ASSESSING THE ENERGY IMPACTS OF URBAN TRANSPORT MANAGEMENT MEASURES

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ABSTRACT: *This paper can be conveniently divided into two main parts, namely: a description of the results of a case study involving the modelling of specific traffic management proposals for the central area of Liverpool; and an assessment of the likely energy consequences of urban transport management measures.*

A number of traffic management measures were tested in the central area of Liverpool by means of a simulation/assignment model - SATURN, which incorporates a fuel consumption sub-model. After outlining the SATURN model, the paper describes in detail its fuel consumption sub-model and the application of SATURN in Liverpool.

The second part of the paper reports on the results of a study into the likely energy effects of urban transport management measures. These include traffic engineering and car restraint measures. The results are placed in the context of overall national fuel consumption in the UK and it is concluded that the achievable savings from individual measures are likely to be small.

* *The work reported here was carried out whilst the author was employed by the Institute for Transport Studies, University of Leeds, England.*

INTRODUCTION

This paper reports on some of the findings of a research project undertaken by the author whilst at the Institute for Transport Studies (ITS), University of Leeds.

The primary objectives of this research work were twofold, namely:

1) to develop fuel consumption sub-models to be used in conjunction with conventional traffic assignment models as well as more detailed simulation-assignment models; and

2) to estimate the likely energy impacts of urban transport management (UTM) measures at the level of the individual area, and to assess the potential that such measures may have in helping to reduce the total national oil consumed in transport.

During the last decade there has been considerable research into ways to reduce the heavy dependence on petroleum products by transport in general and road traffic in particular. Such work has concentrated on developments in vehicle technology and alternative fuels which are the areas where potential savings are likely to be greatest. The quantification of the positive as well as adverse fuel consumption consequences of UTM measures, is an area of research which has not received as much attention. This is mainly because the implementation of such measures are the direct responsibility of individual local authorities for whom energy conservation is not usually a high priority.

There are two main reasons why this trend should be reversed, namely to promote awareness on the part of local planners, elected representatives and other interested parties, of the energy consequences of transport management measures so as to encourage energy conservation; and to quantify the extent to which it is possible to reduce national oil consumption in transport through UTM measures.

The paper is organised as follows. In the next section the SATURN traffic simulation/assignment model is briefly described with specific emphasis placed on the fuel consumption sub-model incorporated in it. This is followed by a section dealing with the use of SATURN to assess the fuel consumption implications of a number of traffic management measures proposed for the central area of Liverpool. Finally, a summary of the results of an assessment of the national fuel saving potential of a range of UTM measures is presented.

THE SATURN TRAFFIC SIMULATION/ASSIGNMENT MODEL

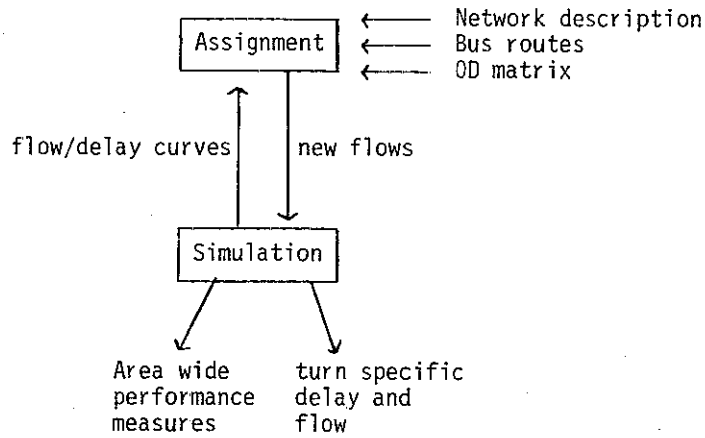
General

SATURN (Simulation and Assignment of Traffic in Urban Road Networks) is a detailed traffic assignment model which incorporates two main components: a detailed simulation model of traffic flow, and a traffic assignment model which uses an 'equilibrium' technique based on an optimum combination of all-or-nothing assignments. The simulation stage determines intersection

delays resulting from a given demand pattern and is based on the same fundamental assumptions used in the traffic model of the TRANSYT program, namely: that the pattern of traffic demand is constant over the time period being studied (normally of the order of 30 minutes or 1 hour); and that traffic flows exhibit a cyclic behaviour which is a direct result of the dominance of traffic signals operating under a common cycle length over the area being studied. In this way only one cycle is simulated and the traffic flow is represented by 'flow profiles'. The simulation therefore takes place by manipulating the shapes of these 'profiles' to take account of platoon dispersion from one junction to the next, the supply characteristics of each turning movement at a junction, and the pattern of opposing flows at the junction. The common cycle time is divided into an equal number of time units or slices (user specified), which form the basic unit of analysis.

Flow-delay curves for each turning movement, based on a given demand, are calculated and passed on to the assignment phase. The latter uses this information to update travel times and hence determine a new pattern of route choice, which is then passed through to the simulation. This iterative process, which is shown in Figure 1, continues until a stable pattern of flow is achieved for each turning movement. The criterion for stability is user specified and under default conditions the model stops when 85 percent of turning movement flows are within 5 percent from one iteration to the next.

FIGURE 1 The SATURN model - basic structure



The input data consists of a road network description, an OD vehicle trip matrix for the time period being studied, and a description of the bus routes and corresponding frequencies. Since the modelling of intersection delays plays such an important role in the simulation stage, a detailed description of each junction, or node, is required. A full description of the characteristics of each 'in-link' joining a node is necessary, in terms of its length, average free flow travel time, number of entry lanes, capacity of each turning movement, and a list of the lanes used by each turn In addition full details of signal settings and offsets must also be input where appropriate.

The output obtained from SATURN is of two main types, namely: junction based delay data and system-wide measures of performance. The latter include the total distance travelled, total delayed time, total travel time, total number of stops, total number of first time, or primary, stops, and total fuel consumption. For each turning movement at a junction the following information is output: average delay to vehicles at the start and end of the time periods being modelled, the capacity of the turning movement; the assigned or 'demand' flow given by the assignment stage which corresponds to the total demand, and the 'simulated' flow which corresponds to the actual flow simulated during the time period. The difference between the 'demand' and the 'simulated' flow is the amount of traffic which wishes to but is not allowed to reach the node during the time period being modelled due to queues upstream of that node. This difference which is a form of 'suppressed' demand, may be 'passed' on to a subsequent time period and modelled then. The structure of the model has been described in detail by Hall et al (1980) and a more recent paper by van Vliet (1982) deals with the latest improvements made to SATURN.

