

Incident Management of the M25

Sphere

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Declaration

This thesis and the research described and presented within have been completed in total by Iain Scott Bell Rodgers, under the supervision of Professor Michael C. Forde and Dr Simon D. Smith, and has not been submitted for any other degree or professional qualification.

Where other sources are quoted, full references are given.



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Abstract

Incidents on motorways, such as collisions, broken down vehicles and debris, temporarily reduce the capacity of the roadway, disrupting the natural flow of traffic. These present serious safety hazards and contribute greatly to congestion which causes financial loss and misery to thousands of motorists daily.

These factors create the need to quickly and efficiently manage incidents. To mitigate the effects of non-recurrent congestion on the United Kingdom motorway and trunk road network, the Highways Agency (HA) has developed the Incident Support Unit (ISU) service.

This research presents a review of incident management practice in the United Kingdom, in particular on the M25 London Orbital Motorway. An international comparison between British incident management operations and those in the United States is also provided. The ISU service on the M25 motorway, operated by the HA's service provider, Carillion plc, is critically examined, including quantitative and qualitative examinations and a benefit-cost estimation.

To understand fully the influence that ISUs have on the M25 road network, incident data was collected and analysed. These incidents have been examined to determine their influence on traffic flow. Specifically, their impact on the capacity of the roadway and the effect of "rubbernecking" is investigated. Investigations and analysis are undertaken to evaluate the delays experienced by motorway users due to incidents.

The effectiveness of motorway matrix signals and signs are then examined including compliance rates with mandatory signals and the impact of variable message signs on driver route choice.

Finally, the optimal standby locations of ISUs on the M25 Sphere road network are established in order to reduce their response times to incidents.

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Notations

AA	...	Automobile Association
AADT	...	Annual Average Daily Traffic
AAWT	...	Annual Average Weekday Traffic
ACPO	...	Association of Chief Police Officers
AID	...	Automated Incident Detection
APCO	...	Association of Public Communications Officials
ATM	...	Active Traffic Management
AVL	...	Automatic Vehicle Location
CAD	...	Computer Aided Dispatch
CCTV	...	Closed Circuit Television
CHART	...	Coordinated Highways Action Response Team
CMAQ	...	Congestion Mitigation and Air Quality
CMI	...	Controlled Motorway Indicators
COBS	...	Control Office Base System
COMET	...	Corridor Management Team
DETR	...	Department for Environment, Transport and the Regions
DfT	...	Department for Transport
DMS	...	Dynamic Message Sign
DoT	...	Department of Transport
EMI	...	Enhanced Matrix Indicator
EMS	...	Enhanced Message Sign
ERCC	...	East Regional Control Centre
ERT	...	Emergency Roadside Telephone
ERU	...	Emergency Response Units
ETP	...	Emergency Traffic Patrol
FDOT	...	Florida Department of Transportation
FHWA	...	Federal Highways Administration
FSP	...	Freeway Service Patrol
GIS	...	Geographical Information Systems
GPS	...	Global Positioning System

HA	...	Highways Agency
HADECS	...	Highways Agency Digital Enforcement Camera System
HATMS	...	Highways Agency Traffic Management System
HATO	...	Highways Agency Traffic Officer
HCM	...	Highway Capacity Manual
HERO	...	Highway Emergency Response Operators
HGV	...	Heavy Goods Vehicle
HIOCC	...	High Occupancy
IPG	...	Integrated Policing Group
IRT	...	Incident Response Team
ISU	...	Incident Support Unit
ITS	...	Intelligent Transportation Systems
LGV	...	Large Goods Vehicle
MAP	...	Motorist Assistance Programme
MDIS	...	Midland Driver Information System
MIDAS	...	Motorway Incident Detection and Automatic Signalling
MS1	...	Motorway Signal Mark 1
MS2	...	Motorway Signal Mark 2
MS3	...	Motorway Signal Mark 3
MS4	...	Motorway Signal Mark 4
MSF	...	Maximum Service Flow
MSHA	...	Maryland State Highway Administration
NAO	...	National Audit Office
NCC	...	Network Control Centre
NHI	...	National Highway Institute
NMCS2	...	National Motorway Communication System Mark 2
NTCC	...	National Traffic Control Centre
OOCEA	...	Orlando and Orange County Expressway Authority
ODOT	...	Oregon Department of Transportation
PCO	...	Police Control Office
PDP	...	Performance and Development Plans
PPE	...	Personal Protective Equipment

