of the controller could be physically diverted to either the SCOOT computer (via the SCOOT OTU) or the SPOT computer. Thus the signals could be under the control of one, but not both systems at any one time. Seven SPOT cabinets were built and as much as possible of the fixed wiring was done in the workshop before the cabinets were installed on street. Such things as the electrical services disconnection point and protective equipment were installed at this stage along with the telecommunications termination units. One end of each cable to the controller cabinet was also fitted with sockets before installation, whereas at the SPOT computer end this had to be done after installation.

Problems

The cabinets used were smaller versions of standard controller cabinets. The base supplied with them was deeper than the normal controller cabinet base and so extra excavation was needed at each site. Each base also had to be cut to provide large entry holes for the cable ducting.

Although the cabinets were adequate, the equipment only just fitted inside. Because of their length the SPOT units had to be installed sideways which made access to the rear connectors rather difficult. On several occasions this resulted in connector pins being bent or broken and constituted a real fault liability. This was alleviated by the provision of extra leads to extend the VDU and keyboard connectors to a more accessible position.

Some problems were encountered with the huge number of cable connections in the system, but out of more than 2000 terminations only 20 were found to be faulty.

Some confusion was caused by the lack of documentation relating to the meaning of I/O signals. After investigation it was found that the I/O software driving routine was not compatible with the signal controllers. It had been designed to accept a closed contact as an active input instead of the open circuit provided by the standard UK controllers. In order to avoid the operation of two different software systems (i.e. in Italy and UK), and to obviate the possibility of side-effects potentially inherent in a software change, the decision was taken to reverse the 'sense' of the input signals in hardware.

Although there were only seven cabinets housing SPOT computers, three cabinets were fitted with two units so there were ten SPOT controllers in total. The contract for the supply of this equipment did not provide for any spares holding, although it did have a contingency provision of course. In the event some failures did occur.

In addition, because of the lack of spares, it was not seen as desirable to use cards from other working units to test by substitution in case further cards suffered damage. This meant that on one occasion it was necessary to return a complete SPOT unit to the supplier for repair. Since the units had been imported from the USA, the acquisition of the necessary parts resulted in an uncomfortably long delay before the unit could be returned to service.

Lessons

The decision to use a plug and socket arrangement to change over control from SCOOT to SPOT was a good idea in principle, since it facilitated changing back and forth between the two systems to be accomplished easily and cleanly without any fear of interaction from the system not in control. However, in practice the frequency of changeover between the two systems was considerably higher than initially envisaged, such that a more robust mechanical arrangement would have been preferable.

The cabinet for a test system should be spacious enough to allow for easy access to all controls and connections.

Making as many of the terminations as possible in the comfort and controlled environment of the workshop also paid dividends in the small number of faults traced to wrong or poor connections. The remainder of the terminations which had to be done on street prompted the purchase of a protective tent to cover the exposed equipment (and personnel) because of the inclement weather (during November).

Reliance upon the quoted reliability of the equipment purchased from the USA for the SPOT computers proved to be a mistake. At least one complete replacement unit should have been immediately available. The provision of two replacement units would have been desirable, and would have allowed the spare units to be set up in the UTC workshop to simulate problems on the network.

Whilst every assistance was provided by the software authors, including telephone discussions and visits back to the UK, it would have been beneficial for configuration of the hardware to have taken place whilst the software personnel were still continuously available at the UTC Centre.

8.5 Data transmission system

Implementation

The Data Transmission lines were installed and commissioned by British Telecom. The data modems were originally obtained by competitive tender, but it proved difficult to achieve reliable adjustment. Eventually they were replaced by high quality, self-adjusting products supplied by British Telecom.

The communications equipment had to be fitted into each cabinet alongside the SPOT controllers. At some sites where two SPOT units and up to four BT termination units were installed this left little room for physical access.

Each of the links was set up and a modem installed at either end. Data was exchanged and then a SPOT unit was installed. It proved difficult to get error free communication between SPOT units at 9600 Baud over several of the links, despite all the links reporting no errors when tested by British Telecom transmission staff.

Problems

Initially, several of the communication links were unreliable. After extensive testing by BT engineers the problem was traced to one SPOT unit which had inadvertently been loaded with the wrong software. When the correct software was loaded, the problem disappeared.

Later in the project a repetitive failure at another site uncovered a faulty printed circuit board in the BT line terminating unit. This prompted an investigation of the other sites which uncovered several boards from the same batch with potentially the same problem. This was reported to BT and as a precautionary measure they promptly changed all the units supplied for the scheme.

After this the fault level dropped to no more than would be expected for these circuits.

Lessons

It was apparent that the Data Transmission system was the cause of many of the difficulties in making the system fully operational. This was partly due to lack of familiarity with the SPOT computers and the higher speed transmission rate employed.