Fuel Consumption Estimates

Two types of urban fuel consumption estimation procedure were investigated, namely:

(i) A linear relationship between fuel consumed (FC), and total distance travelled, D, and total travel time, T, of the form:

$$FC = k_1 D + k_2 T \qquad \ldots (1)$$

where k_1 and k_2 are constants found from empirical evidence and T is calculated using total travel time including all delay and stopped time. The available evidence suggests that by using such an equation only some sixty to seventy percent of the variation in fuel consumption, from one road section to another, is explained.

In spite of this shortcoming such an expression is useful in that it can be used with the output of conventional transport demand modelling techniques. The traditional four-step process which begins with trip generation and ends with the loading of traffic onto a road network, i.e. traffic assignment, provides overall distance travelled and time spent on the network, thus enabling fuel consumption to be estimated directly.

The average vehicle for the U.K passenger car fleet was taken to have an engine size of 1500 cc. Although this value is subjected to errors, the subsequent use to which it is put here means that the value is fairly insensitive to small changes in vehicle size. For such an average vehicle the values for k_1 and k_2 which were put forward are 0.07 l/km and 1.65 l/hr respectively.

This type of fuel consumption sub-model is deficient, in the context of urban traffic management evaluation, since it does not take explicit account of the effect of acceleration/deceleration

cycles under congested driving conditions. We can have the situation where the same total travel time is taken to travel a given distance on two different runs although the number of stops made may be different. As far as fuel consumption is concernned it clearly matters whether one's time is spent idling in a queue or decelerating to and accelerating from a stopped position.

(ii) A number of researchers have highlighted this problem, and models which take direct account of the number of stops have been proposed, Vincent et al (1980), Messenger et al (1980), and Akcelik (1980). Such models usually take into account three separate elements of an urban trip, namely:

1) Distance travelled at cruising speed (D)
2) The amount of stopped time (T_s)
3) The number of stops made (S)

Fuel consumption, FC is thus expressed as:

$$FC = a_1 D + a_2 T_s + a_3 S \qquad \ldots (2)$$

where a_1 = fuel consumed at a steady cruising speed
a_2 = idle fuel flow rate
a_3 = excess fuel per complete stop.

The coefficient a_3 represents the difference between the fuel consumed during a complete stop/start cycle and that fuel which would be consumed if the same distance was travelled at an assumed cruising speed. The time spent stopped is not included here since it is already allowed for under the second term of the equation.

From the results obtained from a recent survey in Leeds using two instrumented vehicles, Ferreira (1982), a fuel consumption expression was derived with the following coefficients:[1]

$$FC = 0.07\ D + 1.2\ T_{Del} + 0.016\ S_1 + 0.005\ S_2 \qquad \ldots (3)$$

Where the coefficient of S_1 - 0.016 litres/stop - assumes that first time stops are made from an average speed of 48 km/h - the assumed cruising speed - and the coefficient of S_2 - 0.005 litres/stop - assumes that the average 'queue-crawling' stop reaches a speed of 20 km/h. Equation (3) shows the default coefficient values presently used in SATURN although it is possible to arrive at different values by using other assumptions more appropriate to local conditions and the methodology described in Ferreira (1982).

The case for using a particular method of fuel consumption estimation depends on the use to which the results will be put, i.e. the reasons for the estimation in the first instance, as well as on the level of detail of the available input data. The more detailed expression, which includes the two types of stops, is to be preferred for an evaluation of a number of different traffic management schemes for an urban area where the degree of congestion is high and the main objective is to alleviate that congestion. This is the case of such traffic management measures as improvements to

[1] In equation (3) FC is in l/100 km and T_{Del} in veh-hrs.

junction control (either individually or as part of an area traffic control system), vehicle restraint measures or the introduction of environmental areas.

The coefficients given above do not include the effect of starting with a cold engine which can be considerable in the case of very short trips. If the average journey length and the proportion of trips which start from cold are known, it is possible to adjust the equations by adding an additional term which would be a constant - i.e. the excess fuel due to a 'cold' start per trip - times the number of trips affected.

Other factors not accounted for directly by any of the sub-models proposed here include the effect of slowdowns and other speed fluctuations, as well as the effect of different gradients. This latter factor may be important when transferring the results in space or when quantifying the effects of UTM measures which are likely to cause rerouting to or from links of considerably different gradients.

AN APPLICATION OF SATURN IN LIVERPOOL

The SATURN model was used to evaluate the fuel consumption consequences of several traffic management measures proposed by the local planning agency. This work was part of a joint project between ITS and the Joint Transportation Unit (JTU) of Merseyside County Council.

The central area of Liverpool covered by the study was sub-divided into a 'core' area surrounded by an outer region or 'buffer' zone. This distinction refers to the level of detail at which the road network and zoning system were treated in the modelling process. The 'core' area, which is under 2 km^2, was modelled in detail using SATURN, and is the area where all traffic management measures reported here were introduced. Outside this 'core' area, a further area was represented in the modelling process by a network which was coded to the same level of detail as that required by a conventional assignment model. This 'buffer' network was incorporated in order to assess the rerouting effects of introducing major highway schemes outside the 'core' part of the central area. The network representation of the SATURN area (i.e. the central 'core'), and the 'buffer' area, are shown in Figures 2 and 3 respectively.

Details of the calibration process which used 1978 as the base year, are given by Choraffa and Ferreira (1983). A brief description of the tests undertaken and the results obtained will now follow.