RAC	...	Royal Automobile Club
RCC	...	Regional Control Centre
RISC	...	Roadway Incident Scene Clearance
RPI	...	Retail Price Index
RTC	...	Road Traffic Collision
SERCC	...	South East Regional Control Centre
STP	...	Surface Transportation Programme
TRB	...	Transportation Research Board
TDAS	...	Traffic Data Analysis System
TDOT	...	Tennessee Department of Transportation
TIM	...	Traffic Incident Management
TMC	...	Traffic Management Centre
TSRGD	...	Traffic Signs and General Directions
VMS	...	Variable Message Sign
WDPY	...	Weekdays Per Year
WSDOT	...	Washington State Department of Transportation



Figure 1.1 Examples of Incidents on the M25. (Source- Mr. Bob Wadsworth)

Figure 1.1 presents two examples of incidents on the M25 London Orbital Motorway. Both of these incidents involved full closure of sections of roadway for extended periods.

One of the key objectives of the Highways Agency, as the executive agency of the Department for Transport who operate, maintain and improve the strategic road network in England, is to reduce congestion and increase the reliability of journey

1 Introduction

This chapter provides an overview of the problems addressed in the research study and the basic project approach and the methods used to address the problems. An outline of each chapter contained within this thesis is also presented.

The rising demand for use of motorway and trunk road networks has not and can not be met with corresponding increases in capacity. This has led to an ever-increasing level of daily congestion. Recurring congestion from the excess volume of vehicles is expected but non-recurring or “incident” congestion is unpredictable. It has been estimated that incidents on motorways and trunk roads in Britain account for approximately 25% of all congestion, which costs the British economy an estimated £750million a year (National Audit Office, 2005). Incidents represent any non-recurrent occurrence or unplanned event that creates a temporary reduction in roadway capacity, which in turn, impedes the normal flow of traffic (TRB, 2003). They can range from broken down vehicles on the hard shoulder to major collisions involving fatalities or hazardous material spills. Depending on the severity of the incident they can disrupt traffic flow causing congestion, increasing travel time, damage to property or even loss of life. They cause bottlenecks, slowing and frequently stopping the flow of vehicles. As the flow of traffic slows, a queue builds upstream of the incident, and continues until the blockage is cleared and flow restored. Due to the backlog of vehicles it can take an extremely long time after the incident for the accumulated traffic to dissipate. Incident management programmes have been developed to mitigate non-recurring congestion from incidents.

Incident management is the process by which incidents are cleared from the road returning them to normal traffic conditions. The purpose of incident management programmes is to rapidly detect, verify and clear temporary obstructions from roads to restore normal traffic flow as quickly as possible. Further, non-recurring congestion can be minimised by clearing incidents as quickly as possible or by diverting traffic before vehicles are caught in the traffic backup. There is now a demand for more efficient roadways.

times. One way to do this is to work with the Police and other emergency services to provide a faster response to incidents and quicker clearance of blocked lanes. The Incident Support Unit (ISU) was developed to support the effective management of incidents and increase co-ordination between the HA's service providers, the Police and other Emergency Services. ISUs are operated on the HA's routes by contractors.

