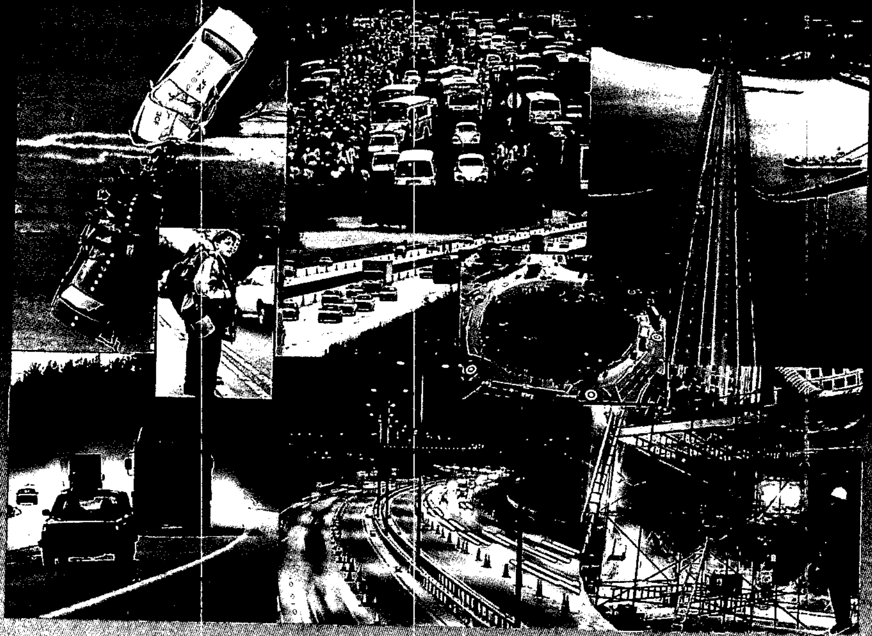

Congestion in urban areas caused by incidents

by D R Leonard

An executive agency of
THE DEPARTMENT
OF TRANSPORT

TRL Report 126

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TRANSPORT RESEARCH LABORATORY
An Executive Agency of the Department of Transport

TRL REPORT 126

CONGESTION IN URBAN AREAS CAUSED BY INCIDENTS

by D R Leonard

Prepared for: Project Record: H5/20C Sources of Traffic Congestion
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CONTENTS

EXECUTIVE SUMMARY

Congestion is an everyday occurrence in most towns and cities during peak periods. One of the major contributors to congestion, during both peak and inter-peak periods, is disruption caused by incidents, or other events unexpected by drivers, such as vehicle accidents, street processions and road works. Everyday on-street activities, such as illegal parking and buses stopping for passengers, also contribute to the general background level of congestion in urban areas. This study is primarily concerned with the first category. Because incidents and the amount of disruption they cause are largely unpredictable, their impact on congestion can be out of all proportion to the incidents themselves and, on occasion, result in 'gridlock' in town centres.

The main report identifies the types and frequencies of incident which occur and their impact in causing congestion, examines the interactions of the various factors which contribute to the formation of congestion, and outlines the steps needed for developing strategies to cope with incidents. The approach embraces a theoretical investigation of the problem, in order to understand the mechanism of the formation and spread of congestion, and an examination of the practical aspects, identifying tools and a framework of techniques for coping with incidents and congestion generally.

Ways of reducing the severity of incidents could include:

- Anticipation of the onset of critical levels of traffic in a network
- Better identification and reporting of incidents
- Faster removal of incidents
- Better feedback to operators of the results of their actions
- Better enforcement of anti-obstruction regulations

Possible tools for improvement which are identified include:

- Dedicated (e.g. tidal-flow or HOV) lanes
- Signal control systems (eg metering)
- Monitoring systems (e.g. video or display of congestion measures)
- Road or congestion pricing, or fiscal policies
- Parking management
- Public transport use, including park-and-ride
- Flexible working arrangements
- Variable message signs (VMS) and dynamic route guidance systems (DRG)
- Education and enforcement

A variant of the CONTRAM time-dependent traffic assignment model, called CONTRAM I, has been developed to model drivers' response to incidents. In order to quantify congestion, and highlight places where it is occurring due to incidents or other effects, a "congestion index" has been defined and implemented in the program, which expresses the ratio of actual travel time to that which would be expected in free-flow conditions. CONTRAM I has been applied in desk studies to networks based on the towns of Reading and Kingston-upon-Thames. The studies show that there would be benefits from providing drivers with information about traffic conditions ahead, and that these potential benefits would be shared by other traffic in the vicinity of the incident, which might otherwise have to compete for road space with diverting traffic.

Further theoretical and modelling work would be needed to turn the framework into effective strategies, and to explore the interaction of these strategies with traffic control measures and driver information systems.

CONGESTION IN URBAN AREAS CAUSED BY INCIDENTS

ABSTRACT

Congestion is an everyday occurrence in most towns and cities during peak periods. Disruption caused by incidents is a major contributor, which, due to their unpredictability, can have a disproportionate impact leading occasionally to 'gridlock'.

The report identifies the types and frequencies of incident and their impact in causing congestion, examines the interactions of the various factors which contribute to the formation of congestion, and outlines the steps needed for developing strategies to cope with incidents. It includes a theoretical investigation, and an examination of the practical aspects, identifying tools and a framework of techniques for coping with incidents and congestion generally.

A variant of the CONTRAM time-dependent traffic assignment model, called CONTRAM-I, has been developed to model drivers' response to incidents, together with a congestion index for quantifying congestion. Desk studies using networks based on two towns are described, and some conclusions reached about the potential benefits of remedial actions.

Further theoretical and modelling work would be needed to turn the framework into effective strategies, and to explore the interaction of these strategies with traffic control measures and driver information systems.

1. INTRODUCTION AND OBJECTIVES

Congestion is an everyday occurrence in most towns and cities during peak periods. One of the major contributions to congestion, both during peak and inter-peak periods, is the disruption caused by incidents.

Incidents occur in a variety of forms such as vehicle accidents, street processions and road works. In addition a number of regular everyday on-street activities, such as illegal parking and buses stopping for passengers, can also be regarded as 'incidents'. This study is primarily concerned with the former type, although the effects of the regular every day activities cannot be ignored as they contribute to the general background level of congestion in urban areas against which incidents occur and cause additional congestion. Because the occurrence of incidents and the disruption caused to traffic is often unpredictable, their impact in causing additional congestion can be out of all proportion to the size of the incidents themselves and, on occasions, have resulted in 'gridlocks' in town centres.

Drivers have difficulty in coping with these unexpected traffic conditions and traffic managers need special methods for coping with the effects of incidents.

Problems could potentially get worse if the present growth in traffic continues, even if traffic control systems continue to make more efficient use of road space, due to the reduction in spare capacity available to absorb unexpected additional congestion.

The objectives of this study are to identify the types of incident which occur and their impact in causing congestion, to examine and understand the interactions of the various factors which contribute to the formation of congestion, and to outline the steps needed for developing strategies to cope with incidents.

The study is based on a twofold approach: a theoretical investigation of the problem, in order to understand the mechanism of the formation and spread of congestion, and an examination of the practical aspects of coping with incidents and congestion generally.

2. THE CAUSE OF CONGESTION AND THE NEED FOR STRATEGIES

Congestion occurs when demand exceeds capacity in all or part of a network. However a distinction has to be made between two types of congestion, 'regular' and 'irregular', as the implications for both motorists and traffic managers are fundamentally different:

Regular daily congestion mainly arises due to the sheer volume of traffic wanting to use a network. This is managed, in most large towns, by the use of signalised urban traffic control (UTC) systems such as TRANSYT and SCOOT. The objective for these systems is to minimise delay in a network, which is often regarded as being synonymous with minimising congestion. Drivers become familiar with 'regular' congestion and choose their routes accordingly; normally this results in a state of equilibrium for each day of the week and traffic patterns are reasonably stable i.e. they are predictable.

When an incident occurs there is a sudden reduction in local capacity, at the site of the incident, and queues form. Fixed-time traffic control systems, such as TRANSYT, are not designed to cope with these sudden changes and even interactive systems, such as SCOOT, require time to respond. In consequence the local queues which form may spread to adjacent links. Drivers are often unaware that an incident has occurred until they encounter long queues in unexpected places; they may then react to these queues by seeking alternative routes. Traffic patterns then become unstable. In most networks, particularly during peak periods, many roads on alternative routes are likely to be operating close to capacity and hence diverting traffic will add to those existing flows with the consequent danger of triggering congestion in other parts of the network.

There is therefore a need for special strategies to cope with congestion caused by incidents arising from the fact that drivers' reactions to unexpected queues are not always predictable and hence current traffic control methods will not be effective in controlling the spread of this type of congestion. In extreme cases special strategies will be needed to avoid gridlocks, and emergency recovery strategies will be needed should gridlocks occur. Suitable strategies can only be developed by understanding the underlying mechanism of the formation of congestion, identifying techniques for coping with the congestion, and by being aware of the practical aspects of handling traffic problems from the points of view of the motorist, the traffic manager, the police, and other organisations concerned with traffic operations in urban areas.

3. TYPES AND FREQUENCIES OF INCIDENTS

An incident can be defined as any activity which interferes with the normal movements of traffic in a network. Although this definition includes the many on-street activities which occur on a regular daily basis, such as illegally parked vehicles, they are not the principal concern of this study which will concentrate on the effects of 'irregular' incidents.

Whether it is a minor traffic accident, a three hour procession or two weeks of road works, all incidents have in common the effect of *reducing local road capacity.* But they obviously differ in their duration which may last for just a few minutes, hours, or even days. However, more significantly, they also differ because some incidents occur at random, i.e. without warning, whilst others, such as roadworks, allow some prewarning to be given.

Before discussing the mechanism for the formation of congestion and strategies for coping with incidents, it is useful to identify the different types of incident which occur, their relative frequencies of occurrence and the severity of congestion caused. This is needed so that strategies can be developed and targeted on the types which cause the most congestion.

Two methods were considered for collecting information. The first involved survey techniques using observers distributed throughout a network or in survey vehicles. An assessment of the resources needed to collect an adequate amount of data showed that the cost to cover a sufficiently large area, for perhaps several months, would have been prohibitively expensive (more than £400,000), and there would have been no guarantee that an adequate sample of incidents, coupled with congestion, would have been obtained. These difficulties were demonstrated in a pilot study using video recordings from coaches to record incidents and congestion in London.

The second method was to analyse historic data. In searching for sources of information it was found that the London Metropolitan Police maintain a continuous 'Congestion file' which contains information on all significant occurrences of congestion, and their causes, for the whole of the London Metropolitan Area (an area of approximately 25 kms x 20 kms). It does not, therefore, contain details of a much larger number of cases of minor congestion (i.e. queues lasting for a few minutes) which are known to occur following small incidents unless the incident itself requires a formal report for some other reason. The file is used for traffic management purposes and to provide local and national radio services, such as AA Roadwatch, with information on traffic conditions.

The file records details of all problems with congestion which have been reported to the Traffic Control Desk at New Scotland Yard. This file was analysed for a period, covering a total of 6 months in 1991, to identify types of incidents and the severity of congestion caused. Whilst a small number of problems with congestion might not have been reported, because their significance was not recognised at the time or if no member of the police force was present, it is believed that the file contains most of the cases of significant congestion which occurred. Hence, because of the large area and period of time covered, it was considered that the data available would provide a sufficiently large number of examples to give a representative picture of the different types of incident which occur and which lead to congestion. In some cases the cause of the congestion recorded was simply due to the sheer volume of traffic at the time - these records were ignored in the analysis and only those relating to actual incidents used. In all a total of 3945 records were analysed for the six month period, i.e. corresponding to about twenty incidents per day. The analysis was carried out by computer by formatting the data from the records so that various types of interrogation could be made, such as incidents by day of the week or by time of day, etc. A more detailed account of the analysis is given in Holmes and Leonard (1993) from which the information discussed below is taken.