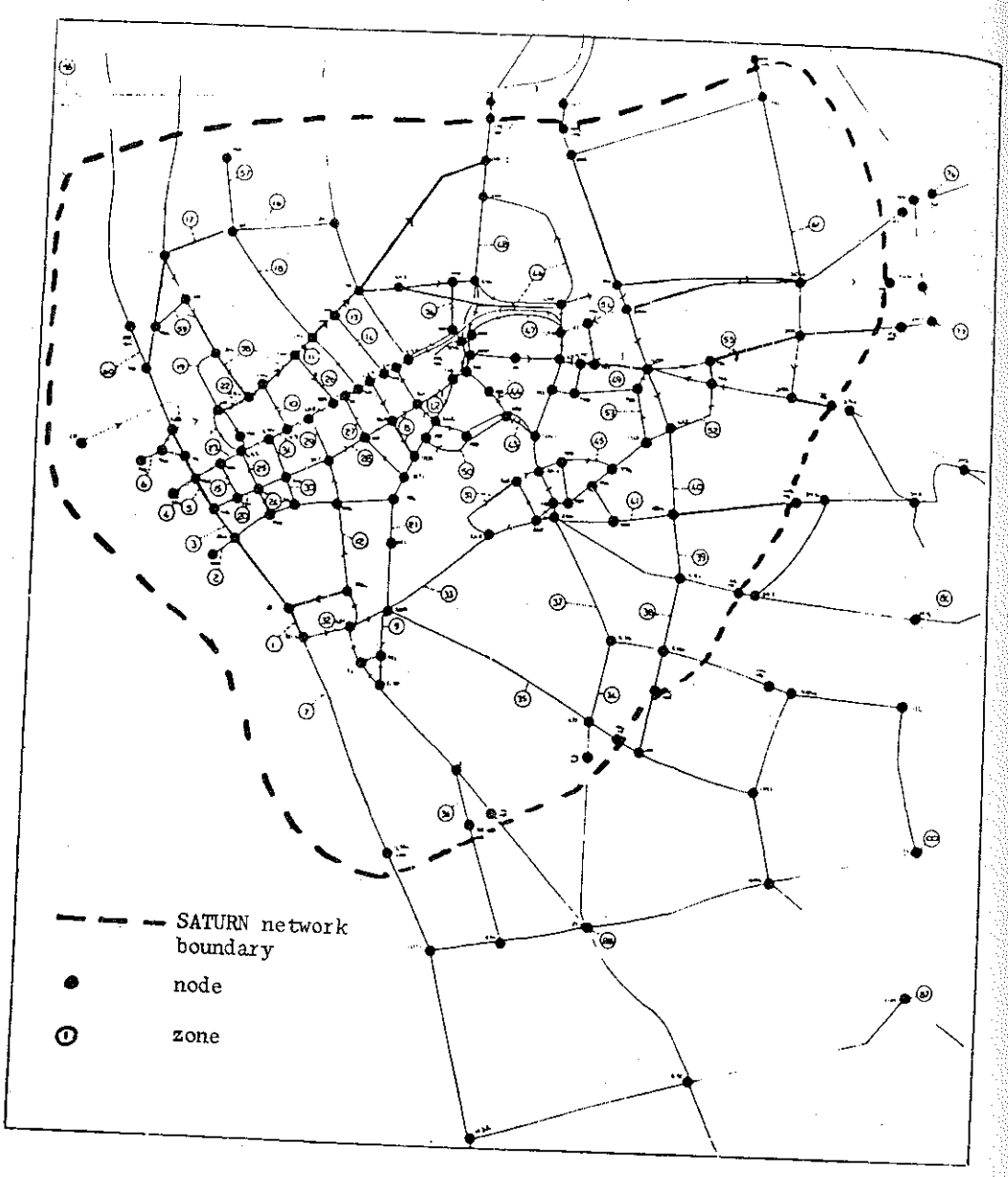
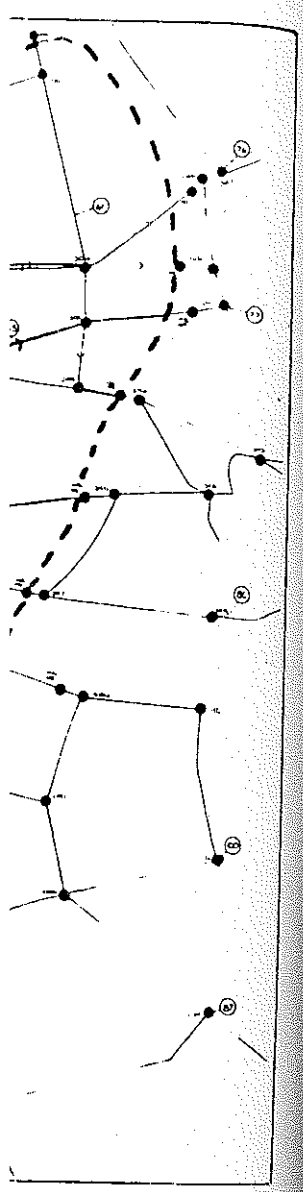