The test equipment in use at the time was not ideal for the specific purpose but, more significantly, the provision of a clearer definition of the demarcations between Communications and Control functions would have been helpful. Control functions are now well catered for in terms of computing power, but it cannot be assumed that the provision of real-time control over a Communications network is a trivial matter - it is clear that this can so easily be the source of delay in project implementation.

8.6 Summary

The main lesson to be learned is that on-street implementation of innovative UTC schemes will inevitably encounter snags and setbacks. Unless sufficient leeway has been built into the hardware and software implementation programme, the field trials survey programme itself may be delayed. Experience has shown that a risk analysis is a useful tool for contingency planning, and that in any case as much flexibility as possible should be built into the design of field trials where new equipment is being tested so as to accommodate delays and interruptions.

9. EVALUATION OF IMPLEMENTED STRATEGIES

9.1 Overall Approach

Figure 9.1 shows the overall approach adopted to evaluation in PRIMAVERA. The starting point, as described in Section 2.3 was the determination of impacts of interest, and the selection of performance indicators (PIs) which a) would reflect those impacts faithfully, and b) could be measured adequately within the project budget and timescale.

Table 9.1 lists the impacts chosen for assessment in PRIMAVERA, and the PI's selected for each. Referring back to Figure 9.1, it should be noted that some PI's are link specific (eg queue lengths, spot speeds), others are system wide (eg fuel consumption), and others such as journey time, can belong to both categories.

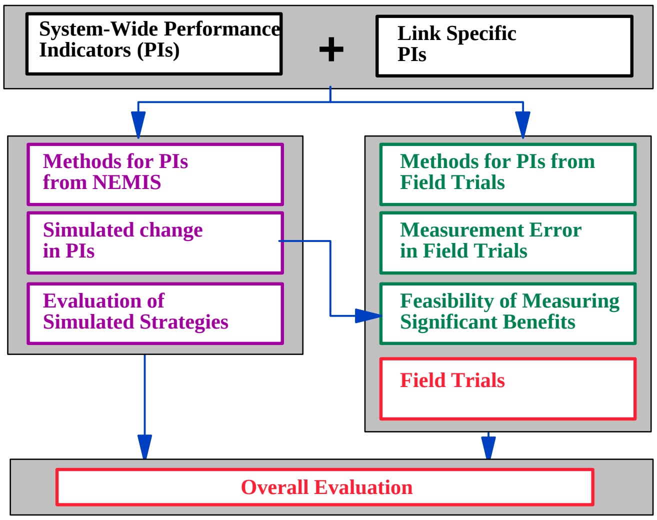

Figure 9.1: Approach to Evaluation

Impact	Performance Indicator (PI)
Journey Time	Lower Journey Time
	Reduced Variance
Speed	Reduced Variance
	Fewer Excessive Speeds
Vehicle Operating Cost	Reduced Operating Cost
	Reduced Fuel Consumption
Comfort	Fewer Stops
Safety	Fewer Conflicts
Pollution	Reduced Emissions
Crossing Delay / Severance	Less Crossing Delay
Visual Intrusion	Shorter Queues
	Lower Flows
Stress	Fewer Stops
	Shorter Queues
Flow	Little Change
	Higher Bus Occupancy

Table 9.1: PRIMAVERA Performance Indicators

The strategy finally selected for field trials will of course have been simulated beforehand, and Figure 9.1 shows that the results of those simulations have an input to the overall evaluation in two ways as follows:

a) Direct estimation of the value of those PI's which, for whatever reason, cannot be measured in the field (eg vehicle emmisions).

b) The likely degree of change in a given PI predicted by the simulation, together with the estimated measurement error associated with the particular survey technique, can be used in calculating the sample size required in the field surveys. Thus the feasibility of measuring significant changes in the PI within the constraints of the survey can be determined.

Thus the final overall evaluation of a field tested strategy consists of a combination of results from field trials and simulations. Table 9.2 shows the sources of the PIs used in the PRIMAVERA overall evaluation.