As of 1st September 2001 Carillion plc became responsible for the maintenance and improvement of motorways and trunk roads of the M25 Sphere, as Term Maintenance Contractor, having been appointed by the Highways Agency (HA). The M25 Sphere or HA Area 5 network comprises over 2500 km total lane length with some sections carrying more than 200,000 vehicles a day. As one of Europe's busiest motorway, congestion is a major problem. Each year, traffic congestion leads to millions of hours of vehicle delays and causes significant losses in productivity, increases in fuel consumption and environmental pollution. Carillion operate a fleet of sixteen ISUs on the M25 Sphere on behalf of the HA. These vehicles are ready to respond to a call for support from the emergency services, 24 hours a day. They assist with incidents, and are manned by specialist crews, equipped with cones, signs, environmental protection packs and suitable equipment to deal with most situations.

1.1 The Problem

An incident is defined as any non-recurring event that causes a reduction of roadway capacity (TRB, 2003). Such events include collisions, broken down vehicles, debris, spills, and any other event that could reduce the capacity of the roadway.

Although the main issue most associated with incidents on motorways is delay, the risk of secondary incidents is also a serious problem. Other secondary effects of incidents include:

- Incident responder personnel exposure,
- Increased response time by emergency services,
- Lost time and a reduction in productivity,
- Increased cost of goods and services,
- Adverse environmental impacts,

- Increased fuel consumption,
- Reduced air quality,
- Increased vehicle maintenance costs,
- Reduced quality of life,
- Negative public image of organisations involved in incident management.

Incidents critically limit the operational efficiency of the transportation network and put all road users at risk.

1.2 Aims and Objectives

The aim of the research presented in this thesis is to provide a critical examination of incidents and the incident management process on the M25 Sphere road network.

To achieve this aim the following measurable objectives have been set:

- Present a review of British incident management practices,
- Produce a critical evaluation of the Incident Support Service on the M25 Sphere.
- A comprehensive analysis of incident characteristics, frequency and duration on the M25 Sphere.
- Provide an optimal deployment strategy for Incident Support Units on the M25 Sphere.

1.3 Thesis Structure

The structure of this thesis is as follows:

Chapter 2 presents an examination of the motorway incident management process and provides a background to this work on the M25 London Orbital Motorway. The five stages of incident management- detection, verification, response, clearance and recovery- are detailed, with programme stakeholders identified and their roles and responsibilities at motorway incidents examined. An introduction to the M25 London orbital motorway is also presented, including the history, future and current maintenance and management arrangements. The Highways Agency's approach to incident management in Britain is also described with their response capabilities

through Incident Support Units and Traffic Officers examined in detail. Finally an incident management programme comparison between Britain and four US states is carried out.

Chapter 3 presents a review of the ISU service on the M25 motorway, operated by the HA's service provider, Carillion plc, including quantitative (analysis of incident data) and qualitative examinations (via questionnaire survey), and a benefit-cost estimation. An analysis of ISU attended incidents, an estimation of ISU benefits and qualitative police and ISU operative survey results will be presented.

Chapter 4 describes the influence and role of ISUs on the M25 Sphere. A detailed study of all incidents which occur on the road network was undertaken. To enable this, motorway incident data was collected by the author through observing motorway operations at a police control room.

Chapter 5 examines the influence of motorway incidents on traffic flow. Their impact on the capacity of the roadway is studied and the impact of rubbernecking is investigated. Investigations and analysis are undertaken to evaluate the impact of incidents on motorways including the total delay experienced.

Chapter 6 presents a review of motorway matrix signals and signs in use on the motorway and trunk road network in Britain. Applications of the discussed signals and signs will also be detailed. The effectiveness of matrix signals and signs will then be examined including compliance rates with mandatory signals and the impact of variable messages on driver route choice.

Chapter 7 examines optimal deployment strategies for incident support units on the M25 road network. This will be completed via the development of a computer model that will determine the shortest response route for a particular network setup. This shortest response route in turn will produce the shortest travel (response) time for each ISU vehicle. Four location strategies will then be considered to optimally locate ISUs on the M25 and for each strategy the optimal number of ISUs is

determined. The objective is to minimise the total travel time to incidents with the minimum number of ISU vehicles required to meet the service provider's contractual response time.