Figure 2 _ The Liverpool SATURN network



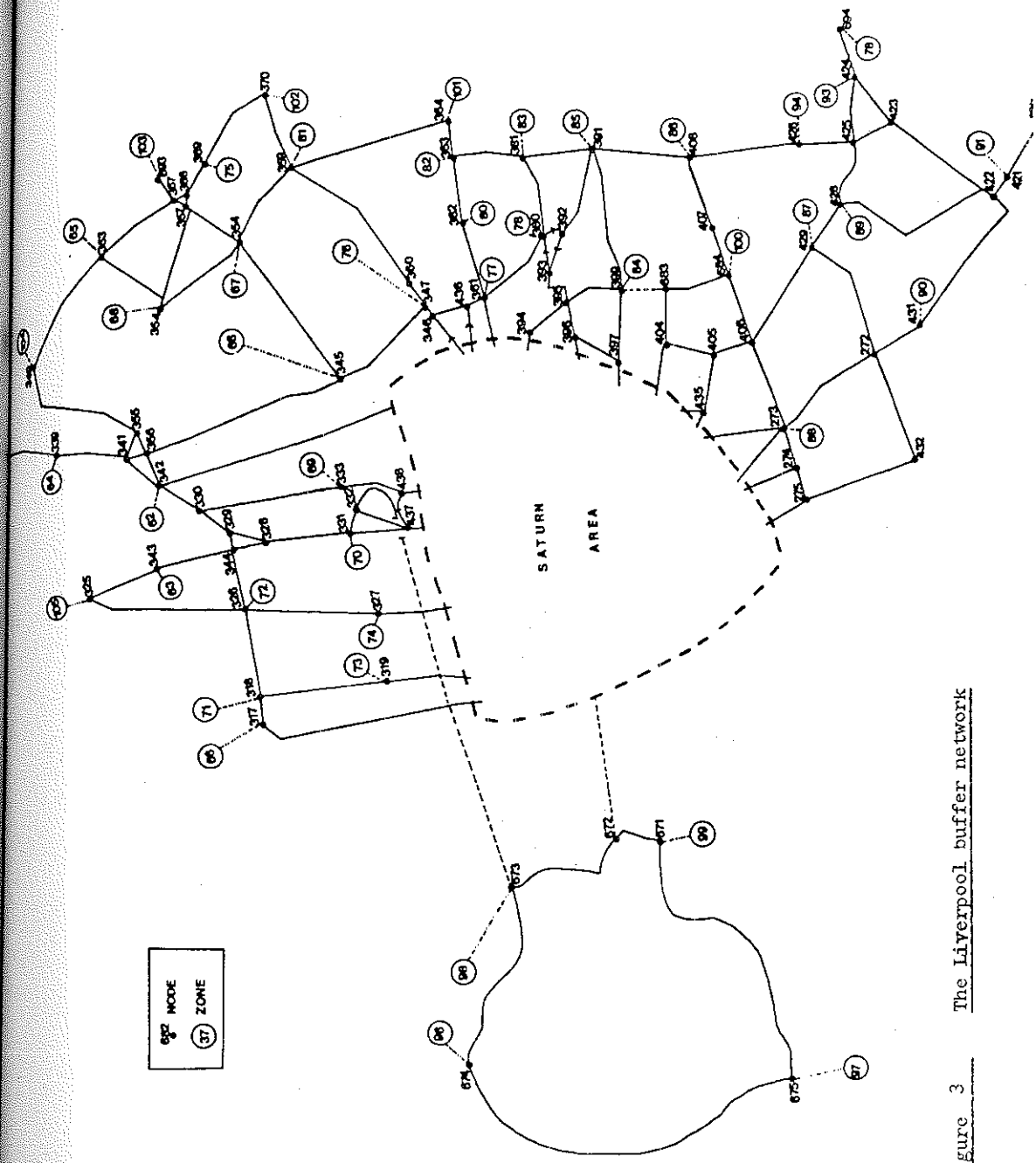


Figure 3 The Liverpool buffer network

Testing UTM Measures

The measures assessed with the help of SATURN can be conveniently divided into two types, namely those that have been put forward by Merseyside County Council planners, either as schemes awaiting implementation or as proposals felt to be implementable in the near future; and those measures which are of an 'academic' nature in the sense that they do not represent current views of local planners, but are felt to be relevant in the context of the work reported.

Test A

The first test carried out was the base or 'do-nothing' situation for 1982. Those changes which had taken place, were under construction, or were contracted to be constructed during 1982 were incorporated as changes to the 1978 network, the main items are:

(i) the upgrading of existing roads to the west and south of the city which form part of the inner ring road

(ii) the completion of a new length of road extending the line of the inner ring road round the north of the city.

The global performance statistics obtained from this test formed the basis for comparison with all other subsequent tests. The results of such a comparison are shown in Table 1.

Test B

In addition to those changes incorporated in Test A network, certain proposals, while not approved by the County Council, were considered to be highly likely to be implemented irrespective of any of the less certain proposals for change which the current study was to consider. This test included these changes over and above those already in the Test A network. The main changes were:

(i) closure of a one-way street to general traffic with part of its length remaining for two-way bus usage only, as access to a large bus terminus

(ii) the closure, as part of a pedestrianisation scheme, of a bus only link and the transfer of services to an adjacent route, utilising the bus terminus mentioned in (i)

(iii) conversion of two links from one-way operation to two-way operation with certain restrictions on access and associated bus route changes.

As can be seen from Table 1, these changes resulted in a small operational penalty, travel distance increased by 3 percent while travel time and delay both decreased by 1.7 percent and 6.8 percent respectively, resulting in an increase of 1 percent in fuel consumed. This was not unexpected since the basis for most of the modifications was environmental and local access improvement. The test served to confirm that no particular operational problems would arise at any specific junction due to the changes.

Test C

Changed circumstances had prevented the completion of the inner ring road in its originally envisaged form, with sections to the west, north and south being completed or under contract, but that to the east being abandoned. Proposals for some improvement in this corridor were developed, involving upgrading several existing roads and restricting access to them, and improving the capacity for certain movements at two junctions, the intention being to divert traffic from parallel routes within the city to this corridor. These changes were imposed on the Test B network and had the effect of redressing the losses at global statistic level experienced by Test B over Test A, as indicated in Table 1. Some diversion did take place, but not to the degree expected.

Test D

The main component of this test was the introduction of a new bus routeing strategy which was developed by officers of the Passenger Transport Executive in consultation with JTU officers. The strategy had two main objectives. The first was to reduce the number of bus terminii in the central area, concentrating operations on purpose-built facilities. The second objective was to route inbound and outbound legs of the same service so that they used a common route.

Global statistics showed a slight worsening of the operational efficiency of the network, but it must be remembered that the same trip matrix was being used for all tests, whereas in practice the availability of different access routes resulting from the extensive change to two-way operation may well have an effect on the distribution of car trip ends. The test did serve to illustrate, however, that despite this constraint on trip ends, only minor operational problems at two junctions occurred, so that the basic premise of change of this nature could be considered feasible and worth further investigation.

Test E

The strategy in Test D was re-run with additional modification, introduced for environmental reasons, to assess in broad terms, the effects on capacity of removing road space. Seven road closures were incorporated, four links converted from one-way to two-way operation, two links converted to one-way operation and one new two-way link added. The reduced road space resulted in a small increase in travel distance, but the reduction in travel time resulting from less junction conflict served to offset this.

The Effects of Cycle Time Changes

The 1978 peak period OD matrix and road network, were used to determine the effect of changing the common cycle time within the central area. The SATURN network comprises 49 traffic signals operating under a peak period signal plan derived from TRANSYT with a common cycle of 75 seconds. This is a short length cycle to accommodate the high pedestrian flows present in the central area.

Figure 4 shows the results of a comparison between this cycle length and those of 90, 105 and 120 seconds, with the 5 performance indicators

Table 1 Traffic Management Options - Areawide Statistics

Performance Measure Index (1) / Test	Number of trips in O-D Matrix	Travel Distance	Travel Time	Delayed Time	Number of Stops	Fuel Consumed
Base 1978 (p.m.)	101.3	96.9	94.0	91.2	96.0	96.1
A	100.0	100.0	100.0	100.0	100.0	100.0
B	100.0	103.3	98.3	93.2	103.5	101.0
C	100.0	100.4	101.3	100.4	101.2	99.9
D	100.0	99.8	102.3	104.3	102.4	101.9
E	100.0	101.2	97.8	93.4	95.4	99.8

(1) With Test A = 100

Number of Stops	Fuel Consumed
96.0	96.1
100.0	100.0
103.5	101.0
101.2	99.9
102.4	101.9
95.4	99.8

shown expressed relative to the base cycle (i.e. 75 seconds). The cycle lengths used here encompass the range of values most commonly used in practice. As can be seen from Figure 4, fuel consumption remains relatively unchanged for all cycles tested. As cycle length increases there is a reduction in travel distance and number of stops, and this is offset by increases in total delay. These results suggest that, as travel times increase, rerouting takes place onto more direct routes (in distance terms). Although total travel time is some 10 percent higher for a cycle of 120 seconds compared with the base cycle, fuel consumption is hardly changed because of a 5 percent reduction in travel distance and a 3 percent reduction in the total number of stops. It is difficult to transfer the results to other areas because it is not possible to know whether either the pattern of demand or the network characteristics make these results applicable to other situations.