The different types of incident which were identified are listed in Table 1. The incidents have been divided into three groups according to whether they were associated with Network conditions (i.e. factors associated with the road network infrastructure), Traffic operations (i.e. vehicle

TABLE 1

Types of incidents

	Predictable/Random
Network conditions	
Road works	P
Public utility works (Gas, Water, Electricity)	P/R
Traffic signal faults	R
Burst water mains	R
Traffic operations	
Vehicle accidents	R
Vehicle breakdowns (light goods, cars)	R
Vehicle breakdowns (heavy goods vehicles)	R
Diesel spillage	R
Other causes	
Public events (processions, sports meetings)	P
Weather	P/R
Hazards (industrial operations, builders skips)	R
Security alerts	R
Other (vehicles attending off-street emergencies)	R
'Regular' incidents	
Illegal parking	P/R
Vehicle deliveries	P/R
On street parking activities	P/R
Parking search	P/R
Bus, Taxi operations	P/R
Anti-social manoeuvres	R
Pedestrian activity (e.g. uncontrolled crossings)	R/P
Traffic demands at major generators	P
(Daylight / darkness)	P

related problems), or Other Causes. For completeness a fourth group has been listed which identifies the normal or 'regular' day-to-day activities which contribute to the background level of congestion. Incidents have been labelled according to whether they were more likely to occur at random (R), or with some prewarning (P), as this will have a significant affect on the types of strategy that can be used.

Table 2 provides a breakdown of the frequency of incidents according to the severity of congestion caused. The analysis for this breakdown highlighted a number of problems about the way in which incidents and congestion are currently identified and related. It was evident that interpretation of the 'severity' of congestion was very subjective and reports used the very general terms 'moderate', 'heavy' and 'severe' to describe increasing levels of congestion; but the reports also used 'road closed' when it occurred to imply congestion. For the purpose of the analysis, unless mentioned specifically in the original police reports, the duration of congestion was taken as a proxy for 'severity' and 'road closed' will be equated with 'heavy' congestion. The terms used in the Metropolitan police congestion file are not untypical of the terms used by police and local authorities elsewhere in the country and show a need for a more systematic method for identifying and reporting both incidents and severity of congestion, for traffic management purposes; this is discussed in Section 5.1.

The key findings from the survey were:

1) The proportions of Network and Traffic incidents causing serious congestion were about the same (36.4% and 39.7%) - but it was noted that 'Other' causes (23.9%) were not insignificant. It is likely that the latter group is bigger for London than would be expected in most other towns because of the relatively large number of public events and security alerts which occur in London.

TABLE 2

Incident Type by Severity of Congestion

	Planned (P) or Random (R)	Serious Congestion	Heavy Congestion	Moderate Congestion	Road Closed	Total
Network Effects						
Traffic Signal Faults	R	39 (1.0)	152 (3.9)	112 (2.8)	9 (0.2)	312 (7.9)
Road Works	P	183 (4.6)	316 (8.0)	140 (3.6)	226 (5.7)	865 (21.9)
Burst Water Mains	R	10 (0.3)	39 (1.0)	14 (0.4)	72 (1.8)	135 (3.4)
Other Works	P/R	23 (0.6)	17 (0.5)	24 (0.6)	60 (1.5)	124 (3.2)
		255 (6.5)	524 (13.3)	290 (7.4)	367 (9.3)	1436 (36.4)
Traffic						
Traffic Accident	R	109 (2.7)	299 (7.6)	293 (7.4)	413 (10.5)	1114 (28.2)
H/V Breakdowns	R	19 (0.5)	107 (2.7)	179 (4.6)	9 (0.2)	314 (8.0)
L/V Breakdowns	R	6 (0.2)	44 (1.1)	68 (1.7)	2 (0.1)	120 (3.0)
Diesel Spillage	R	4 (0.1)	6 (0.2)	5 (0.1)	5 (0.1)	20 (0.5)
		138 (3.5)	456 (11.6)	545 (13.8)	429 (10.9)	1568 (39.7)
Other causes						
Events	P	29 (0.7)	37 (0.9)	10 (0.3)	12 (0.3)	88 (2.2)
Weather	P/R	5 (0.1)	5 (0.1)	5 (0.1)	14 (0.4)	29 (0.7)
Hazards	R	21 (0.5)	35 (0.9)	21 (0.5)	182 (4.6)	259 (6.6)
Security	R	14 (0.4)	14 (0.4)	10 (0.3)	219 (5.6)	257 (6.5)
Other	P/R	46 (1.2)	141 (3.6)	26 (0.7)	95 (2.4)	308 (7.8)
		115 (2.9)	232 (5.9)	72 (1.8)	522 (13.2)	941 (23.9)
Total		**508 (12.9)**	**1212 (30.9)**	**907 (23.0)**	**1318 (33.4)**	**3945 (100.0)**

Notation : 39 (1.0) = No of incidents (and percentage of cases).

2) In ranking the importance of types of incident, which caused congestion, Traffic accidents (28.2%) and Road and other works (25.1%) were found to be the most frequent, accounting for over half of the numbers, with Vehicle breakdowns (cars + hgvs) (11.0%) and Traffic signal faults (7.9%) of lesser significance.

3) Overall a significant proportion (approximately 30%) of the incidents did not occur at Random and hence would have allowed some preplanning to be made and prewarnings to be given.

4) A relatively large percentage of congestion reported (33.4%) resulted from road closures (which in themselves cause drivers to find alternative routes even if they only amount to minor diversions). Apart from the need to close roads for roadworks many of the other closures probably reflect a cautious attitude on the part of the police to protect people's safety, in which case any effect on traffic congestion would be considered to be of lesser importance.

5) Rapid action to remove an incident was the most effective way of minimising congestion. This requires a traffic controller to have immediate access to specialist services to deal with the technically more complex incidents such as breakdowns and accidents to heavy commercial vehicles (requiring heavy lifting equipment), spilt chemicals, etc.

6) Diesel spillage deserves special comment because it usually requires the immediate closure of part of a road to prevent skidding accidents, and to prevent the diesel fuel from being spread on vehicle tyres over a much wider area. Most of the spillages occur because fuel tanks are overfilled or filler caps not properly secured - in either case there is some scope with vehicle design to reduce this type of incident.

7) In ranking incidents, in terms of the duration of their effects, it was found that the longer periods of serious congestion (greater than 4 hours) were mainly due to roadworks, with traffic accidents

accounting for the largest proportion of congestion lasting between 1 and 4 hours.

8) For all types of incident the severity of the additional congestion caused increased with the background level congestion. (Also see later Section 6.2.)

In summary the most significant findings from the survey for developing strategies are:

a) The need to restore road capacity as quickly as possible following an incident,

b) A significant proportion of incidents, which lead to serious congestion (in this case about 30%), should enable some preplanning and warnings to be given.

c) Traffic controllers need immediate access to specialist services at short notice, to deal with difficult problems.

and d) The significance of the background level of congestion at the time of an incident

Although the survey related to incidents in London it is believed that the conclusions will have general application for the development of strategies for use in all urban areas. However it is likely that the proportions of the different types of incident will differ according to the type of town and the mix of cars and heavy goods vehicles. But, in any case, it is expected that the proportions will change with time as strategies are developed to cope with individual types of incident.

4. THE COST AND IMPLICATIONS OF INCIDENTS

A question often asked is what is the cost of congestion caused by incidents. This is usually considered in terms of the additional cost of travel due to the extra delay encountered. Attempts have been made to estimate this for motorways and freeways in the USA by Lindley (1987) and Hanks and Lomax (1990), but these were for relatively simple situations where queues are contained within the motorway system and where there is virtually no choice of alternative route to bypass the congestion.

There is no simple answer to the question for urban areas because the effect and extent of congestion caused by each incident varies considerably, depending on the type of incident, its duration and time of occurrence, lay out and control of the network, location of the incident within the network, drivers' familiarity with alternative routes and, perhaps most significantly, the level of regular, recurrent congestion existing at the time (See, e.g., Figure 4 later in Section 6.2). Unlike for recurrent congestion, the effect of an incident ripples outward, often in an unpredictable way, affecting traffic conditions in areas far from the incident. Clearly, surveys to collect sufficient data for estimating congestion costs would be impractical due to their scale and cost, while modelling would need to cover a large number of incidents in a variety of conditions and over a range of urban areas.

Because of the difficulties of quantifying costs, the problem may better be approached qualitatively, in terms of the consequences for people travelling, and for the social and economic impacts of the life of towns. The major problems caused by incidents arise from the unpredictability of their timing, and the level and extent of the resulting congestion, which cause many forms of disruption such as missed appointments, missed transport connections, lost opportunities etc. More importantly, perhaps, there are adverse and potentially very serious effects on the operation of emergency services.

If the general increase in travel demand continues then the levels of recurrent congestion will increase, and so will the impact of incidents. Ultimately this will cause an increase in the number of occurrences of gridlock in towns. It is known already that gridlock has brought traffic to a halt in the centres of towns for periods of two hours or more. It is even more difficult to put a price on such disruptions, but it is apparent that the adverse effects on the quality of life will become more and more prominent, unless measures are taken to produce strategies for coping with incidents in congested urban conditions. Before discussing such techniques and strategies it is necessary to understand the underlying mechanism of the formation of congestion in urban areas.

5. UNDERSTANDING CONGESTION IN URBAN AREAS

It has already been stated in Section 2 that congestion occurs when demand exceeds capacity in a network or, conversely, when local capacity is reduced, for example by an incident, such that the remaining capacity cannot cope. In either case queues form, and people often refer to such queuing as 'congestion'. Whilst it is true that queue formation is a basic factor in the formation of congestion it does not provide a full explanation of the underlying mechanism of its growth in urban networks. It is useful to approach the understanding of the mechanism by examining what is actually meant by the term 'congestion' and, in addition, to see how the level of congestion in a network can be quantified.

5.1 THE MEANING OF THE TERM CONGESTION

A major problem in defining 'congestion' is that everybody 'knows' what they mean by the term. It is used loosely to describe 'too much traffic', 'queues of vehicles', and 'unnecessarily long journey times'. And, in fact, to describe a whole range of traffic conditions from roads which are 'very busy' through to 'gridlocks' in town centres. But these descriptions tend to be subjective and hence a more objective definition is needed which is of practical use for developing strategies and which also recognises different conditions and severity of congestion. A further problem in trying to define the term is that there are no agreed measures of congestion.

The problem of defining 'congestion' in urban areas, for analysis purposes, has been discussed in the paper: The meaning of the term congestion for urban areas (van Vuren and Leonard 1994). By analogy with the medical definition that 'congestion is an excessive accumulation of blood in an organ, the functions of which are thereby disordered', the paper argues that *traffic congestion** can be defined as the condition when queuing becomes such that there is a *breakdown in the orderly movement of traffic* in a network. Using this definition it can be seen that the formation of queues of vehicles at a junction does not in itself constitute congestion if the queues are being dissipated in an orderly manner by the control mechanism operating at the junction e.g. by signal controls, or priority rules at give-ways.

Hence, in addition to the formation of queues, there is a second factor which needs to exist for a breakdown to occur in the orderly movement of traffic. This exists, in the case of urban areas, because travel takes place in a network of roads, which means that vehicles merge or cross paths at junctions. Because junctions are linked together by roads a queue at one junction can grow back along a road to block an upstream junction. It is this second factor, i.e. a link becoming full and interfering with the free movement of traffic through the upstream junction, which provides the underlying characteristic or 'mechanism' for the formation of *congestion* in urban areas. In contrast the underlying mechanism of congestion on motorways, apart from long queues caused by incidents, is due to a 'headway' effect (Hunt and Yousif 1992) which occurs when drivers realise that they are travelling too close to the car in front for safety and hence slow down causing bunching to occur. The bunching sends a shock wave backwards through the following traffic effectively reducing capacity and causing large queues to form.

In urban areas various states or degrees of *congestion* can be identified according to the way in which junctions are affected by blocking:- *congestion* occurs when two or three junctions are linked together in sequence by queues (in effect resulting in an extended queue from the first junction), and start to interfere with cross movements of traffic. Severe *congestion* exists when groups of junctions are linked together and blocking restricts all of the movements through junctions. In the extreme, if several adjacent junctions in all directions are linked by blocking, then cross movements become severely restricted and queues grow faster than they can be dissipated - the area linked in this way then increases in size resulting in a gridlock with traffic virtually coming to a standstill.

In Section 3 it has been stated that interpretation of the Metropolitan Police's records of levels of congestion was difficult because of differences of interpretation between individual police officers when reporting congestion and the form of descriptions used, hence a more systematic system was needed for reporting purposes. The stages of *congestion* described in the previous paragraph have therefore been listed in Table 3, along with other traffic states, to provide a graded 'observational scale' for identifying traffic conditions. These range from free flow conditions through to gridlock.

In addition to observational criteria there is also a need to be able to quantify congestion for traffic control purposes and for use in understanding the mechanism of the spread of congestion. The next section describes a measure for congestion.