Chapter 8 summarises the conclusions that can be drawn from this study. Suggestions for future research are also presented.

2 An Investigation into the Incident Management Process

2.1 Introduction

Incident management is the process by which the duration and impact of incidents is lessened. By managing incidents effectively the operational efficiency of a facility can be enhanced and the safety of incident responders and motorists can be improved. The process is involved in every phase of an incident from the detection, through verification, response and clearance to recovery.

As the mitigation of incident related congestion is very important, rapid response and clearance is essential. Incident management methods used in Britain include Incident Support Units and Highways Agency Traffic Officers, provided by the Highways Agency, as the managers of the national strategic road network. These programmes are intended to work in partnership with the emergency services to manage incidents and mitigate their impacts through quick response, clearance and traffic management.

As dedicated incident management programmes have been in use on freeways in the United States since the 1960s there is much that can be learnt by examining their operations. A comparison between incident management operations on the M25 and four programmes in the US is presented to provide validation of current practices and ideas for future implementation.

This chapter examines the motorway incident management process and provides a background to this work on the M25 London Orbital Motorway.

This chapter is structured as follows:

- **Section Two.** Motorway incidents are described and defined.
- **Section Three.** The incident management process is detailed. Each of the five parts (detection, verification, response, clearance, recovery) of the process are examined in detail. A case study of an incident on the M25

motorway is detailed to provide clarification of the process. Individual incident responder roles and responsibilities are also examined.

- **Section Four.** A history and review of current operations on the M25 London Orbital Motorway is presented.
- **Section Five.** A description and background of the Highways Agency is described.
- **Section Six.** The role of the Highways Agency Incident Support Unit programme on the M25 is presented. Details of ISU operative training, vehicles and equipment are also shown.
- **Section Seven.** The role of the Highways Agency Traffic Officers programme on the M25 is presented. Details of ISU operative training, vehicles and equipment are also shown.
- **Section Eight.** Four US incident management programmes are reviewed and a comparison is presented.
- **Section Nine.** Chapter summary and conclusions.

2.2 What is an Incident

An incident on a motorway represents any non-recurrent occurrence or unplanned event that creates a temporary reduction in roadway capacity, which in turn, impedes the normal flow of traffic (TRB, 2003). Incidents can range from broken down vehicles on the hard shoulder to major collisions involving fatalities or hazardous material spills. Depending on the severity of the incident they can disrupt traffic flow causing congestion, increased travel time, damage to property or even loss of life. Incident management is the process by which incidents are cleared from the road returning them to normal traffic conditions.

2.3 Incident Management

In the US Traffic Incident Management Handbook (FHWA, 2000) incident management is defined as “the systematic, planned and coordinated use of human, institutional, mechanical and technical resources to reduce the duration and impact of incidents and improve the safety of motorists, crash victims and incident responders. Effectively using these resources can also increase the operating efficiency, safety,

and mobility of the highway. This results from reducing the time to detect and verify an incident occurrence; implementing the appropriate response; safely clearing the incident; and managing the affected flow until full capacity is restored”.

Incident management is the coordination of activities undertaken by one or more organisations to restore traffic flow to normal conditions after an incident has occurred (Ozbay and Kachroo, 1999). Incident management programmes are designed to manage incidents on roadways, reduce the associated cost of an incident and increase safety for both responders and motorists.

Incidents on motorways and trunk roads in Britain account for approximately 25% of all congestion (National Audit Office, 2005) but the greatest impact of motorway incidents concerns the safety of incident responders and motorists. In 2001, 28 law enforcement officers and 6 fire fighters and emergency medical technicians died in the United States after being struck by another vehicle (TRB, 2003). From 1997 through 2001, there were 26 fire fighter and emergency medical technician fatalities from vehicle strike in the US, some 2.6 times greater than the total number of fatalities from the previous 5 year period. Nearly 40% of all law enforcement officers who died on duty died in traffic incidents (Qin and Smith, 2001). Similar emergency services statistics are regrettably not available for the UK, but the Highways Agency recently highlighted the dangers experienced by its staff, with 11 road workers killed in roadworks on motorways or trunk roads in England, between October 2000 and February 2002, which equates to 1 in 1000 (Highways Agency, 2004a). Also according to research by Dr Stephen Roberts reported in *The Lancet* (Roberts, 2002), road workers have the 16th most hazardous occupation in Great Britain; higher even than for military personnel. These statistics demonstrate the importance of safety at motorway incidents.