It should also be noted that the various cycle times were tested with unchanged signal times and offsets. The signal timings and offsets used throughout were those corresponding to a cycle length of 75 seconds, and used in the calibration of the model. They were therefore optimised by the TRANSYT program for that specific cycle length and set of flows. Since the demand pattern changes with cycle length, i.e. some rerouting takes place, new signal timings would be required. Revised values for the offsets would also be needed for each cycle time chosen.

Demand Management Measures

SATURN, being a detailed assignment model, is only able to deal with route choice and is not designed to predict the effects of those policy options which are designed to influence modal shifts. However it is possible to use the model to predict changes in link traffic levels that would result from assumed changes in the number of vehicle trips travelling between given zone pairs. In this way it is possible to model the effects of OD matrix changes to the traffic flow characteristics, at both the local and areawide levels.

Although specific demand management measures such as car restraint, parking policies, and public transport fare subsidies cannot be modelled directly, it is possible to evaluate the upper bounds of the likely benefits of such policies in terms of their ability to reduce peak period congestion.

Figure 5 shows the results of the analysis carried out on the sensitivity of the outputs to changes in the overall size of the OD matrix. The base used here is the one-hour evening peak OD used in the calibration of SATURN. The entire matrix was factored to ± 50 percent of the base, in 10 percent steps, and the results for the corresponding changes in travel distance, travel time, delay, stops and fuel consumption, are shown here. For example, if it were possible to reduce the overall level of tripmaking by 20 percent, uniformly over the area, the overall fuel consumption would be reduced by approximately 25 percent. The corresponding increase in fuel consumption due to an increase in the size of the OD of 20 percent, would be in the region of 35 percent.