5.2 QUANTIFYING CONGESTION

A variety of descriptors have been considered for the measurement of congestion - these are examined in the paper on Limits to traffic growth in urban areas (Hounsell 1989) and include speed, degree of saturation, traffic density, etc. Most of these have applications for roads such as motorways and for isolated junctions, but are of little practical use for urban networks because of difficulties of measurement and interpretation over an area. Speed has tended to be the most widely used measure but has the disadvantage that it becomes less sensitive and more difficult to interpret as speeds become lower i.e. when the effects of congestion become most significant.

The problem of measurement was also considered in the paper by Leonard (1992) in which it is proposed that a measure is based on the most direct consequence of congestion, namely that journey times increase with increasing congestion. For a given journey, between two points in a network, the excess journey time (d) over and above the free or unconstrained running time (t) for the journey, can be regarded as a measure of the congestion encountered on that journey - the excess journey time being the extra time spent delayed in the network due to the presence of other vehicles. This measure can be normalised to take account of journey length by dividing the total journey time (t+d) by the free running journey time (t), along the same route, to give a measure or *index of congestion* for that journey. The

* Footnote: the use of the word '*congestion*', as defined in the context of this section, will be indicated by italics. Otherwise it will continue to be used, in the rest of this report, in the more widely accepted sense as meaning 'too much traffic'.

index automatically takes into account any increase in delay time due to the effects of blocking back between junctions and hence to all conditions of congestion.

The index has a valid meaning which can be applied to journeys along particular routes.

Thus, the index of congestion is given by:

$$\text{Congestion Index} = \sum_i (t_i + d_i) \Big/ \sum_i t_i$$

where the summation is over all vehicle journeys. In practice congestion in a network will vary with time, for example throughout a peak period, in which case the index also varies with time and would need to be determined accordingly. The index is versatile in its application as it can be applied over a whole network, along particular routes, or to local areas within a network. This is useful in cases where one part of a town, or a particular route, is more congested than another. An example of the variation of the index, for a whole town, with changes in level of demand is shown in Figure 1. Figure 2 shows the variation with time through a peak period corresponding to the same traffic conditions.

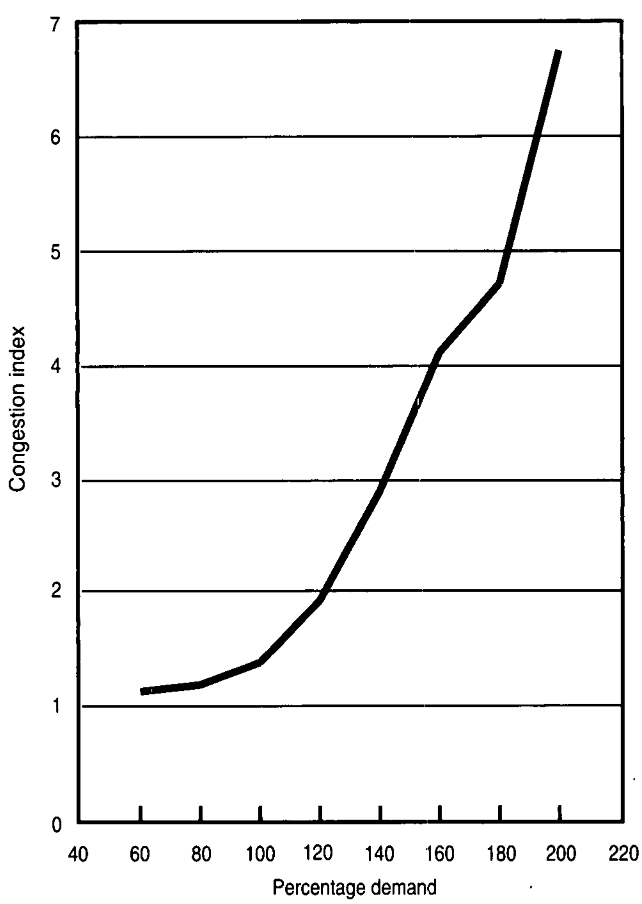

Fig 1 Average congestion index for a.m. peak period for different levels of demand

The free running journey times used as the basis for the congestion index should include geometric delay on links, arising from the need for vehicles to slow down to negotiate junctions. It is also usual to include in the free running times for links an allowance for the effects of 'regular' on-street activities such as vehicles parking or delivering goods. Although some people may associate the interference from on-street activities with increased journey time and hence with the formation of congestion, it does not form part of the same underlying mechanism which is primarily due to the effects of vehicles queuing and blocking junctions. (It should be noted that there are likely to be some differences between practitioners in estimating or measuring free running times - such differences need not be important as, once values have been established for a given network, the congestion index would normally be used on a comparative basis for that network).

However care should be taken when interpreting values for the index after changes have occurred in a network which result in drivers using different routes. The denominator in the index should then be based on the totals for the free running journey times along the original routes rather than on ones corresponding to the new routes.

The calculation of the congestion index is also valid on an individual link basis. Figure 3 shows changes in the index for links along three main routes through the network based on Kingston, under normal conditions and when an incident has occurred. The values for the index have been estimated from modelling studies (Section 6), but could eventually be estimated using on-line SCOOT data. The on-line estimates could also be presented in the form of a dynamic mimic display to indicate levels of congestion as they vary in different parts of a network, which would be useful for traffic control purposes.

It may also be possible, using calibration techniques, to link values of the congestion index with the various states of congestion in Table 3, to provide advance warning of critical changes in traffic conditions.

6. MODELLING INCIDENTS AND CONGESTION

The interactions of traffic in towns are now so complex that it is virtually impossible for traffic engineers to appreciate the consequences of local traffic control actions on the formation of congestion in other parts of a network. But it is impractical to collect on-site information to build up sufficient experience to cope with the different types and locations of incidents in a town. It is therefore necessary to resort to modelling techniques to understand these effects and to provide a systematic basis for developing and testing strategies to cope with incidents. Models can also be used

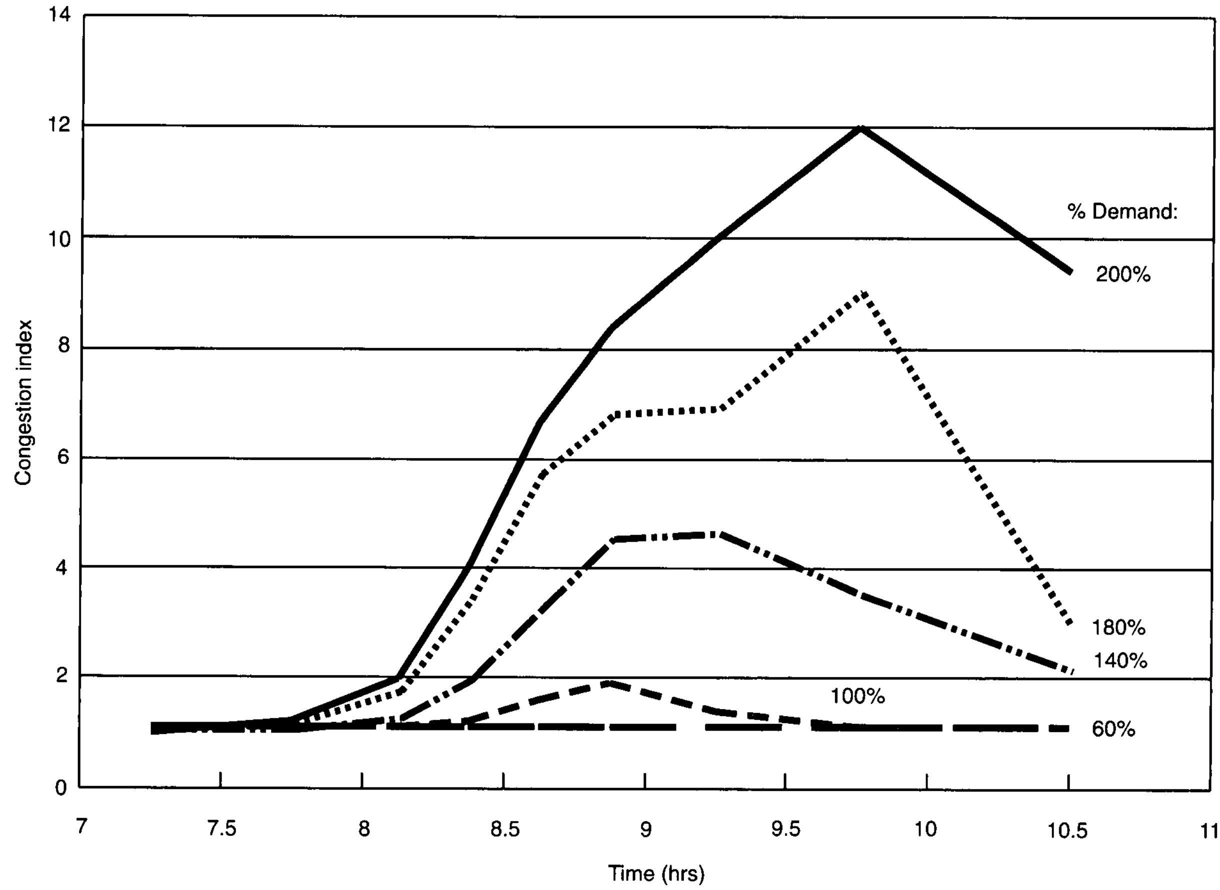

Fig 2 Variation in congestion index through an a.m. peak period for different levels of demand

to determine the sensitivity of traffic conditions to variations in network and demand parameters.

The fundamental needs for modelling congestion and the effect of incidents are to represent the variation through time of the build up and decay of queues and blocking, and to predict drivers' response to unexpected changes in traffic conditions following an incident.

Current traffic assignment models such as CONTRAM, SATURN and JAM can model regular congestion but only CONTRAM provides a consistent representation of the changes in traffic conditions as they vary through time during peak periods (for a comparison of models see Thomas 1991). All of the models make the assumption that drivers are familiar with regular traffic conditions in a network. However, when an incident occurs traffic conditions change and drivers do not have immediate knowledge of these changes. A new model - CONTRAMI has therefore been produced for modelling the effects of incidents on drivers' choice of routes. The model is an adaptation of the assignment process in CONTRAM as this is the only model which assigns vehicles and stores route information on an individual vehicle basis.

6.1 AN INCIDENT VERSION OF CONTRAM

The two key effects of an incident are that queues may be generated in unexpected places in a network, and that drivers may choose to react to the unexpected queues by seeking alternative routes; some drivers may, of course, elect to stay on their original routes. CONTRAMI has been produced in a modular form to model these effects and is run in conjunction with a normal run of the CONTRAM model. The sequence of operations for using CONTRAMI is:

1) CONTRAM is run to establish the 'normal' routes taken by drivers before an incident occurs.

2) CONTRAM is re-run for three iterations, in a fixed-route mode using the routes established in stage 1, to ensure consistency between vehicle routes, flows and delays on links.

3) The CONTRAMI module is run with network capacities changed to represent an incident. The input to CONTRAMI is the original traffic demand, with vehicles initially constrained to take the routes established in stage 1, i.e. drivers are assumed to set out along their original routes without prior knowledge of the incident.