Performance Indicator	NEMIS	Field Trials
Journey Time	✓	✓ MVO + NPM
Speed	✓	✓ Spot Speeds
Vehicle Operating Cost	Calculated	✓ Calculated
Stops	✓	✓
Conflicts	Not modelled	✓ Conflict surveys
Pollution Emissions	Calculated	✕
Crossing Delay	Not modelled	✓
Queue Lengths	✓	✓
Flows	✓	✓
Bus Occupancy	Not modelled	✓

Table 9.2 Sources of PRIMAVERA Performance Indicators

9.2 Statistical Considerations

The main use of statistics in the context of field trials is in testing the hypothesis that there has been a significant change in an indicator variable (such as mean travel time, number of serious conflicts etc). Traffic data exhibits a great deal of variation due to a numerous factors such as weather, roadworks, public events etc on top of the regular cyclic variations (by time of day, day of week, season of year), and secular trends. If the change brought about by an ATT strategy is small compared to this existing variation, then it may be very difficult (perhaps impossible) to tell whether the differences observed between 'before' and 'after' the strategy are really due to the strategy, or simply due to chance. In order that meaningful conclusions can be drawn from before and after studies, it is necessary that i) an appropriate experimental design is used; ii) sufficient data is collected. (It may be noted that a major reason behind the establishment of Topic Group 8 and the subsequent CORD Guidelines (see 9.3) was the fear that, without guidelines, many project field trials could produce results which were statistically unsound.)

Thus the experimental design for the PRIMAVERA project was critical to establishing and measuring the impact of the integrated transport strategies not only in simulation but more importantly in the field. Deliverable 11 (Data Collection and Evaluation Methodology) showed that significant and meaningful results could be obtained through the careful choice of impact variables and associated evaluation criteria. Using the procedures described in Deliverable 11, it was thus possible to collect and measure field trial data which was used as a basis for sound and rigorous statistical analysis.

Formulae are given in Deliverable 11 for estimating sample sizes required for the following:

- Estimating the mean of a variable (eg speed) to a given accuracy;
- Detecting a change of a given size in the mean of a variable;
- Detecting a change in the variance of a variable;
- Detecting a change in the proportion of vehicles having a given characteristic (eg the proportion exceeding a given speed).

As an example of the calculation involved, the procedure for estimating the sample size required to estimate the mean speed to a given accuracy is reproduced below:

9.2.1 An example of estimating sample size

An overall definition of the sample size required (n) to estimate the mean speed along a link to a given degree of accuracy is given by Fowkes and Watson [21]

$$n = \frac{var(x)}{\bar{x}^2[cv^2(\hat{y}) - cv^2(F_1) - cv^2(F_2) - cv^2(F_3) - cv^2(F_4)]} \qquad \textbf{(1)}$$

where $cv^2(\hat{y})$ is the coefficient of variation in the estimate of average speed on any weekday in any year (the object of our interest).
x is the measured speed along the links
$cv^2(F_1)$, $cv^2(F_2)$, $cv^2(F_3)$ and $cv^2(F_4)$ are coefficients of variation for grossing up factors and sources of variability as follows:-

F_1 grosses up from a particular hour to an average hour
F_2 grosses up from a particular weekday to an average weekday
F_3 grosses up from a particular month to an average month
F_4 has mean 1 but variance which allows for unexplained (Ambient) variability

At present such grossing up factors are not readily available and so may have to be derived from other survey data. Intuitively it is clear that the more conversions that are required, the greater the sources of variation introduced and therefore the larger the required sample size is likely to be. In the simplest case, we are interested in a particular hour in a particular day and particular month so the use of conversion factors is therefore avoided.

In such a case, (1) is reduced to

$$n = \frac{var(x)}{\bar{x}^2 cv^2 \hat{y}} \qquad \textbf{(2)}$$

Say we wish to estimate y to within ± 10% of its true value with 95% confidence in the result.

We then introduce the constraint

1.96 SD (ŷ) = 0.1 ŷ

(from established sampling theory and assuming a normal distribution for speeds)

$$then \quad cv(\hat{y}) = \frac{SD(\hat{y})}{\hat{y}} = \frac{0.1}{1.96}, \; so \quad cv^2(\hat{y}) = \frac{0.1^2}{1.96^2}$$

Substituting in (2) gives

$$n = \frac{\frac{cv^2(x)}{0.1^2}}{1.96^2} \quad i.e. \;\; 19.62^2 cv^2(x)$$

$$giving \;\; n = \underline{384 \;\; cv^2(x)} \qquad \textbf{(3)}$$

The final figure for the sample size depends on the value of $cv^2(x)$ ie the coefficient of variation in measured speed along the link, and different values will be required for each link of interest. If we are interested in a more accurate result, ie to estimate mean speeds to within ± 5% of their true value with the same 95% confidence then $cv^2(\hat{y})$ becomes

$$cv^2(\hat{y}) = \frac{0.05^2}{1.96^2}$$

and the required sample size is

$$n = 39.2^2\, cv^2(x)$$

ie $\underline{n = 1537\, cv^2(x)}$ **(4)**

As already stated (3) and (4) refer to the simplest possible survey design where we are interested in a specific hour/day/month. If we wish to generalise to speeds for any month ie we survey in March but with the estimate speeds for an 'average' month then the conversion factor F_3 comes in to play and the corresponding sample size requirement is:

$$n = \frac{cv^2(x)}{cv^2(\hat{y}) - cv^2(F_3)} \qquad \textbf{(5)}$$

A reasonable estimate for $cv(F_3) = 0.02$ (see [21]) so to estimate y to within ± 10% with 95% confidence we get

$$n = \frac{cv^2(x)}{\left(\frac{0.1^2}{1.96^2} - 0.002^2\right)} = \underline{384.75\, cv^2(x)} \qquad \textbf{(6)}$$

and to estimate y to within ± 5% with 95% confidence

$$n = \frac{cv^2(x)}{\left(\frac{0.05^2}{1.96^2} - 0.002^2\right)} = \underline{1546.1\, cv^2}(x) \qquad \textbf{(7)}$$

comparing (3) and (4) with equation (6) and (7) we see that the generalisation to an average month is unlikely to lead to a greatly increased sample size requirement working to a 10% accuracy. At the more precise 5% accuracy requirement a more marked effect may be seen. Of course the precise values of n will depend on $cv(x)$.

The above sample sizes refer to estimation of mean speeds, but the main concern of the evaluation study will be to detect a statistically significant difference in the mean speeds for the before and after surveys. As far as the goal of the integrated strategy is concerned, we require that a successful outcome should either reduce mean speeds (through traffic calming measures) or at least retain existing mean speeds with a significant reduction in their variability. The latter would be the result of a more controlled progression of traffic through the system. If we are not concerned with the size of the strategy impact, but merely wish to check whether any significant change has taken place, then it is sufficient to measure mean before and after speeds to a given accuracy as illustrated in equations (1) to (7).

A formal test for a significant difference in mean speeds can then be given by testing

H_0: $(\mu_1 - \mu_2) = 0$
H_1: $(\mu_1 - \mu_2) > 0$ (ie a 1 tailed test as we can only hypothesise that the speed has reduced)

Where μ_1 is the theoretical mean for the 'before' speed and μ_2 is the theoretical mean for the 'after' speed.

The test statistic is then given by

$$z = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{sd(\bar{x}_1 - \bar{x}_2)} \tag{8}$$

$$and \quad var\,(\bar{x}_1 - \bar{x}_2) = \frac{s_1^2}{n_1} + \frac{s_2^2}{n_2} \tag{9}$$

assuming large samples ie n_1, n_2 > 25 and s_1^2, s_2^2 are the sample variances for the before and after studies respectively.

If the sample sizes are less than 25, then a pooled estimate of the variance could be used, provided the variance of the populations could be taken to be equal.

$$ie \quad \hat{s}^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \tag{10}$$

and the test statistic compared to the t-distribution

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\hat{s}^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{11}$$

Since we expect the integrated strategy could affect the variance in speeds the assumption of equal population variances is unlikely to hold, in which case we would apply the Welsch t-test. This uses equation (11) but with degrees of freedom given by:-

$$df = \left[\frac{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2^2}}{\frac{\frac{s_1^2}{n_1^2}}{n_1 - 1} + \frac{\frac{s_2^2}{n_2}}{n_2 - 1}} \right] \qquad \textbf{(12)}$$

9.3 CORD Guidelines

PRIMAVERA was one of 57 projects running concurrently in the DRIVE II programme. In order to coordinate their activities and achieve cross fertilisation of ideas, representatives of each of the projects attended concertation meetings in Brussels every 2-3 months. The format of these two-day meetings was organised by the Transport Telematics Central Office (TTCO). The main business was carried out either in the seven Areas (in which projects were grouped according to their area of application, eg Urban Traffic Management) or in the ten Topic Groups (in which specific issues concerning several projects could be discussed). Topic Group 8 was concerned with Assessment and Evaluation of Projects, and had a membership of around 30 projects. In order to facilitate the objectives of this Topic Group, TTCO accepted a proposal by the CORD project to establish a Task Force on Evaluation, the aims of which were to "carry out the work of preparing and delivering guidance to the projects on harmonised approaches and methods for assessment for key impacts, applications and technologies." (CORD deliverable AC07 Vol 5). Eight working groups were established corresponding with different application areas, and a set of "guidelines for assessment" produced by each working group for its application area. The working groups consisted of delegates from the projects, and therefore the guidelines reflect the consensus view of those projects participating.

The PRIMAVERA project was a major contributor to Working Group 4 (Urban Traffic Management and Information) and the Guidelines resulting from that group are contained in CORD deliverable AC07 Vol 4 [22]. This deliverable gives "details of the assessments being undertaken by projects in the Urban Traffic Management and Information Working Group of the ATT Task Force on Evaluation. It identifies the commonalities in system objectives, evaluation methods and indicators, and areas where comparative studies of project results can be carried out."

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