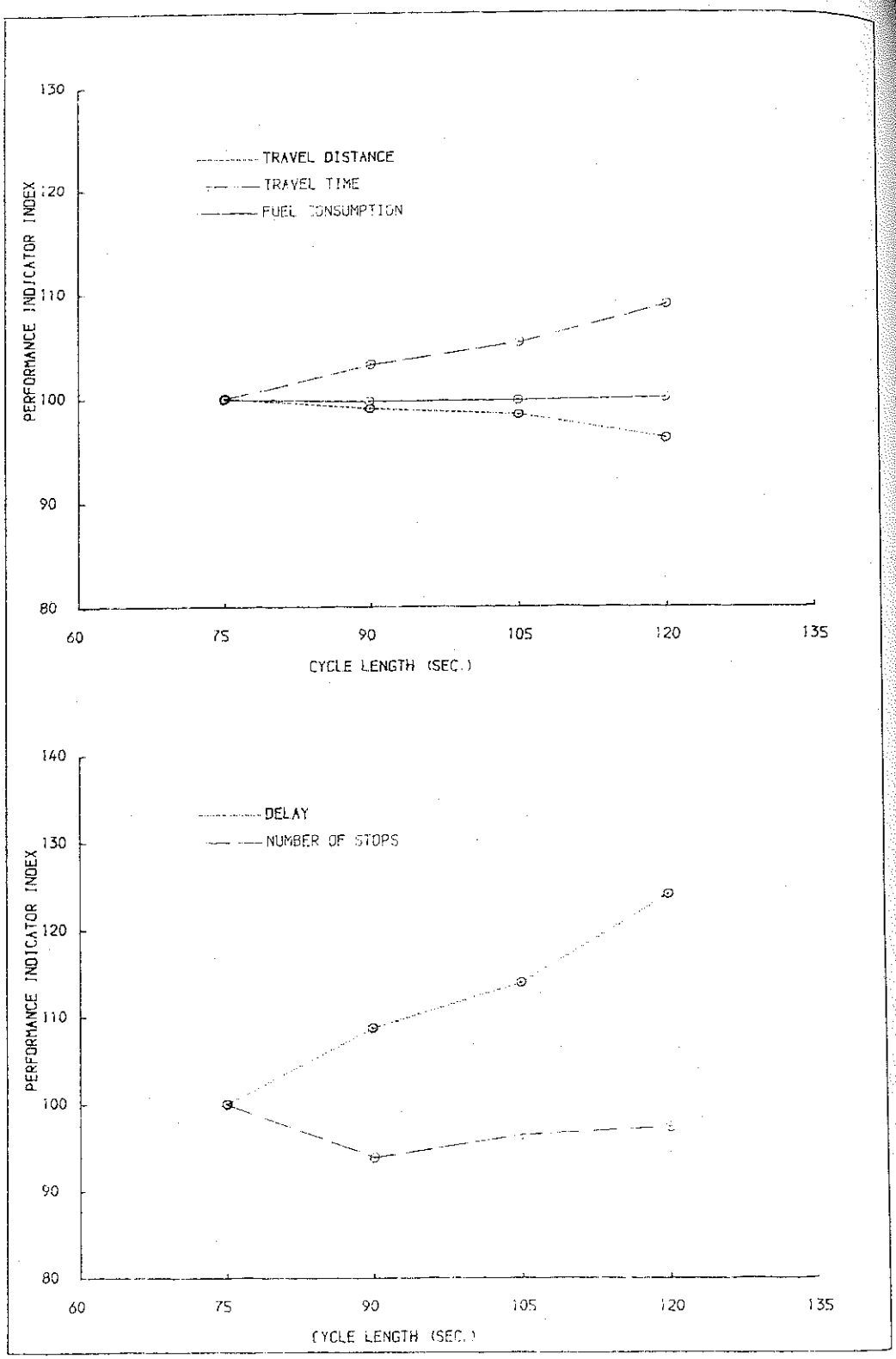


Figure 4 Sensitivity of SATURN outputs to cycle time changes

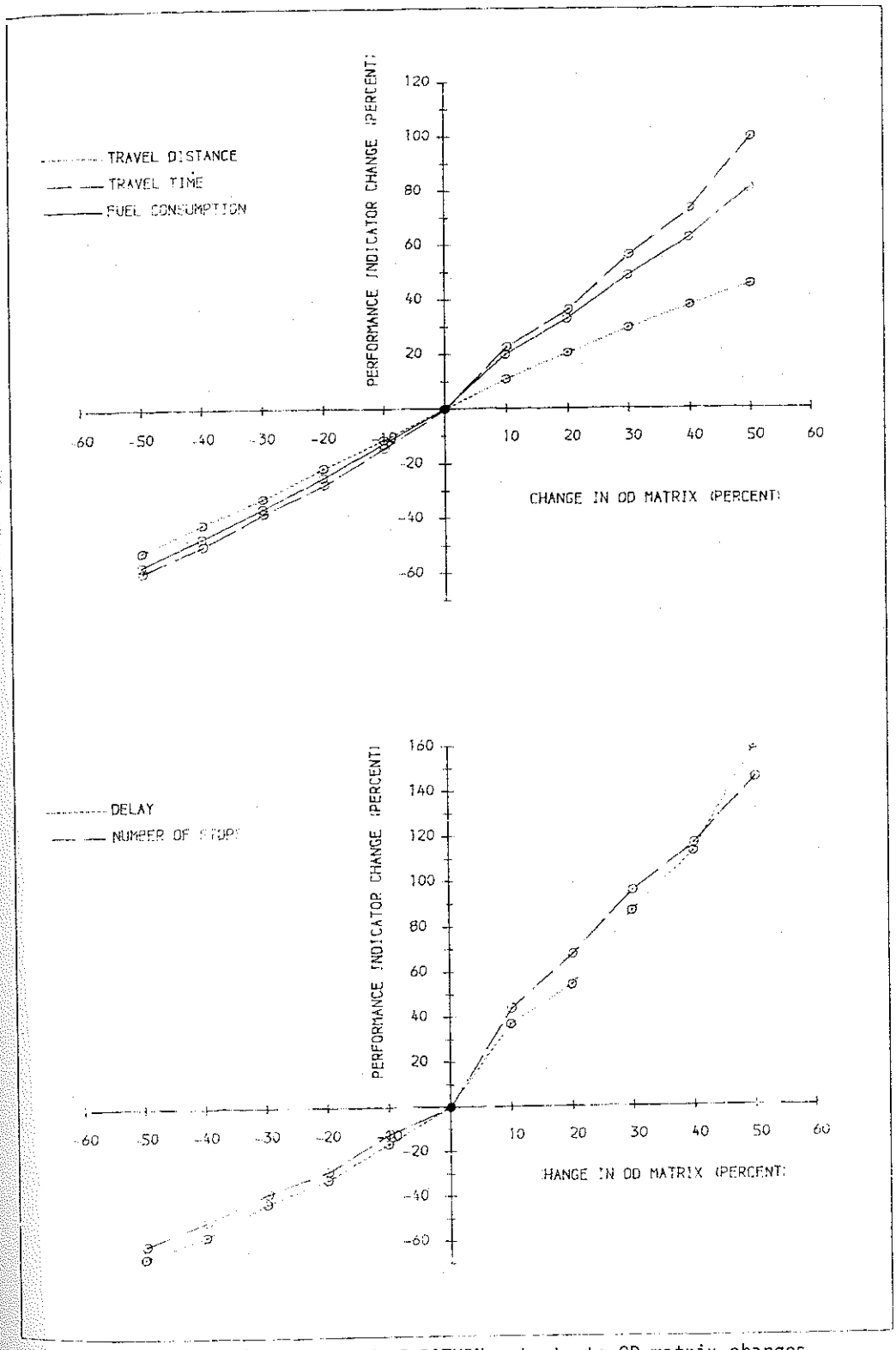


Figure 5 Sensitivity of SATURN outputs to OD matrix changes

Clearly such tests serve only to indicate the order of magnitude of changes to be expected if certain assumptions about achievable reduction are made. Since it is unlikely that a uniform reduction over the entire area would be possible by means of demand management measures, it is perhaps useful to deal at the level of individual zonal movements. For this purpose two sub-areas were used to determine the sensitivity of the outputs to changes in total vehicle trip origins in those areas. Origins were factored because we are dealing with the evening peak-hour matrix with its predominantly outbound movements from the central area.

The two sub-areas have the following characteristics:

Sub-area A

This is made up of 19 zones with a total number of vehicle trip origins of 2566 pcu/hr in the evening one-hour peak period, representing 8 percent of total matrix trips. The zones were chosen in consultation with planning officers in Merseyside and represent those areas where the long-stay car parking space is mainly under the control of the local authority. They exclude central area zones where control of price and supply of commuter parking would be extremely difficult to be applied by the Local Authority because of the predominance of private non-residential parking.

Sub-area B

This area is made up of the 19 zones of sub-area A and an additional 17 zones in the central area. The total number of vehicle trip origins associated with these 36 zones is 6333 pcu/hr, i.e. 19 percent of the total matrix trips. This sub-area forms a central 'core' area where car restraint policies such as cordon restraint or a supplementary area licensing scheme, would be applied, if such measures were under consideration.

A number of model runs were undertaken using the calibrated base network for the SATURN and the 'buffer' areas, in conjunction with different OD matrices to assess the impact of changes in the total number of trip origins in sub-areas A and B. Table 2 compares the fuel consumption reduction potential from reductions in vehicle trips from sub-areas A and B.

Table 2 The fuel consumption effect of reducing trip origins in sub-areas A and B

Percentage reduction in sub-area origins	Percentage reduction in areawide fuel consumption from changes to:	
	sub-area A	sub-area B
10	0.7	3.0
20	2.2	7.8
30	3.9	11.0
40	4.7	14.6
50	5.2	18.1

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The fuel consumption effects obtained in all the tests are based on the assumption that all trip origins which were constrained would no longer be made by car, and that any increase in public transport patronage that might occur as a result would not involve additional public transport fuel consumption.

If car trips from sub-areas A and B were restrained by parking controls, for example, then some of those trip-makers might change mode, others might change destinations (origins) to adjacent unconstrained zones, and others might change their parking location. In the case of other car restraint strategies such as cordon pricing during peak periods, terminating traffic might be affected in a similar way and in addition some tripmakers might decide to travel at other unconstrained times of the day. Through traffic would also be likely to divert around the area thus avoiding the restraint. SATURN, being essentially a route choice model, cannot provide answers to modal or destination choice questions.