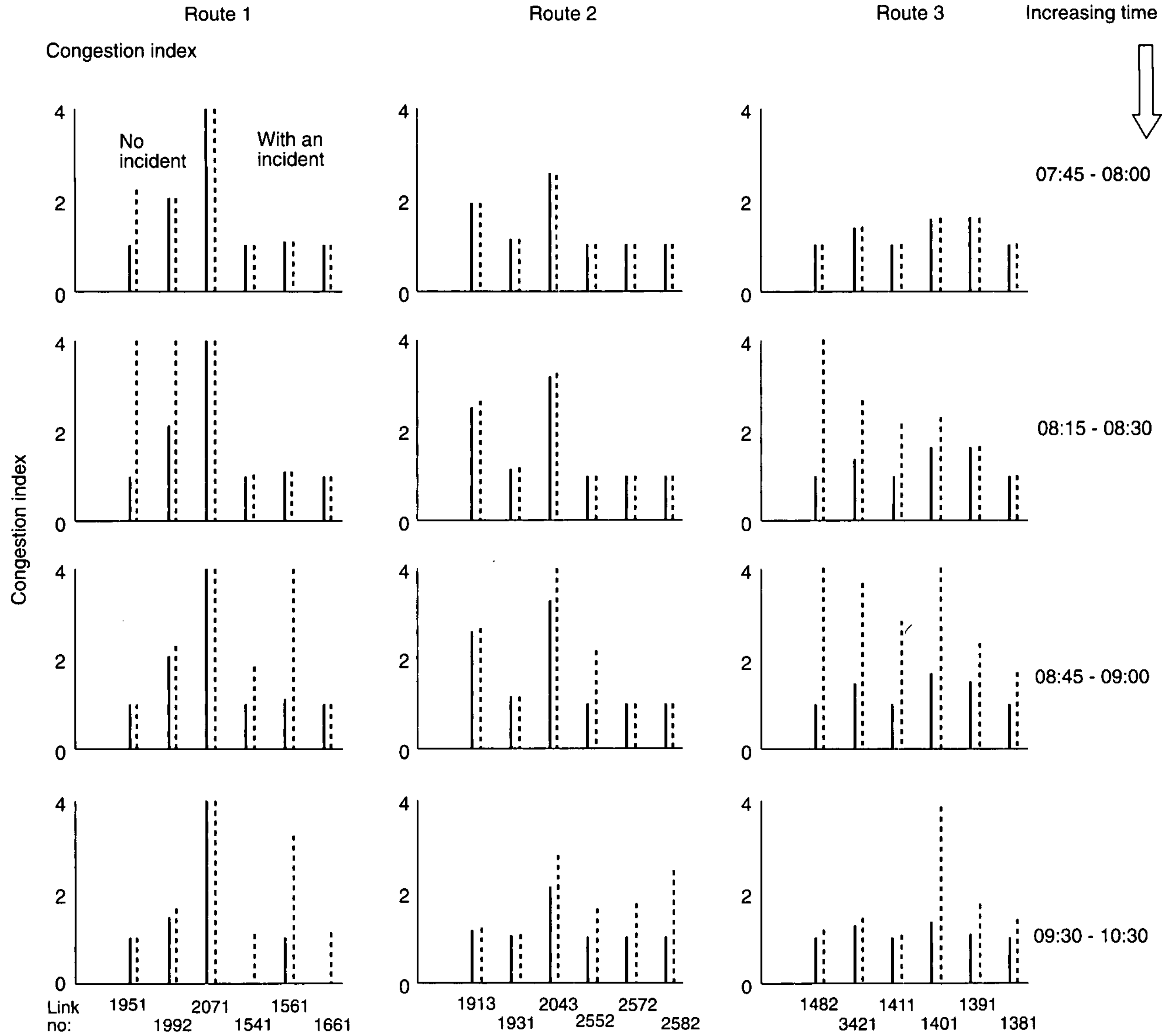

Fig 3 Changes in congestion index for links along three main routes through a town with and without an incident
(Incident from 07:30 to 08:30)

4) The following assignment logic is then applied:

A specified proportion of vehicles are made eligible for diversion to an alternative route from any position (i.e. decision point) along their original route if they encounter a queue which is longer than the previous 'normal' queue established in stage 1, and if the new queue length is longer than a specified proportion of the link length. (In practice this is usually set to be when a link becomes full).

A vehicle is allocated to an alternative route to its destination, from the decision point along its previous route, based on the lowest free running journey time along all possible routes from the decision point, and which is within a specified ratio of the corresponding old free running time.

If the free running journey time, along the new part of the route, is greater than a prescribed ratio of the corresponding original journey time then the vehicle is constrained to complete its journey along its original route.

The revised route data (link numbers) are stored for all of the vehicles.

TABLE 3

Observational scale for identifying levels of congestion

A.	Vehicles moving in a regular manner on roads. Any queues at traffic signals clear within one cycle; small queues at other junctions.	Free moving
B.	Large amount of traffic on main roads. Long, slow moving queues on some links which may block up to one adjacent junction; vehicles still able to clear queues at signals within two cycles.	Very Busy
C.	Large traffic movements on all main roads. Vehicles moving in stop-start fashion on many links. Long queues on some links starting to block back to affect up *two or more adjacent junctions* in isolated groups across a network. Cross movements of traffic at a few junctions affected. Persistent queues at most signals; individual vehicles still able to clear a queue at signals within two or three cycles.	*Congestion* (-orderly movement of traffic starting to break down)
D.	Large amounts of very slow moving traffic on most roads. Very long queues on many links; some queues starting to block back to link three or four adjacent junctions into groups. Cross movements of traffic at many junctions severely restricted. Delays in some queues exceeding ten minutes; vehicles queuing at some junctions for three or more cycles.	Severe congestion (-orderly movement of traffic has broken down)
E.	Many junctions linked together into one large group by blocking back. Traffic virtually at a standstill over large proportion of network.	Gridlock

5) CONTRAM is run again for three iterations, in fixed-route mode, using the original demand profile and the new route data (link numbers) established in stage 3. This is again to establish consistency between journey routes, flows and queues.

6) The output from running CONTRAMI provides information on flows, queues, delays, vehicle routes, etc. in the same format as that from a run of CONTRAM.

The percentage of vehicles eligible for diversion and the free running time ratio is specified by the user. The percentage eligible for diversion in effect specifies the percentage of drivers who are constrained to travel along their original routes. These might represent, for example, drivers who are just passing through a town and who do not have any detailed knowledge of alternative routes.

At present little research is available to confirm the assumptions used in CONTRAMI, however the underlying assumptions are believed to be reasonable for representing the way in which drivers take decisions when reacting to congestion caused by incidents. In the absence of other methods CONTRAMI provides a systematic basis for desk studies to examine the effects of variations in network and incident parameters, and strategies for coping with incidents:

6.2 DESK STUDIES OF INCIDENTS AND FACTORS AFFECTING CONGESTION

Desk studies have been made to model the effect of incidents in networks based on two towns, Reading and Kingston-upon-Thames, using CONTRAM and CONTRAMI to simulate a number of scenarios. A number of incidents were modelled in both networks, with different timings and locations, to see whether any general principles could be established for coping with the effects of incidents. The objectives of these studies were:

(a) to examine the ways in which CONTRAM and CONTRAMI could be used to represent drivers' response to different levels of information about incidents

(b) to assess the importance of different incident, network and demand parameters in contributing to the congestion caused by incidents and

(c) to investigate the effect of some of the techniques for controlling congestion, as a preliminary step for developing strategies, and to identify needs for further research

6.2(a) Drivers' responses to different levels of information were modelled as follows:

CONTRAM /CONTRAMI	Incident?	Objective
(A) CONTRAM	No	Normal traffic conditions - establishes base case for comparison purposes
(B) CONTRAM	Yes	Drivers respond to complete information about effect of incident
(C) CONTRAMI	Yes	All drivers constrained to remain on original routes
(D) CONTRAMI	Yes	No prewarning of incident - drivers respond to unexpected queues - some drivers remain on original routes

Case (B) corresponds to the condition where drivers having complete in-car (including VMS) information so that they are able to select their own best route; this might therefore be expected to result in optimal conditions (i.e. minimum congestion) for the network as a whole. Case (C) represents the condition where all drivers are constrained to stay on their original routes irrespective of the amount of congestion encountered. This would be expected to result in the worst levels of congestion overall as vehicles continue to arrive at the scene of an incident, with queues increasing until capacity is restored. Case (D) represents the more usual situation for drivers with no information about traffic conditions ahead; some drivers elect to stay on their original routes whereas others may divert if they encounter unexpectedly long queues. The proportion of drivers constrained to their original routes and the values of the parameters which affect choice of alternative routes can be varied.

For comparison purposes values of the congestion index (Section 5.2), for the network as a whole, have been used as the measure of congestion in the network, but it is realised that their can be local variations in levels of congestion which could be important. However, such a breakdown would require a much more detailed analysis and it was considered that the overall values are suitable for present purposes.

The results mostly confirmed that remaining on original routes (C) caused the worst congestion, but there were a few exceptions dependent on the location of an incident within a network, the duration of the incident and the background level of congestion.

Case (B) showed that there were benefits in providing drivers with complete up to date information about traffic conditions, as this usually resulted in the least increase in the amount of overall congestion. But counter to expectations one or two runs showed that an incident could actually result in a reduction in the overall level of congestion. This apparent anomaly arises because drivers normally choose their own quickest route, irrespective of the effect on other drivers (i.e. user optimum route choice), and the presence of an incident causes drivers to take routes which are closer to network optimum conditions for minimising congestion. This is a recognised paradox which might eventually be exploited, for the benefit of reducing congestion in a network as a whole, if some means could be found to constrain some drivers to take different routes.

Case (D) represented the more usual situation for drivers, i.e. no prewarning of traffic conditions ahead. Whilst congestion was not usually as bad as for fixed routes the analysis showed that the spread of congestion was complex and that there was always the possibility that traffic diverting to avoid congestion could make matters worse in another part of the network. This was likely to be the case if two incidents occurred at similar times in different parts of a network.

The general conclusion resulting from this part of the work was the benefit to be gained, for minimising congestion, from providing drivers with as much information as possible about traffic conditions. This is an important conclusion which can be used to help cope with incidents for which there is some prewarning.

6.2(b) A number of model runs for each of the cases (A) to (D), above, were made with variations in different incident, network and demand parameters to determine the effects of these parameters in contributing to congestion. As might be expected interpretation of results was complex and there were occasional anomalies requiring explanations which reflected more on the particular type and layout of a network or on the local pattern of traffic demand at the time of an incident than on the nature of the incident itself. Comments on the effects of the different parameters are divided into two groups - first, local factors associated with the incident itself, and second, factors associated with network conditions, traffic demand and drivers' response to unexpected congestion.

The incident factors are:

The amount of *reduction in throughput capacity.* The amount of congestion caused depends on whether the reduction in capacity on a link is only partial or amounts to a whole road closure. The reduction has the immediate effect of causing local queues to form, the significance of the queues depending on the extent to which they grow and block movements at upstream junctions.

In a similar manner the *duration of an incident* affects the extent to which queues grow. The longer the duration the more likely that queues will extend to block upstream junctions, and the longer that it persists the more severe the additional congestion becomes.

Incidents may occur at *Random or with some Prewarning.* This has already been mentioned in the previous section. Prewarning enables strategies to be implemented in advance to contain congestion and, should enable warnings to be given to drivers so that they can choose to avoid congestion. Again, for an incident which lasts beyond one or two hours, even if it initially occurs without warning, the build up of further congestion can be minimised by providing warnings to drivers at that stage.

The *position of an incident along a link* affects the number of vehicles that can queue before the queue affects an upstream junction. The closer an incident is to the upstream junction the more likely that blocking back will occur.

The *location of an incident,* in relation to the layout of the network, will have varying effects depending on how close it is to key junctions. This will have the most effect if it reduces the number of alternative routes that are available to avoid any build up in congestion.

More than one incident may occur at the same time in which case the effects of each may overlap causing even more congestion, particularly if drivers are not warned of their coexistence.

The other factors which contribute to the formation of congestion are associated with the background level of congestion, the type of network, and drivers' knowledge of the network:

The *background level of congestion* at the time of an incident has been found to have the biggest effect on the final amount of congestion. The rate at which congestion can increase with changes the background level of congestion is illustrated diagrammatically in Figure 4.

The *timing of an incident* in relation to the profile of the traffic demand on a network suggests that the level of congestion caused will be worse, and last longer, if the incident occurs just before or at the peak of the demand rather than later when demand has already started to decrease. The consequences of the same incident can also be markedly different if it occurs during an a.m. or p.m. peak period.