The overall goals of any incident management programme are to minimise the impact of an incident and improve safety. Five objectives of any incident management programme should be to:

- Reduce incident detection and verification times,

- Reduce response time,
- Exercise proper and safe on-scene management of personnel and equipment, while keeping as many lanes open to traffic as possible,
- Reduce incident clearance time,
- Provide timely, accurate information to the public that enables them to make informed choices.

When achieved, these combined objectives reduce the overall delay incurred by motorists using the road network and improve the overall safety of the network. At a social level, this translates into gains in economic productivity, reduced fuel consumption and air pollution, increased on-time delivery of goods and improved public image of transportation agencies (ITS, 2001).

There are three parts that combine to make a successful incident management programme: communication, coordination and cooperation. These components combine to create an integrated incident management approach.

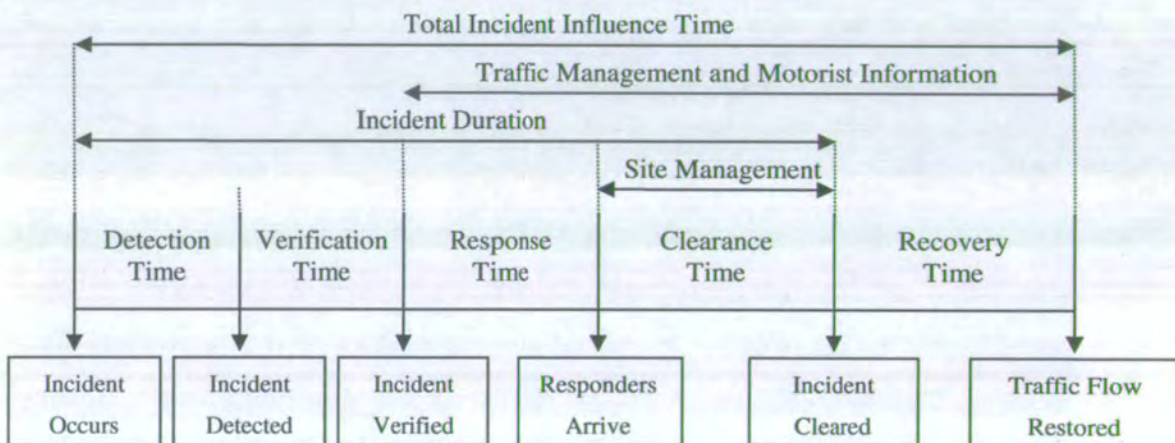


Figure 2.1 Generic Incident Management Time Line

Incident management can be categorised broadly into the following five set of activities, shown graphically in figure 2.1:

- Incident detection,
- Incident verification,
- Incident response,
- Incident clearance,
- Incident recovery.

2.3.1 Incident Detection

Incident detection is the process of determining the presence of an incident on the motorway and bringing it to the attention of the authorities. Incident detection initiates the whole incident management process. Quick incident detection allows rapid resource dispatch, allowing responders to arrive at an incident quickly and initiate the clearance of the incident thus minimising the overall incident duration and impact. Quick detection and response reduces the exposure to those involved in the incident.

In the US, the incident detection is estimated to be between 5 and 15 minutes (Cambridge Systematics, 1990)

There are many methods commonly used to detect incidents including:

- Emergency vehicle patrols,
- Maintenance vehicles patrols,
- Notification from a passing motorist,
 - 999 calls,
 - Emergency Roadside Telephones (ERT), SOS boxes,
- Notification from a party involved in the incident,
 - 999 calls,
 - Emergency Roadside Telephones (ERT), SOS boxes,
- Closed Circuit TV (CCTV) observations in control rooms,
- Electronic detection systems (loop detectors, radar detectors or video capture),
- Recovery services.