The tests just described were undertaken using both the SATURN and the 'buffer' area networks. Therefore, the fact that central area trip origins were constrained affected zone-to-zone travel times and hence the choice of routes throughout the study area. Restraining trip ends in this way may, in practice, lead to some diversion of through traffic which was previously by-passing the central area, and which may now find more attractive routes through it. In the case-study being considered, through traffic which at present by-passes the central area in its vicinity, a small proportion of total movement in the evening peak period, does so mainly via a well established inner ring road to the west of the central area. It is unlikely that such through traffic would be induced through a less congested central area as a result of stringent parking controls for example. Although the results of the tests just described were not analysed on a route choice basis for through movements, the traffic link flows on the inner ring road decreased in accordance with corresponding reductions in central area trip origins, suggesting that rerouting of through movements would not occur in any significant way.

Conclusions

In this section the effects of several traffic management measures, which may be implmenented in the central area of Liverpool, were assessed using the SATURN model. These measures, which have been put forward mainly to improve public transport operations and enhance environmental conditions in the central area, were found to have a very small impact on areawide fuel consumption. This is in spite of the fact that some of the measures involved substantial changes to the circulation patterns within the area. Therefore it is concluded that, if the pattern of demand is assumed fixed in the short term - a plausible assumption in the case of traffic circulation changes - overall fuel consumption impacts are likely to be small. However, it must be stressed that the measures tested were not specifically designed to either substantially reduce vehicular delay or drastically change environmental conditions within the central area. Although such severe measures would produce higher fuel savings, they are not financially or politically feasible.

Total trips assumed constant irrespective of mobility. As with standard models. Doubtful in the context of estimating overall fuel consumption.

Overall fuel consumption was also found to be very insensitive to changes in the common cycle time used for the operation of traffic signal timings, within the range most commonly used in practice. These results can only be seen as tentative since changes were made to the common cycle time without adjusting individual signal timings and offsets to optimise traffic flow conditions under the new cycle time and route choice regime.

Finally, the effect of changes to travel demand patterns were studied by defining two sub-areas where parking restrictions and private vehicle restraint might apply. Although such demand management measures are not being contemplated by the local authority planners, the latter were consulted when defining the appropriate sub-areas.

& the effect of improved link times

A full demand modelling exercise would have involved the prediction of the effect of any proposed restraint measures on trip generation, distribution, modal-split and traffic assignment. In the present study only the last of these stages was modelled using SATURN to predict the effects of assumed changes in the level of tripmaking from those zones comprising the two sub-areas. This represents a very simplified treatment of the problem of predicting the impact of car restraint policies on traffic levels, and hence on fuel consumption. However it gives an indication of the maximum effect likely by assuming that all restrained trips would either not take place at all, or would change mode. Also ignored in this analysis are the possible longer-term effects of these policies - e.g. changes in the location of employment and homes; loss of attraction of central area as an employment and shopping centre; and changes to the rate of increase in car ownership.

It was found that a 20 percent reduction in trip origins within the parking control area - sub-area A - would result in a 2 percent reduction in area-wide fuel consumption. The same percentage reduction in demand in the larger car restraint sub-area would produce a reduction in fuel consumption in the order of 8 percent.

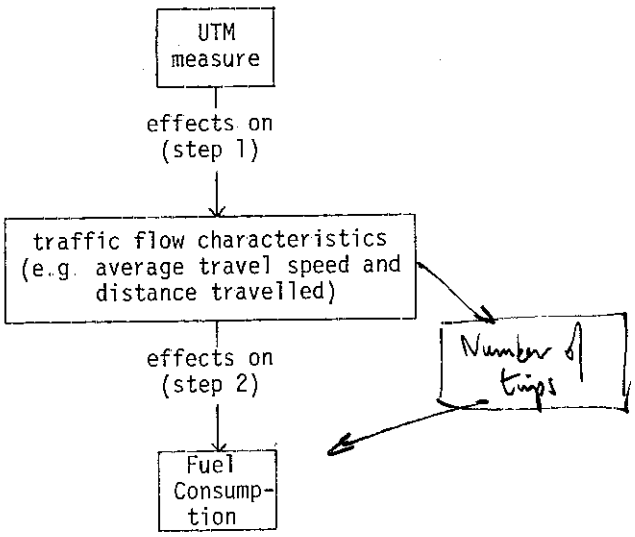
URBAN TRANSPORT MANAGEMENT (UTM) AND FUEL CONSUMPTION

General

This section reports on the potential energy savings that are likely to result from UTM measures. The term transport is used in preference to traffic (e.g. Urban Traffic Management) to reflect a broader range of measures than are usually associated with traffic management (e.g. those measures which have a direct impact on modal choice decisions such as public transport fares policy).

Clearly energy conservation is but one of the objectives which a local authority needs to consider. The degree to which any particular strategy achieves other objectives and the costs associated with the introduction of that strategy are clearly important issues. However their detailed consideration falls outside the scope of the present work.

The main aim of the work described here was to assess the energy consequences of UTM measures using the results of previous studies and the process outlined below:



This process considers only the short-term impact of the measures on fuel consumption. It does not represent a comprehensive energy evaluation which would need to take into account indirect and long-term energy effects as well as ease of implementation, cost and other impacts such as environmental and safety aspects. Such comprehensive analysis is very difficult to undertake quantitatively although it would be essential if a measure or package of measures were being proposed for a specific urban area and energy conservation was put forward as a high ranking objective.

Prediction and Measurement of Direct Impacts

There are two basic approaches to the quantification of energy impacts, namely:

1) the use of 'before' and 'after' surveys and
2) the use of predictive traffic models to estimate the likely direct changes in traffic patterns.

'Before' and 'after' surveys

Such surveys will usually involve the collection of data on traffic flow characteristics to be used with the kind of fuel consumption sub-models given by equation (1). Alternatively changes in fuel consumption can be measured directly using vehicles instrumented with accurate fuel flow meters. Ideally it would be desirable to use a number of such vehicles representing the complete range of sizes in the traffic stream, as well as a number of drivers to represent the range of driver behaviour, although this is costly to undertake.