The *type of network* has a strong effect depending on a number of factors such as the proportions of signal controlled and give-way junctions, and roundabouts. Networks with dominant one-way systems and which allow limited route choice are likely to be more sensitive to the effect of incidents than ones with multiple route choice. And it is possible that networks with short links between junctions

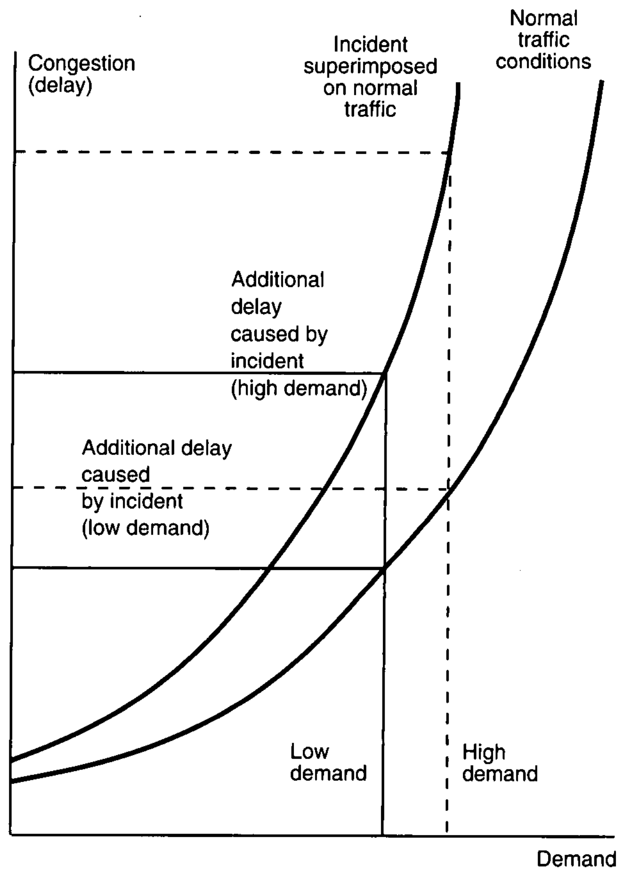

Fig 4 The influence of the background level of congestion on the severity of incident-induced congestion

will be more prone to blocking back problems than ones with long links.

Network control parameters. These largely relate to the manner of response of UTC systems. Fixed time signals will not change automatically in response to an incident, unless an alternative fixed time plan is introduced (this must, of course, be prepared in advance); and adaptive systems, such as SCOOT, will only respond to the changes in traffic flows and queues detected by traffic sensors. Hence, until signal control systems can be designed to adapt to the circumstances of the incident itself, the signal settings are likely to be inappropriate for the changes in journey patterns and may add to the build up of congestion.

Drivers knowledge of a network affects their ability to choose alternative routes to avoid incidents. This will clearly be dependent on the numbers of drivers making local journeys and those who are just passing through a network or visiting it for the first time.

In the event of an incident *drivers will not have knowledge of changes in traffic conditions* and any diversions to alternative routes may spread congestion to those routes.

It should be noted that the above factors do not operate separately from one another and several are likely to be operating at any one time making the spread of congestion even more difficult to predict and control.

6.2(c) Techniques for controlling congestion are discussed in the next section. A number of model runs have been made to assess the potential benefits of control strategies using some of these techniques. The strategies tested were:

- signal optimisation downstream of an incident
- gating or metering upstream of an incident
- overall demand restraint
- re-routing of traffic or restriction of traffic to original routes

Signal optimisation downstream of an incident appears to be a very constructive control strategy. The diminished throughput at the incident warrants a reduction in green time for that approach, which can be used to reduce the delays on the non-affected approaches. Such a strategy is particularly effective when drivers are encouraged to divert away from the incident. Ultimately it may be possible to integrate these changes into advanced UTC systems such as SCOOT.

Gating, or metering, is another signal-based strategy which aims to reduce the in-flow into a congested area by throttling demand and by displacing traffic queues to areas where they cause less harm. The result of gating is a reduction in congestion and delays in the most congested area, and an increase in queue lengths and delays in peripheral regions. The benefits of reduced congestion should outweigh the disbenefits of extra queues for this policy to be efficient. Out of three preliminary tests of gating strategies, for a hypothetical incident in Kingston, only one of these showed a beneficial effect.

The following tentative conclusions with respect to potential benefits of gating were drawn from an analysis of the tests:

- the position of the incident in the network and the possibility of queue displacement determines the potential of metering: in the case of a City Centre incident in the PM peak insufficient queue storage capacity is available for such a strategy, but in the AM peak this may be fundamentally different.
- the exact amount of metering (defined by the reduction in green time) is crucial, as the overall effect of the gating strategy is a balance of benefits and disbenefits.
- an important aspect of gating is the stage definition at the metering junctions, which determines what use can be made of the green time taken away from the metered movements.
- the effectiveness of a gating policy is determined by the position of traffic signals in the network; as a result gating is more easily applied, and more likely to be effective in a signal-controlled grid network than in a heterogeneous historic city, where metering may lead to undesired re-routing and ratrunning.
- exact design of a metering strategy, including stage diagrams and timings, and proper assessment of the benefits of gating requires more detailed modelling of queuing in the congested area and at the metered junctions.

The effectiveness of overall demand restraint measures has already been mentioned in Section 6.2(b) in terms of background level of congestion. A reduction in overall demand not only reduces regular congestion, but also, and even more so, reduces the impact of incidents on congestion. Test runs indicate that with an incident the reduction in the value of the congestion index amply exceeds the reduction in actual demand. The wider benefits for operating this type of strategy to provide a Quality Margin for the traffic operating in a town is discussed by Goodwin (1992).

There are two aspects of traffic re-routing when an incident occurs:

- re-routing by drivers who meet unexpected traffic conditions; this is reactive re-routing, which is the type modelled by CONTRAMI.
- and, diversion of drivers before they reach the congested area in response to advice on traffic conditions; this is pro-active re-routing, which could be achieved by variable message signs (VMS) or electronic route guidance systems (ERG).

The second type of re-routing cannot readily be modelled with the tools currently available, but the CONTRAM model runs, with an incident in place, provide an indication of what could be achieved by route guidance systems which provide complete knowledge of network conditions.

And although the re-routing as modelled by CONTRAMI is meant to represent drivers' selfish routing decisions, it provides an insight into the relative (dis)advantages of re-routing in general in different scenarios and circumstances.

The general conclusion drawn from the simulations is that the effectiveness of traffic re-routing depends on where the traffic is re-routed to, and the base level of congestion there. This implies that re-routing becomes potentially highly detrimental when the overall level of demand in the network increases, as the harmful effects of the diverted vehicles on existing traffic on their new routes then outweighs their own benefits. Along similar lines, re-routing of traffic is likely to be detrimental when several incidents occur simultaneously.

On the other hand, the potential benefits of advanced VMS or ERG systems are substantial. In the majority of cases the reduction in the values of congestion index, for runs of CONTRAM with full knowledge of network conditions over the values determined by CONTRAMI, is approximately 25%. In some cases full knowledge of network conditions more than halve the value of the congestion index.

7. TECHNIQUES FOR CONTROLLING CONGESTION

A variety of techniques exist for use in controlling congestion, ranging from local manual or temporary signal controls to more sophisticated information and communication systems which influence drivers' choice of route and even mode of travel. But ultimately all techniques can be regarded as ways of managing demand or managing capacity, or combinations of the two. Many of these can be applied, in principle, to managing both regular daily congestion and the random congestion caused by incidents -the main difference in requirement being the time scales available for action.

Long term measures for managing congestion (of the order of months or years) are mainly concerned with the level of regular congestion in a town - the objective being to contain levels within acceptable limits for the benefit of the social and economic welfare of the town. The time scale for handling incidents is much shorter (minutes or hours), as rapid response is needed to prevent the breakdown in the orderly movement of traffic and contain the spread of congestion.

A second difference between the control of regular and random congestion is that the former is usually managed on a network wide basis, which enables optimised signal control strategies to be used to minimise delay and hence congestion in the network. In contrast, in the initial phase immediately following an incident, local measures are needed to control the build up of queues and prevent blocking back. In this case optimising signal settings to minimise delay is not likely to be a priority. Of course, if it is known in advance that an incident will exist, even if it will last for only a short period of time, then control over a wider area and optimisation may be possible.

Several reviews have been made relating to methods for managing congestion: Quinn (1992) has provided a comprehensive summary of queue management techniques, and an ITE report (1989) provides a useful general summary of congestion management techniques. Tables 4.1, 4.2 and 4.3, partly based on these reviews, summarise the different techniques which can be used and identify their suitability for handling regular (background) congestion and congestion caused by incidents. An indication is also given of the time scales for implementing techniques (since incidents require a quick response), and whether a technique could influence a driver's choice of route either before the start of a journey or whilst travelling. The objectives and the additional effects identified in the table are given from the point of view of controlling congestion and hence do not include comments on economic or social impacts. The techniques are summarised under three broad headings: Network infrastructure (changes which affect capacity in a network); Demand management (factors associated with traffic operations); and Driver behaviour (factors which affect drivers' choice of route, and drivers' behaviour in traffic). The breakdown into these three groups is not exclusive as some methods could be described in more than one category.

The most suitable techniques, identified by the table, which can be used in short time scales for coping with the effects of incidents are:

Manual control or temporary traffic signals. These can be used at junctions if there is a signal failure and also at the sites of other types of incidents. However it should be noted that any local control measures should take into account their effect on traffic conditions in other parts of the network.

Signal control techniques such as gating, downstream optimisation of signals and reverse signal progression can be used locally to control the formation of queues, and over a wider area to regulate demand and contain the spread of congestion. In these cases signal control plans need to be prepared in advance, to cope with incidents anywhere in the network and at different times of the day, so that they can be implemented by the traffic controller as soon as an incident has been reported. Such plans could also be automatically triggered by signals from traffic sensors (see Appendix A 1.10).

Temporary use can be made of Bus only and High occupancy vehicle (HOV) lanes, and tidal flow lanes, to provide increased capacity to relieve the build up of queues or to help by-pass an incident. For these applications adequate warning of changes in lane use must also be given as there may be safety implications for drivers.

All of the information (communication) systems can be used as immediate measures to advise drivers of traffic conditions and hence to influence demand and route choice to avoid congestion. In the short term VMS systems are potentially the most useful method for direct communication with drivers,

TABLE 4.1

Techniques for controlling congestion - NETWORK INFRASTRUCTURE

Technique	Objectives	Incidents or Background congestion (I / B)	Time Scale (Short or Long Term) (S / L)	Affects Pre-journey or En-route decisions (P / E)	Additional effects Advantages and disadvantages
Road use					
Bus and High Occupancy Vehicle (HOV) lanes	Reduce journey times for public transport and HOV's.	I and B	L	P	Encourage use of public transport and HOV. Reduces road capacity for other users. Could be useful in emergency for incidents.
Restrict number of spaces for on-street parking	Improve traffic flow.	B	L	P and E	May increase parking search and hence demand on neighbouring roads.
One way streets Banned turns	Reduce conflicting movements and incidents. Improve flow of traffic.	B	L	P	Reduces route choice. Increases journey distance Increases flow on some links.
Road improvements :					
Tidal flow lanes	Increase capacity.	I and B	L	P	Can be used in emergency for incidents.
Add lanes without widening	Increase capacity.	B	L	P	Increase demand.
Intersection improvements Widen roads Construct new roads	Increase capacity.	B	L	P	Increase demand.
Construct ring-roads	Decrease demand on inner network.	B	L	P	Increase demand.
Signal control systems :					
Manual control, temporary signals	Emergency control for signal failures, and at incidents.	I	S	E	Effects on traffic in other parts of the network are unpredictable.
UTC's (SCOOT, TRANSYT)	Reduce delay (reduce congestion)	B	L	E	
Gating Reverse signal progression	Control queue length. Prevent blocking back.	I and B	S	E (and P)	Regulates demand and hence the build up of congestion.
Downstream signal optimisation	Relieve congestion.	I	S	E	
Monitoring systems :					
Detector loops Video imaging methods CCTV's Traffic wardens, police and other observers	Monitor traffic conditions to provide prewarning of critical traffic conditions. Detect incidents	I and B	L	E	Police and traffic wardens are instantly available to deal with incidents. Conflict of priorities with other work.

TABLE 4.2

Techniques for controlling congestion - DEMAND MANAGEMENT

Technique	Objectives	Incidents or Background congestion (I / B)	Time Scale (Short or Long Term) (S / L)	Affects Pre-journey or En-route decisions (P / E)	Additional effects Advantages and disadvantages
Fiscal measures :					
Road & Congestion pricing	Decrease demand.	B	L	P	Discourage use of 'sensitive' roads.
Variable Road & Congestion pricing	Decrease demand. Control journey arrival times.	B	L	P	Discourage use of 'sensitive' roads.
Taxation (Road, Fuel and Parking)	Decrease demand.	B	L	P	
Parking management :					
Vary parking prices and availability of spaces	Decrease demand. Control journey arrival times.	B	L	P	
Public transport operation :					
Park and ride	Decrease demand of cars in towns.	B	L	P	Encourage use of public transport.
Bus deregulation	Provide better bus service. Decrease use of cars.	B	L	P	Increase number of buses in a network. Increase stopping activity, may increase congestion.
Improve bus operation (travelcards, subsidised fares)	Improve journey times for bus passengers.	B	L	P	Decrease bus boarding time.
Introduction of guided busways or LRT	Improve journey times for passengers.	B	L	P	Can take up road space used by other vehicles.
Social Conditions :					
Work location and timing Flexible working hours Telecommuting	Reduce need for journeys. Redistribution of journey timing. Reduce demand.	B	L	P	Results in peak spreading.