In recent years, increasing numbers of incidents are being notified by motorists, either by those directly involved or just passing, by use of mobile phone. This regularly means that a large number of calls are received very quickly. The information however can be lacking, with motorists only having a vague idea of their location. Unfortunately this inaccurate information can often increase response times to incidents.

Detection of incidents can be improved by having more patrols on the road and by using enhanced marker posts enabling motorists to accurately inform operators of their location.

Incident detection can take place at the same time as incident verification either from a patrol or by using CCTV.

2.3.2 Incident Verification

Once an incident has been detected it must be verified. Verification involves confirming that an incident has actually occurred, determining the exact location and obtaining as many relevant details about the incident as possible, including gathering enough information to be able to dispatch the appropriate response. Verification is required when initial incident reports are received from an untrained observer, who may exaggerate the severity of the incident or give erroneous location information. Incidents are usually verified using the following methods:

- Closed Circuit TV (CCTV) cameras,
- Dispatch vehicles to the incident site,
- Combining information from multiple reports.

Typically, on the M25, CCTV will be used to verify an incident, but where there is no coverage a police, Incident Support Unit or Highways Agency Traffic Officer vehicle will be sent to verify the incident and assess what resources are required to respond. Incident detection and verification can often coincide, for example if a police officer or ISU is the first to detect the incident.

2.3.3 Incident Response

Incident response involves the deployment of appropriate personnel, equipment and motorist information as soon after notification as possible. The complete response phase is the period between incident verification and the time that the responders arrive at the incident scene. The duration of response is dependent on the location of resources and the location of the incident. Depending on the type and severity of the

incident, response can occur in stages, with different resources dispatched for various phases of the clearance process.

The response phase is also when traffic management and motorist information should commence. Initial traffic management, prior to responder arrival, could include setting lane control signals, advisor speed limits or variable message signs to warn motorists. Motorists should also be kept fully informed by disseminating incident related information. This can be done in various ways:

- Commercial and public radio broadcasts,
- Variable Message Signs,
- Telephone information systems,
- In vehicle navigation systems
- Commercial and public television traffic reports,
- Web sites (for example the Highways Agency- www.trafficengland.com)

2.3.4 Incident Clearance

Once responding equipment and personnel arrive at the incident scene they must manage the site and effectively coordinate and manage on scene resources. Incident clearance encompasses not only the physical clearance of the incident but also site and traffic management. During the clearance phase the safety of response personnel, incident victims and other motorists is the primary objective of incident site management. Incident site management includes at least the following activities:

- Accurately assessing incidents,
- Properly establishing priorities,
- Notifying and coordinating with the appropriate agencies and organisations,
- Using effective liaisons with other responders,
- Maintaining clear communication.

Management of the traffic is one of the vital parts of incident management. Traffic management at an incident site involves many parts:

- Establishing incident site emergency traffic management,

- Managing the road space (opening and closing lanes, blocking only the portion of the incident scene that is required for safety, staging and parking to minimise traffic flow),
- Deploying appropriate personnel to assist in traffic management (Incident Support Units, Highways Agency Traffic Officers, traffic management vehicles, etc.)
- Actively manage traffic control devices (lane control signals, Variable Message Signs)
- Implementing emergency diversion routes.

Incident clearance is one of the most critical stages in incidents. It can however be the longest stage due to the length of time required to remove obstructions and restore traffic flow (FHWA, 2000). Minor incidents such as debris can take only a matter of minutes to clear, but other incidents, such as incidents involving rolled Heavy Goods Vehicles (HGV) or spilled cargo, can take many hours. If incidents involve serious injuries the police may have to investigate for evidence prior to re-opening lanes, adding to the delay.