Such 'before' and 'after' surveys using instrumented vehicles avoid errors in estimating fuel consumption using traffic data and predictive sub-models. As discussed earlier, and recently confirmed by Stimpson and Takasaki (1982) fuel consumption sub-models with average speed as the only

explanatory variable may produce misleading results in cases where traffic flow 'smoothness' has been significantly affected without corresponding changes in overall journey travel time. As stressed by OECD (1981), the use of instrumented vehicles in actual traffic is preferable to using estimating equations whose coefficients may have been determined from standard driving cycle tests, since such tests take no account of weather conditions, road network layout, gradients and driver behaviour. However such survey methods are inappropriate where the impacts of a number of different packages of UTM measures need to be predicted. In such cases it is necessary to assess impacts prior to implementation using the results of traffic models.

Traffic models

The range of such analytical tools available can be briefly summarised as follows:

a) Sketch-planning models usually based on aggregate data and simple demand functions. Such models can be used to assess major demand management measures with output in a very aggregate form (e.g. changes in areawide total distance travelled).

b) Macro-level transport demand models dealing with trip generation, distribution, modal-split and assignment. Such models can deal with measures which affect demand for a particular mode (e.g. public transport fares changes) as well as measures directly affecting choice of route (e.g. road closures). To the conventional zone based models of this type more disaggregate models have been added using the individual as the unit of analysis (e.g. logit and probit analysis). Such models are capable of predicting changes in modal market shares that result from changes in the costs and level of transport services provided. The output of such macro-level modelling will usually be in terms of travel distance and travel time. The simple fuel consumption model given by equation (1), relating the fuel consumed per unit distance to the average traffic speed, is well suited to be used in conjunction with this type of model.

c) Micro-level models of traffic simulation and assignment. These can range from the very detailed traffic flow simulation of each vehicle as in the case of the US model NETSIM, Worrall and Lieberman (1973), where no route choice is modelled, to more hybrid models incorporating traffic flow simulation and route choice decisions. The traffic parameter outputs available for use in fuel consumption prediction vary with the level of detail being modelled.

Individual vehicle simulation models enable fuel consumption to be estimated internally from the vehicle velocity profile and therefore account is taken of acceleration and deceleration rates (e.g. the NETSIM model). The models developed in the UK simulate traffic flow in less detail by considering several vehicles as one unit for ease of computation. This is the case of TRANSYT, Robertson (1969); CONTRAM, Leonard et al (1978) and

SATURN, Hall et al (1980). The only UK model of this type which simulates traffic flow on a vehicle by vehicle basis is TRAFFICQ, Logie and Dawson (1979).

Fuel Consumption Impacts of UTM Measures

The measures analysed were divided into traffic engineering and demand management measures and the likely national fuel consumption effects of each measure are summarised in Table 3.

It was found that in most cases only theoretical or qualitative results can be obtained due to lack of empirical evidence. Therefore the summary of the findings given here contains qualitative and quantitative estimates of the maximum likely fuel consumption impacts for each of the measures considered. The following comments are related to Table 3.

(i) Each measure was arbitrarily assumed to be applicable to one or more of the four urban area categories, i.e. those with populations greater than 50,000; 100,000; 300,000 and all areas. (First column.)

(ii) Quantitative estimates were made of the national impact of introducing UTC systems; strict speed limits; supplementary area licensing schemes; cordon pricing and strict parking controls.

Of the traffic engineering measures discussed, the introduction of UTC systems is likely to result in the highest fuel savings. Using the results of 'before' and 'after' surveys conducted in Leeds to evaluate the UTC system introduced in part of the urban area, it was estimated that that system has saved some 7 percent of fuel consumed in the affected area. At the national level it was estimated that UTC systems could save up to 2 percent of total road fuel consumption in the UK.

Of those measures which are aimed at reducing peak congestion through vehicle restraint, cordon pricing and supplementary area licensing schemes offer the highest potential savings although the scope for their implementation in the UK is very limited. It was also found that car restraint by physical means is likely to produce negative fuel consumption effects.

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Table 3 Fuel consumption impacts of UTM measures - summary

UTM Measure	Size of urban area likely to be affected (pop.)	Time of day likely to be affected	Maximum likely traffic affected (% total urban area travel)	Maximum likely fuel consumption impact as a percentage of:		Scope for implementation in UK under present conditions
				Consumption in affected area	Total national road consumption	
1) Traffic Engineering						
Intersection Improvements	All areas	All day	Small	Up to 20	Small	Limited to selective sites
UTC Systems	> 50,000	All day	Up to 50	Up to 10	Up to 2	Very good
One-way Systems	> 50,000	All day	Up to 5	Small, positive or negative	Very small	Limited to selective sites
Speed Limits	All areas	All day	Up to 20 (50 km/h limit)	Up to 30	Up to 3	Very unlikely and probably unenforceable
Bus Priorities	All areas	Peaks or All day	Very small	Small, positive or negative	Very small, positive or negative	Limited to selective sites
Cycleways	All areas	All day	Very small	Small, positive	Very small, positive or negative	Limited to selective sites
2) Demand Management						
Cordon Restraint	> 100,000	Peaks	Up to 20	Small, negative	Very small, negative	Very unlikely
Traffic Cells	> 50,000	All day	Up to 20	Small, positive or negative	Very small, positive or negative	Very limited
Supplementary Area Licensing	> 300,000	Peaks	Up to 20	Up to 50	Up to 0.3	Unlikely
Cordon Pricing	300,000	Peaks	Up to 20	Up to 30	Up to 0.3	Unlikely
Parking Controls	> 50,000	Peaks or All day	Up to 20	Up to 5	Up to 0.2	Stricter controls very limited
Car Pooling	> 50,000	Peaks	Very small	Very small, positive	Very small, positive	Limited to selective sites
Work Journey Rescheduling	> 50 000	Peaks	Very small	Very small, positive	Very small, positive	Limited to selective sites
Public Transport Incentives	All areas	Peaks or All day	Very small	Very small, positive	Very small, positive	Difficult under present economic climate

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Licensing							
Cordon Pricing	300,000	Peaks	Up to 20	Up to 30	Up to 0.3	Unlikely	
Parking Controls	> 50,000	Peaks or All day	Up to 20	Up to 5	Up to 0.2	Stricter controls very limited	
Car Pooling	> 50,000	Peaks	Very small	Very small, positive	Very small, positive	Limited to selective sites	
Work Journey Rescheduling	> 50 000	Peaks	Very small	Very small, positive	Very small, positive	Limited to selective sites	
Public Transport Enhancement	All areas	Peaks or All day	Very small	Very small, positive	Very small, positive	Difficult under present economic pressures	

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