#Note: Local short term measures for controlling demand are not listed here as they are a direct consequence of some of the techniques listed in tables 4.1 and 4.3

TABLE 4.3

Techniques for controlling congestion - DRIVER BEHAVIOUR

Technique	Objectives	Incidents or Background congestion (I/B)	Time Scale (Short or Long Term) (S/L)	Affects Pre-journey or En-route decisions (P/E)	Additional effects Advantages and disadvantages
Information :					
VMS Radio broadcasts	Inform drivers of incidents and congested traffic conditions. Decrease demand on congested routes.	I and B	S and L	P and E	May spread congestion to other routes.
Road signing (Road names and routes, parking locations)	Improve flow of traffic.	I and B	L	E	Reduce journey times. Improve knowledge for route choice.
Advisory speed signing	Control growth of queues.	I and B	S and L	E	Can be changed according to traffic conditions
In-car information systems (eg trafficmaster)	Inform drivers of incidentsI and and congested traffic conditions.	B	S	E	May spread congestion to other routes.
Dynamic route guidance systems	Minimise driver journey times. Inform drivers of incidents and congested traffic conditions.	I and B	S	E	May spread congestion to other routes.
Education :					
Driver responsibilities towards other road users Use of yellow lines and yellow boxes	Improve traffic flow. Reduce incidents and blocking at junctions.	I and B	S and L	E	
Enforcement :					
Prevent obstructive parking and improper use of roads and junctions	Maintain capacity. Aimed at controlling background level of congestion.	I and B	S and L	P and E	Transfers parking or loading to adjacent roads.
Remote camera recording systems	Deter traffic infringements. Maintain capacity.	I and B	L		Smooth traffic flow. Improve junction efficiency.

as they do not require specialised in-car equipment, but ultimately in-car systems should be the most effective way for coping with incidents especially if the route guidance aspect can be coupled with the traffic control system. To be effective all of the information systems should provide up to the minute traffic information as traffic conditions change in a network.

Driver education supported by enforcement methods can be used effectively to help control the background level of congestion and to discourage motorists from making anti-social traffic movements (speeding, improper lane use, junction infringements) which further contribute to the formation of congestion. In this respect the police consider motor cycle patrols as being particularly effective for enforcement purposes and as a deterrent to bad driving habits. The recently introduced remote camera recording systems are becoming increasingly respected by drivers as enforcement measures.

It should be noted that as the additional congestion caused by an incident is directly affected by the background level of congestion (Section 6.2) then any of the techniques in Tables 4.1, 4.2 and 4.3 which reduce that level will be of benefit for minimising the effects of an incident.

8. ORGANISATIONAL ASPECTS OF MANAGING INCIDENTS

Two organisations are involved with the control of traffic in urban areas - the Local Highway Authority and the Police. The local highway authority is responsible for the provision and maintenance of the network infrastructure, i.e. the road system, the means for controlling traffic, and communications with motorists. Trunk roads that pass through urban areas are nominally the responsibility of the Department of Transport (DoT), but in practice they are managed by the local highway authority, under delegated responsibility, as part of the local highway network. (The recent pilot Red Route in London (see Appendix A 1.1) is a scheme to reduce vehicle journey times which was instigated and controlled by the DoT, with the local authorities along the route being required to cooperate with the operation of the scheme over the management of any of their roads affected by the scheme).

In most large towns traffic operations are controlled through a traffic control unit which is part of, or responsible to, the Local Highway Authority. There is usually a traffic controller in charge of the unit who is responsible for the day-to-day operation of the UTC system and for the operation of the network infrastructure generally. Smaller towns may not require the services of a traffic control unit, in which case the control of any UTC system is 'managed by the computer', which operates as an (unattended) independent unit or in the form of a satellite unit connected to the computerised control system for a larger town. In this case, and in very small towns, the police take on local responsibility for controlling traffic. In practice most small networks do not require active traffic control and it is only when an incident occurs that problems of congestion arise. In such towns traffic wardens, who are responsible to the local police force, are often available for emergency traffic control purposes. However these small town arrangements raise the question of who to contact locally in the case of an incident and, more importantly, how long it can take to produce effective action.

Although responsible for the operation of the UTC systems in the larger towns, the local highway authority, and hence the traffic controller, does not have any on-street authority for dealing with the actions of motorists except indirectly by means of signal control settings and various message facilities.

The police, together with traffic wardens who are under the control of the police force, are the only people who have the authority to deal directly with motorists, or with any problems which occur on the street. The principal responsibilities of the police are concerned with people's safety (for whatever reasons) and the maintenance of law and order, but they are also expected to deal with all types of emergencies which arise (traffic accidents, crimes, crowd control, etc). In the context of traffic operations this means dealing with incidents which the police judge to be serious enough to need attention. Clearly a vehicle accident involving personal injury would be classed as serious whereas a vehicle parked on double yellow lines might not - even though both could eventually result in a similar build up in the amount of congestion caused. The amount of attention that can be given to traffic problems by the police has to be balanced against priorities for their other duties, many of which will be of greater importance. It has been estimated that traffic duties account for between 5 and 7 per cent of total police time (Audit Commission 1992), and it is known that, with the exception of motorway policing, traffic control duties have a poor image with many police officers. Much of the interaction with motorists, and on-street activities relating to traffic infringements, is therefore left to traffic warden patrols. Little emphasis is given at present to preventing or controlling congestion and hence most police operations, relating to traffic congestion, are of a 'firefighting' or reactive nature - i.e. responding when incidents have occurred or when traffic congestion has already become so much of a problem that intervention on the street is needed, for example in the case of gridlocks.

Legislation introduced in the 1991 Road Traffic Act (HMSO, 1991) enables some of the duties carried out by traffic wardens to come under the direct control of local authorities. The act authorises the use of 'parking attendants', who have some of the powers of traffic wardens, to deal with certain types of parking offences. It would seem a natural step if the work and control of traffic wardens and parking attendants could be integrated with the work of the traffic control unit so as to provide traffic controllers with direct control over the activities of motorists who are causing obstructions which are affecting the operation of a network. They could also be used effectively as observers on the street for spotting and reporting incidents and for identifying critical build ups of traffic in parts of the network not covered by automatic detection systems.

The Metropolitan Police, who operate traffic patrols and the traffic warden services in London, are also responsible for controlling traffic in London. This set up comes closest to the ideal of a combined organisation for dealing with incidents and traffic congestion.

It is evident from the discussion in this section that there are potential gaps in the control of traffic operations in towns because of the separate responsibilities and authority of the organisations who deal with traffic problems. There are further gaps in that the emergency services and various support services are also responsible to different organisations, the combined effect of which can have an adverse effect on the quick response needed to deal with incidents. However, in spite of these cautionary comments, which are intended to be constructive by drawing attention to potential problems, it is known that good cooperation at the operational level between traffic control units, the police, and the emergency services, overcome many of the organisational problems which could arise.

9. A FRAMEWORK FOR THE DEVELOPMENT OF STRATEGIES

The response needed to cope with the effects of an incident can be broken down into the following sequence which forms a basis for developing strategies:

Incident occurs:

- Incident identified and reported
- Remove incident
- Action to control congestion
- Communicate traffic information
- Feedback information

Each stage will be considered in turn to identify objectives, to examine which techniques can be used, and to comment on the roles of the organisations involved.

But before considering each stage in detail it should be noted that the sequence is essentially a 'reactive' one, triggered by an incident. Most traffic controllers know when traffic conditions in their network are approaching critical levels such that any sudden reduction in capacity can precipitate congestion. This suggests that an anticipation stage needs to be included, at the beginning of the sequence, to detect or predict the build up towards critical conditions.

Up to the present time the 'action to control congestion' stage has received most attention in discussions of strategies, however it will become apparent that all stages in the chain are important if effective strategies are to be produced to cope with the effects of incidents. Each stage will therefore be examined in that context, i.e. as part of an overall systems approach to the problem:

9.1 ANTICIPATION

The objective at this stage is to detect or anticipate when traffic conditions are approaching critical levels. This can be achieved using monitoring techniques and the systematic use of previous experience.

It is now common practice, in most large towns, to use closed circuit TV cameras (CCTVs) to monitor traffic conditions. Controllers are aware of the more important junctions in their networks, where traffic movements are known to be seriously affected if blocking back occurs, and keep a regular check on their operations. CCTVs can be used to monitor the build up of queues and video image processing techniques are being developed (e.g. Hoose 1992), which will enable the onset of blocking back to be automatically detected.

Signals from detector loops, which form part of a UTC system, can also be used for monitoring queues. The output from SCOOT systems can be processed, using the automatic data storage system ASTRID (Hounsell, 1990), to predict when congestion is likely to occur. This uses a comparative method for matching queue and flow patterns with historic data profiles to identify critical changes in traffic patterns.

Both types of system can be used to give automatic warnings to traffic control staff, thereby avoiding the need for staff to be permanently employed watching monitors.

As well as making use of technological aids it is recommended that a Congestion Log, similar to the Metropolitan Police congestion file (Section 3), is kept to record information on congestion caused by incidents so that practical experience is built up for anticipating similar situations. 'Post mortem' meetings, involving the various organisations responsible for handling traffic problems, would also be useful for adding to this experience.

The anticipation stage should also include *preventative* action aimed at controlling the general background level of congestion by enforcing restrictions on illegally parked vehicles at critical locations, and vehicle loading operations, during peak periods. Such measures have proved effective in the operation of the pilot Red Routes scheme in London (Turner, 1992), however it must be recognised that there are likely to be considerable costs incurred in implementing enforcement measures over a large area at the level applied in the pilot scheme. The annual cost of implementing the pilot Red Route scheme has been estimated as being £0.9m which would correspond to a total cost of about £25m p/a for red routes for the whole of London.

Effective enforcement operations require cooperation between the police, traffic wardens and the traffic controller to identify and set priorities for critical locations. As well as using previous experience modelling work can be used to identify critical links and junctions in a network.

9.2 IDENTIFY AND REPORT INCIDENTS

Early detection and action to remove an incident has been shown to be the most effective way of minimising the build up of congestion. However the actual detection of an incident is potentially one of the weakest links in the sequence. This is because the people responsible for traffic operations on the street, normally the police or traffic wardens, may not be in the vicinity of an incident when it occurs and because it is not always obvious to an observer when an incident is sufficiently important to need reporting.

As in the previous Section, CCTVs or detector loops can be used to provide early warning that an incident has occurred, and considerable research effort is currently in hand to develop automatic incident detection systems using UTC facilities (Bretherton 1991). But current monitoring facilities normally only provide good coverage in the centre of towns and at key junctions, and only in towns with UTC systems. But even if there is automatic detection that an incident has occurred the detection system itself is unlikely to be able to identify the type of incident involved. For that purpose it is suggested that a more positive role is played by traffic wardens and the police, by emphasising that the detection and reporting of incidents is an important part of their traffic duties for minimising congestion, particularly during peak periods. Traffic wardens can be very effective in this role as they usually have telephone or radio contact with their control centre which can critically cut down reporting time.

Another potential source of information is reports from local transport bus drivers and other professional drivers who also have radio contact with their depot. The use of bus drivers has the particular advantage that bus services cover most of the major roads in an area. Bus drivers are also likely to have the experience to judge the significance of an incident as they will be familiar with local traffic conditions. They are also likely to be reliable with their reports as minimising congestion is of direct benefit to bus operations.

It is also important that the type of incident is correctly identified as the measures needed to cope with different types of incident can be considerably different (see next section).

However whilst it is acknowledged that the correct and rapid reporting if incidents is vitally important, there is a danger that too many reports of insignificant incidents would swamp the reporting system and be counter productive. A cut off level for reporting incidents would therefore need to be developed, by experience and by close cooperation between the people and organisations involved.

9.3 REMOVE INCIDENT

The first objective for any strategy, apart from ensuring the safety of people involved, will be to remove the incident in order to restore capacity as quickly as possible.