The end of incident clearance marks the end of the incident duration but not the end of the influence of the incident, which may however carry on for several hours until traffic has fully recovered.

2.3.5 Incident Recovery

Incident recovery is the final stage of incident management. It covers the period between clearance of the incident and the return of traffic to normal flow. This may be a lengthy time for major incidents, to allow the traffic queue to dissipate, or a very short time for minor incidents. Traffic management and motorist information should continue through to the end of the incident.

Once traffic has fully recovered the incident can be considered to be concluded. Post incident multi-agency debriefs should be held to ascertain what worked and what did not, as well as what can be improved for next time. Thus ensuring that

recovery vehicle was requested at 12:18 and arrived at 12:50. The ambulance left the scene at 12:28 clearing lane 3. The closure was left in place to aid recovery of the vehicle. Once the recovery vehicle had removed the van from the central reservation the ISU crew dealt with all the remaining debris and a minor spillage from the vehicle. As the recovery vehicle left the scene at 12:56 the ISU crew then started to recover the emergency traffic management, clearing all the travel lanes. As the police and ISU left the scene at 13:02 the lane control signals were deactivated allowing the traffic to clear. At its peak the queue as a result of this incident was 2.4 kilometres long and required a considerable amount of time to recover.



Figure 2.2 CCTV Image of an Example Incident Scene.

communication, coordination and cooperation is continued and incident management is successful.

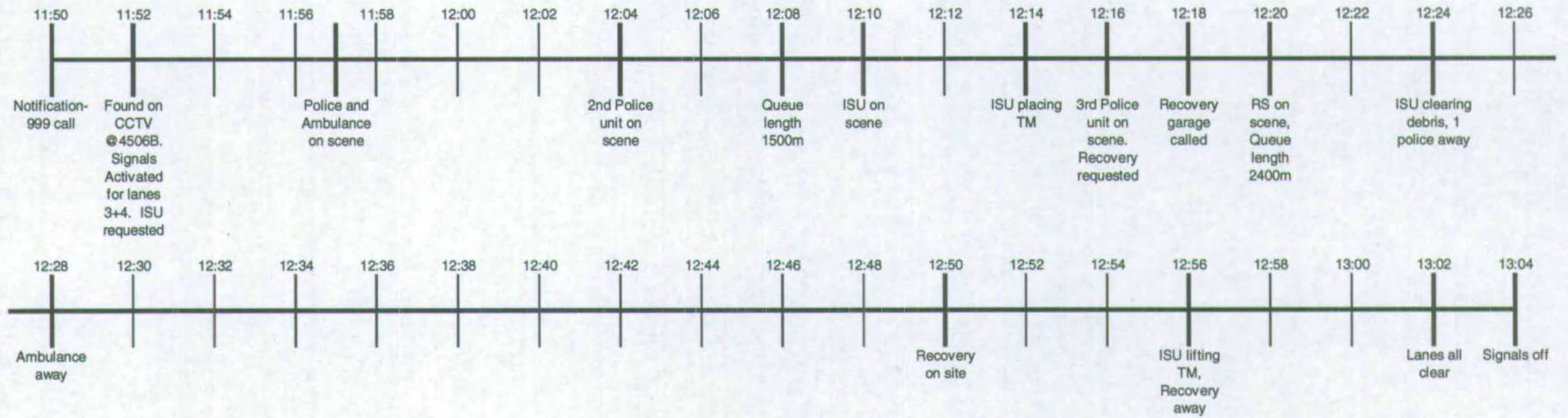
2.3.6 Case Study of Incident Management

To provide clarification of the incident management process an example incident on the M25 will be detailed. A CCTV image is shown in figure 2.2 and a chronological time-line of the incident is shown in figure 2.3.