The correct identification of the type of incident, in the previous stage, is essential for calling out the correct emergency services (ambulance, fire service, etc) and any specialist services which are required. In most cases minor incidents, such as problems with vehicles, can be handled on the spot by the police or the driver of a vehicle. In other cases only a few specialist garages have the equipment and knowledge to deal with the breakdown of a heavy goods vehicle or an overturned car. Specialist services are also needed to deal with signal failures, chemical spillages and any unusual types of incident.

In all cases it is recommended that one central person (the traffic controller) is responsible for initiating action and coordinating the efforts of the different people and organisations involved.

9.4 ACTION TO CONTROL CONGESTION

Various techniques which can be used for managing congestion have been listed in Section 7. Before making use of any of the techniques it is necessary to be clear about the objectives for this stage.

If the action is in response to an incident, which has only just occurred, then the prime objectives will be to restore capacity and prevent queues from blocking back to upstream junctions so that the spread of congestion is contained. In the very short term this can be managed using manual control (by the police or traffic wardens), or by the use of temporary signals.

But often the traffic controller will only become aware of an incident when congestion is already building up. It will then be necessary to minimise the spread of congestion to adjacent areas. In both this and the previous case the spread of congestion can be controlled by using gating strategies, downstream optimisation of signals and backward progression of signal timings, or by providing drivers with information to encourage them to use alternative routes, or even delay the start of their journey.

Actions can be taken by the traffic controller to change signal settings for gating purposes, etc, Communication can most easily be achieved, using current technology, with variable message signs or broadcast messages, as this would not incur extra costs for motorists. Eventually in car communication and route guidance systems will be available for communication purposes. It is also important at this stage that progress on the street in handling congestion is monitored to provide feedback to the traffic controller and to drivers (especially in those networks where gridlocks are known to have been triggered before).

At present, reactive strategies will not be concerned with optimising network conditions, however this would be possible if plans can be produced in advance to respond to incidents at particular locations in a network. Such plans are already effectively employed in London.

So far the previous comments on action have implied that there is a UTC system in operation and that traffic can be controlled over an area by changes in traffic signal settings. However there are many towns which, although experiencing regular daily congestion, are not large enough to merit control by a UTC system; and such towns probably do not have traffic control staff or even traffic wardens permanently on duty, if at all. Significant congestion can occur in such towns, particularly following an incident. In these cases traffic control would be exercised by the police or the use of traffic wardens.

An important aspect of strategies is that techniques have to be implemented on the street which will involve several organisations (Section 8). It is therefore essential that there is good cooperation between the organisations and that operations are properly coordinated This is best achieved if the control of traffic in a network is under the control of one person, the Traffic Controller, and under the responsibility of one organisation.

9.5 COMMUNICATION WITH DRIVERS AND OTHER ORGANISATIONS

Much of the adverse reaction by drivers to congestion, particularly following an incident, is the frustration of not knowing what is happening, and in particular having insufficient information on current traffic conditions to take decisions on route choice. These problems can be helped by use of a variety of communication systems.

Communication systems can be divided into external or in-car systems, and can be further subdivided according to whether the information given is purely informative or is interactive between the driver and the network control system. External systems include: radio broadcasts, variable message signs, and diversion notices. These have the short term advantage that no specialised receiving equipment is required. In-car systems require dedicated equipment to be installed; these are now starting to become available as commercially operated systems such as the TRAFFICMASTER system which displays congestion information for the M25 motorway. In-car systems range from 'static' systems which use historic data, for broad route choice purposes and where the driver makes his own decisions, through to 'dynamic' interactive systems where the driver is instructed which route to take; the details of the journey are fed into a computer which takes that information into account when routing another vehicle.

The benefits of these systems, as a means for controlling congestion, have still to be established but it is expected that their main use will be to help avoid the effects of incidents.

To be useful to a driver information needs to be Timely, Relevant and Reliable so that drivers can take positive decisions relating to their journey. Technical advances will eventually result in 'expert' in-car systems for this purpose which automatically provide information or change radio channels when traffic information is being transmitted. At present most communication systems rely on drivers having their radio switched on and tuned to the correct channel and research has shown that, during one survey, only 11% of drivers actually received a message during their journey on a particular day. A temporary expedient to help drivers be ready to receive a message would be to use flashing lights or indicators along the side of the road or at junctions when a message was about to be transmitted.

A second technique for communicating information uses variable message signing. These are already in use to provide car parking information and messages to motorists on motorways. Whilst the rotatory prism style of VMS is limited in its versatility this can be improved using a dot matrix display which enables a traffic controller to type in any suitable message.

A variation on this is to use mobile variable message signs on the back of trucks which have the advantage that they can be positioned at strategic locations - but even this could loose valuable time whilst the mobile display was deployed.

Good communication systems are particularly important for the emergency services, especially when lives are at risk. This is currently achieved using telephone hot lines, but there is clearly scope for the use of dedicated 'expert' systems.

A telephone advisory service would be helpful to most motorists for use before they set out on a journey. Reliable information could then be given on the location and expected clearance time for incidents, and also for weather conditions (ice and snow) so that journeys can be retimed if necessary. The logistics of updating such a system would need to be worked out.

9.6 FEEDBACK

Feedback of information on the current state of traffic conditions and on the results of actions is also a neglected step. Apart from the need of the traffic controller to know how effective an action has been, drivers need to be informed as quickly as possible about progress, to discourage unnecessary diversions to avoid an incident or congestion which has already been cleared. Feedback is particularly important if two or more incidents occur simultaneously as drivers attempting to avoid one may well run into the effects of the other. The overlap of effects will further complicate the traffic manager's selection of strategies. The feedback part of the sequence is clearly closely tied in with the communications stage above.

9.7 DRIVERS' BEHAVIOUR AND RESPONSIBILITIES

Whilst not being a stage in the sequence of response of response to an incident Driver behaviour and responsibility is an important factor to be taken into account. It is clear from the way in which drivers attempt to by-pass queues on motorways that such behaviour can further reduce capacity in the vicinity of incidents. Much of the blocking up of junctions in urban areas is due to selfish or aggressive driving behaviour of this type. In theory, provided that traffic control systems have been set up properly and there is an appropriate metering of demand, then it should be possible to avoid gridlock situations. However when gridlocks do occur it is likely that it is due to a small number of impatient drivers occupying the 'clear space' in the centre of junctions which then encourages other drivers to follow suit.

There are no particular instructions in the highway code to drivers for handling such conditions or indeed for dealing with incidents generally other than to avoid causing obstruction to other vehicles.

Drivers also need to be more aware of the interpretation of parking restrictions, particularly the use of single and broken yellow lines, as this is not always clear. One reason for this is that most motorists do not receive guidance or even look at the highway code once they have passed their driving test.

The recent introduction of remote camera recording systems will help to make drivers aware of the need to consider the effects of their actions on other motorists as some of these actions can contribute significantly to the build up of congestion.

It is believed by many traffic engineers that drivers' behaviour contributes to congested conditions and that there would be benefits from educating drivers to exercise more responsibility in responding to such conditions, and to incidents, in order not to make conditions worse.

10. FURTHER WORK

This study has established the tools and a framework of actions for coping with incidents. Further work is needed to turn these into effective strategies.

Theoretical and practical studies are required to establish the validity of the modelling work which will form a necessary part of developing and testing strategies. Modelling work is needed as the interaction between traffic control measures and drivers' choice of routes, following an incident, become more and more complex. In addition there is a need to put into practice the various stages identified in the framework for strategies; in particular a considerable impact can be made with improvements to, and the application of, driver communication systems, and with *cooperation and coordination* between the different organisations concerned.

There is a need to carry out the theoretical and practical studies on a variety of towns because, although some of the basic principles of traffic control and recovery from congestion are applicable to most networks, preliminary work on strategies has shown that every town has its own individual characteristics which affect the formation and recovery from congestion, and the response of drivers to incidents. Post-incident analysis and assessments will provide a useful means for building up experience. It is recommended that all the organisations involved in controlling traffic are involved in this process.

A particular area which needs further attention is the *feedback of information.* Communication techniques can be improved to help drivers but traffic controllers need more awareness of changes in traffic conditions in their networks. This can be achieved by better reporting procedures and by improvements to monitoring techniques. Two important areas here are the use of video imaging procedures and the automatic estimation and display of the congestion index.

It is suggested that these proposals are tested in a number of towns by setting up demonstration projects, in cooperation with local authorities, to develop and demonstrate the usefulness of strategies for coping with incidents.

11. SUMMARY AND CONCLUSIONS

1. Incidents can be defined as any activity which interferes with the normal movement of traffic in a network.

There are two types of incident: activities which are part of *regular daily traffic operations* e.g. illegal parking and buses stopping for passengers, and activities which are *superimposed on regular operations* e.g. accidents and signal failures.

This study is primarily concerned with coping with the effects of incidents which are superimposed on the network.

2. The objectives for this study were to:

1) Identify the types and impact of incidents which cause congestion in urban areas

2) Understand the underlying mechanism and the factors which give rise to congestion

3) Establish a framework for developing strategies to cope with the effects of incidents

The following conclusions were reached:

3. The different types of incident are listed in Table 1. They have been grouped into three categories according to whether they are associated with Network conditions (relating to the network infrastructure), Traffic demand (factors associated with the traffic), and Other causes (such as processions, weather and security alerts).

The fourth group lists the 'regular' incidents which occur on a daily basis and are regarded as being part of normal traffic operations in a town. These, however, can contribute significantly to the regular background level of congestion.

4. All incidents cause a reduction in road capacity. The key differences between types of incident are the amount of reduction in capacity, their duration (minutes, hours or days) and whether they occur at *random* or *with some degree of prewarning* (classified R and P in Table 1). The recognition that some incidents do occur with prewarning provides an important opportunity for the development of strategies to minimise the effects of incidents.

5. Congestion occurs on a regular daily basis, in most large towns, when demand exceeds capacity e.g. during peak periods. If an incident occurs it can cause congestion which is superimposed on existing traffic conditions resulting in a combined level of congestion which is out of all proportion to the size of the incident itself.

6. The cost of incidents cannot be quantified in any simple way because it is linked to the congestion effects referred to above, and therefore depends both on the existing traffic conditions and on unpredictable factors such as timing and location. However, there clearly can be important effects apart from delay, such as missed appointments and connections and obstruction of emergency services.

7. Incidents cause congestion for two reasons:

Directly - because all incidents result in an immediate reduction in local road capacity; demand then exceeds capacity in the vicinity of the incident causing queues to form locally leading to a build-up of congestion.

and Indirectly - because drivers react to the unexpected queues which form and seek alternative routes to by pass the congestion. Without full knowledge of traffic conditions on the alternative routes the diverting traffic adds to the demand on those routes, causing congestion to spread further.

8. The study has shown that the *underlying mechanism* for the spread of congestion, both regular and due to incidents, is due to queues at junctions extending upstream to a previous junction thereby blocking the orderly movement of traffic through that junction. Thus *congestion* in an urban area can be defined as the condition when there is a *breakdown in the orderly movement of traffic in the network.* The various stages of *congestion* which have been identified are set out in Table 3.

9. A survey, to identify the types and frequency of incident which can lead to congestion, was carried out by an analysis of the Metropolitan Police's congestion file which contains data on congestion and incidents throughout the whole of the London Metropolitan Area. The main results showed:

a) The need to restore road capacity as quickly as possible following an incident,

b) A significant proportion of incidents, which lead to serious congestion (in this case about 30%), should enable some preplanning and warnings to be given.

c) Traffic controllers need immediate access to specialist services at short notice, to deal with difficult problems.

and d) The significance of the background level of congestion at the time of an incident

Modelling work has been used to investigate the effects of incidents:

10. In order to obtain a better understanding of the formation of congestion caused by incidents the TRL's traffic model CONTRAM has been adapted to model drivers' reactions to the unexpected queues which they encounter following an incident.

CONTRAM models drivers' choice of routes assuming that they have complete knowledge of network conditions. Thus CONTRAM can model drivers' reactions to long term incidents, such as roadworks lasting for several weeks, since drivers are able to adjust to the new network conditions once they have settled down into a stable pattern.

However, immediately after an incident occurs there is insufficient time for drivers to become familiar with the changes in traffic conditions. A modified version of CONTRAM has therefore been produced which models drivers' reactions to the unexpected queues which occur immediately following an incident. CONTRAMI assumes that a proportion of drivers using a network will endeavour to seek an alternative route to bypass any unexpected congestion. It takes into account the fact that these drivers will not have knowledge of traffic conditions along those alternative routes and may in fact encounter congestion on alternative routes.

11. CONTRAMI has been used to help in the understanding of the growth of congestion following incidents in two different types of town and to examine conditions which have lead to gridlocks. It can eventually be used to test different types of strategy for coping with the effects of incidents before the strategies are implemented on the streets.

12. The modelling work has examined the effects of an incident for three basically different scenarios following an incident:

1) Drivers restricted to remain on their original routes.

2) Drivers allowed to divert assuming complete knowledge of network conditions (corresponding to the case where drivers are provided with complete in-car information or an incident has persisted for a number of days).

3) A proportion of drivers seek alternative routes, but without complete knowledge of traffic conditions. (This is likely to be what happens in practice).

These scenarios were tested for incidents in networks based on Reading and Kingston. Studies were also made of the effects of the background level of congestion, different reductions in road capacity, and duration of incidents.

13. *Factors affecting congestion.* The modelling studies, and the incident survey work, have shown that the following factors are important to the formation of congestion following an incident:

Background level of congestion is perhaps the most important factor since an incident is only likely to trigger a significant amount of congestion if the network is already operating close to capacity i.e. if congestion already exists.

The amount of reduction in road capacity caused by an incident and the duration of the incident. These affect the formation of queues in the immediate vicinity of the incident

Whether an incident occurs at Random or with some Prewarning

Position of an incident along a link, which affects the chances of queues blocking back to a previous junction

Location of an incident within a network affecting route choice

The occurrence of more than one incident at a time resulting in a superpositioning of congestion from more than one direction

Timing of an incident in relation to the growth and decay of congestion during peak periods

Type of network in terms of size, proportion of signal controlled junctions to roundabouts and give-way junctions, and the number of alternative route paths within the network

Network control parameters relating to signal control settings, the type of UTC system in operation e.g. SCOOT or fixed time plans

Drivers' knowledge of the network road system and local traffic conditions

14. *A framework for strategies.* This study has identified a sequence of stages which can be used as a framework for producing strategies for coping with the effects of incidents:

- *Anticipation.* It should be possible to monitor and predict the onset of critical levels of traffic in a network so that preventative measures can be introduced to limit the formation of congestion should an incident occur.

- *Identify and report incidents.* This is currently one of the weakest links in the chain because of the resources needed to cover a network. Vital time can be lost at this stage before the traffic controller is aware that an incident has occurred. Correct identification of the type of incident is critically important to the traffic controller to enable him to summon the appropriate emergency and support systems and trigger the correct strategies.

- *Remove incident.* This stage is dependent on the previous stage for the correct identification of the type of incident as the right emergency services and specialist services need to be contacted at short notice. *The rapid removal of an incident is fundamental to the operation of all strategies.*

- *Action to control congestion.* There are a number of techniques, summarised in Tables 4.1, 4.2 and 4.3, that can be used to deal with congestion. Only a few are suitable for use in the short time scale available to react to an incident. But traffic managers can also use the longer term techniques to control the overall background level of congestion.

- *Communication of traffic information* to drivers and the emergency services will become a key part of strategies as drivers can be informed of changes in traffic conditions both before and after they set out on their journeys. It is vitally important that communications systems provide information which is Relevant, Accurate and Timely - and much needs to be done to improve the quality of information provided by some of the current broadcast systems. Communication is one area in which technology is making rapid advances and it will eventually be possible to provide in-car guidance systems to avoid congestion and incidents.

- *Feedback of information* on the results of actions is also a neglected step. The traffic controller needs to know how effective his actions have been and drivers need to be informed as quickly as possible about progress with clearing an incident. The feedback part of the sequence is clearly closely tied in with the communication and the action stages.

15. *Regular congestion.* Although this study is primarily concerned with the effects of superimposed incidents it is recognised that regular 'incidents', such as illegally parked vehicles and legitimate activities such as vehicles delivering goods and buses stopping, can contribute significantly to the regular background level of congestion. The former is an enforcement problem and needs to be tackled positively in the same way that incidents are handled whereas the latter may require some agreement to be reached with local traders to avoid disruption at critical times. *The effects of regularly occurring activities, particularly illegal parking acts at critical junctions must be taken into account when preparing strategies for coping with incidents generally.*

16. *Drivers' behaviour and responsibilities.* Comment needs to be made about the actions of individual drivers in contributing to congestion, both to regular congestion and that caused by incidents. Many drivers act selfishly by ignoring parking restrictions or by infringing the use of yellow boxes at junctions. As well as reducing capacity their actions encourage other drivers to behave in a similar way. More positive education needs to be given to encourage drivers to be helpful towards one another when dealing with congested conditions and in particular with gridlock situations.

17. *Further work.* The study has established the modelling methods and a framework of action for developing strategies for coping with the effect of incidents in urban areas. Further work is needed to turn these into effective strategies :

Theoretical and practical studies are needed to establish the validity of the assumptions and the parameter values for the modelling work.

There is scope for improving both techniques and application of each of the stages required for the operation of a strategy.

Strategies for coping with incidents need to be developed and tested in a number of different towns to demonstrate the effectiveness of using pre-planned strategies.

The further work is needed as the interaction between congestion control measures and drivers choice of routes has now become so complex that it is almost impossible for traffic controllers to understand the full impact of any control actions following an incident. There is therefore a real danger that some actions, which seem sensible for local purposes, could in fact lead to an increase in congestion and even to the possibility of gridlocks developing.

18. In conclusion this study has identified the types of incident which cause congestion in urban areas and the underlying mechanism for the formation of congestion. Modelling studies and a review of related work have established the significance of different factors in contributing to congestion. The methods and a framework for action have been produced for developing strategies for coping with effects of incidents and this has shown the importance of cooperation, coordination and communications between the different people and organisations involved. Further work is now needed to put the proposals into practice.

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13. REFERENCES

Audit Commission. Fine Lines: Improving the traffic warden service (1992). *Police Paper 11,* HMSO, London.

Bretherton R D and G T Bowen. Incident detection and traffic monitoring in urban areas (1991). *Proceedings of the DRIVE Conference 'Advanced Telematics in Road Transport', Brussels.* 4-6 February 1991.

Brocken M G M and M J M Van der Vlist. Traffic control with variable message signs (1991). *Paper presented at 2nd Vehicle Navigation and Information Systems Conference, Dearborn,* 1991.

Department of Transport. *The Highway Code (1993).* HMSO, London.

Department of Transport, STC5 Division. London traffic monitoring report for 1989 (1989). HMSO, London.

Department of Transport. Night-time traffic speeds in London (1992). *Transport Statistics Report,* HMSO, London.

Department of Transport. Traffic in London. Consultation on draft traffic management and parking guidance for London from the Secretary of State (1992). HMSO, London.

Department of Transport. Traffic Quotes. Public perceptions of traffic regulations in urban areas (1990). HMSO, London.

DRIVE Deliverable 05. Strategies using information from UTC sensors (1991). *DRIVE V1056* Project MONICA.

Goodwin P B. A Quality Margin in transport (1992). Transport Studies Unit, University of Oxford, Oxford.

Goodwin P, S Hallett, F Kenny and G Stokes. Transport: The new realism (1991). 21 March 1991, Rees Jeffreys Road Fund, London.

Hanks J W and Lomax T J (1990). Roadway congestion in major urban areas. *Report FHWA/TX-90-1131-3,* July 1990.

HMSO. *Road Traffic Act (1991).* HMSO, London.

Holmes G N and D R Leonard. The frequency and importance of incidents which cause congestion in urban areas (1993). *Contractor Report 342.* Transport Research Laboratory, DTp, Crowthorne, Berkshire.

Hoose Dr N. Using state of the art image processing techniques for incident detection in road networks (1992). *PTRC, 14-18 Sept.1992,* PTRC, London.

Hounsell N B. Limits to traffic growth in congested urban networks (1989). *Department of Transport, TRRL Contractor Report CR 171,* Transport and Road Research Laboratory, Crowthorne, Berkshire.

Hounsell N B and F McLeod. ASTRID: Automatic SCOOT Traffic Information Database (1990). *Department of Transport, TRRL Contractor Report CR 235,* Transport and Road Research Laboratory, Crowthorne, Berkshire.

Huddard K W and C C Wright. Catastrophic congestion, and some possible ways of preventing it (1989). Proceedings TRAFFEX International Traffic Engineering Exhibition, *Seminar on Control, Congestion and Enforcement, Brighton,* April 1989. PTRC, London.

Hunt J G and S Y Youssif. The effects of incidents at motorway roadworks on traffic throughput (1992). *PTRC, 14-18 Sept, 1992,* PTRC, London.

Hunt P B, D I Robertson, R D Bretherton and R I Winton. SCOOT- A traffic responsive method of coordinating signals (1981). *Laboratory Report 1014.* Transport and Road Research Laboratory, DoE/DTp, Crowthorne, Berkshire.

Keen K. Traffic control at a strategic level (1989). *Second International Conference on Road Traffic Monitoring, 7-9 February 1989,* Institute of Electrical Engineers, London.

Kompfner P(TRRL), K Shoarian-Sattari, R H C Hudson and D M Todd (W S Atkins Planning Consultants). Company travel assistance in the London area (1991). *Research report RR326,* Transport and Road Research Laboratory, DTp, Crowthorne, Berkshire.

Leonard D R, P Gower and N B Taylor. CONTRAM: Structure of the model (1989). *Research Report 178.* Transport and Road Research Laboratory, DTp, Crowthorne, Berkshire.

Lindley J A (1987). A methodology for quantifying urban freeway congestion. *Transportation Research Record 1132,* pp 1-12. TRB, Washington DC.

Luk J. Models for travel demand management: a review (1992). *Road and Transport Research, Vol 1, No 3* (Sept 1992), pp58-73.

Marshall A N and M P Higginson (Transport Studies Group, University College, London). Tourist coaches in London. *Contractor Report CR 187 (1991).* Transport and Road Research Laboratory, DTp, Crowthorne, Berkshire.

Meyer M D, T F Humphrey, C M Walton and K Hooper. A Toolbox for Alleviating Traffic Congestion (1989). Institute of Transport Engineers, Washington D.C.

Michalopoulos P G (Department if Civil Engineering, University of Minnesota), Jacobson R D, Anderson C A and DeBruycker T B (Image Sensing Systems Inc., Minnesota). Automatic Incident Detection through video image processing (1992). *Traffic Engineering and Control (1992).*

National Economic Development Council. Amber Alert: Relieving Urban Traffic Congestion (1991). NEDC, London.

Owens D and M J Schofield. Motorway access control: implementation and assessment of Britain's first ramp metering scheme (1990). *Department of Transport, TRRL Research Report RR 252,* Transport and Road Research Laboratory, Crowthorne, Berkshire.

Quinn D J. A review of queue management strategies (1992). *Traffic Engineering and Control, Vol 33, No 11,* (November 1992), pp 600 - 605.

Rathi A K. Traffic metering: an effectiveness study (1991). *Transportation Quarterly, Vol 45* (1991), pp 421 - 440.

Southgate P and C Mirlees-Black. Traffic policing in changing times (1991). *Home Office Research Study No. 124,* HMSO, London.

Thomas R. Traffic Assignment Techniques (1991). Avebury Technical, Aldershot, Berkshire.

Transportation Research Board. Freeway Incident Management (1990). Transportation Research Board, Washington D.C.

Turner D. Traffic initiatives for the capital priority (red) routes and the Traffic Director for London (1992). PTRC, 14-18 Sept. 1992. PTRC, London.

van Vuren T and D R Leonard (1994). Urban congestion caused by incidents. Traffic Engineering and Control, July/ August 1994.

Vincent R A and R E Layfield. Nottingham zones and collar study - overall assessment (1977). *Laboratory Report 805,* Transport and Road Research Laboratory, DTp, Crowthorne, Berkshire.

Wackrill P and C Wright. A new design tool for traffic management schemes (1992). Road Traffic Research Centre, Middlesex Polytechnic, *London. Traffic Engineering and Control, No 33(2),* pp 54-63.

Wood K and R Smith. Monitoring the pilot Red Route (1991). PTRC 19th Summer Annual Meeting, *Proceedings of Seminar K. Brighton.*

Wright C (Road Traffic Research Centre, Middlesex Polytechnic, London) and K W Huddard(Traffic Engineering Consultant, Claygate, Surrey). Strategies for urban traffic control (October 1989). Middlesex Polytechnic, London.

Zupan M.J. Transportation Demand Management: A cautious look (1992). *Transportation Research Record 1346,* New York.

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