At 11:50 on 5th December 2003 Surrey police were notified of an accident that occurred at marker post 4506B on the anti-clockwise M25 adjacent to the on slip road at junction 8. The initial reports were received in Surrey police's Godstone motorway control room from the force control room where all 999 calls are answered. The incident was verified at 11:52 using CCTV as a small van rolling over the central reservation barrier with a car stranded in lane 4 and partially in lane 3. Multiple police traffic units were dispatched to the incident scene by the radio operator. Other control room operators contacted the ambulance service, to request their presence and confirm with them the exact incident location and best access route, set motorway gantry matrix signals and signs, to give advanced warning of the incident and protect the scene, as well as contact the M25 Sphere control room to request the support of an Incident Support Unit (ISU). The HA's Traffic Control Centre were also informed of the incident and disseminated the information on their website, to the media and activated variable message signs to inform motorists of the incident.

The police were the first to respond to the incident scene at 11:57 with the ambulance service arriving very shortly thereafter. The police assessed the scene and quickly set up emergency traffic management whilst the ambulance service assessed the casualties. A second police unit arrived at 12:04 and further reinforced the closure. At 12:10 the ISU arrived on scene and promptly set about placing improved traffic management to further protect the incident scene as this proved to be in a dangerous location on the outside of a bend in the road. The ISU operatives then tackled the debris in the carriageway and examined any damage to the road infrastructure. A

Figure 2.3 Example Incident Time Line.



2.3.7 Incident Roles and Responsibilities

There are many organisations and agencies who are involved in incident management on motorways in Britain. A selection is shown and detailed below of the major partners involved, which include:

- Police,
- Fire and Rescue Service,
- Ambulance Service,
- Transportation Agencies,
- Recovery Services.

There are however several organisations such as the Environment Agency and various specialist contractors who become involved in more severe incidents and participate on an as-needed basis.

Police

Typically the police are the first to receive notification of an incident (as recipient of 999 calls). They also often detect incidents due to the nature of their role in policing the traffic and law enforcement. The police are in overall command at an incident scene. They will request additional resources and services and will investigate incidents if they involve criminality or result in significant property damage, personal injury or fatalities.

Fire and Rescue Service

The fire and rescue services attend approximately 3% of all incidents (Highways Agency, 2002) but do not have a statutory duty to attend motor vehicle collisions. They do however have statutory control powers at a “fire ground” but the police will still remain in overall control of an incident scene, supporting the fire services activities. The fire service will respond, when requested, to fires, hazardous material incidents and rescues.

Generally, when requested, the fire service sends two appliances, one to each carriageway of a motorway. This can greatly reduce response times, especially when incident locations have been incorrectly identified. However this can also

significantly increase motorist distraction and thus safety by having several large vehicles responding to what could be a very minor incident.

Ambulance Service

The ambulance service provides essential medical treatment to those injured in incidents. Generally they are only involved at the very early stages of an incident and will have left prior to scene clearance.

Transportation Agencies

The Highways Agency (HA) is responsible for the trunk road network as the executive agency of the Department for Transport. The HA's road network is split into areas which are managed and maintained on a contractual basis by agents. These agents are responsible for providing incident support units, traffic management support, equipment and personnel for incident clearance, debris removal, minor hazardous material spills and other incident related activities.

Originally the HA and its contractors role was purely one of assisting with the clearance of an incident. Now it has become more proactive when it comes to dealing with incident management, with the provision of ISUs across the majority of its network instigated to support the emergency services and the roll-out of Highways Agency Traffic Officers (HATO) in certain areas. The new HATOs will provide a first response to incidents in conjunction with ISUs to clear incidents and reduce congestion on the trunk road network. The HA's National Traffic Control Centre (NTCC) provides national strategic traffic management and motorist information for incidents, operating variable message signs to advise of delays and diversions and disseminating information to pertinent agencies.

Recovery Services

The privately operated recovery services are arguably one of the most important partners in motorway incident management as many incidents can not be cleared until they have finished their job. On motorways these services are generally operated under contract to the police but many motorists are also members of

automobile clubs such as the RAC, AA and Britannia Rescue who will provide them with services.

2.3.8 Section Summary

It can be seen how complex an incident can be with many agencies having varied roles and responsibilities. It is occasionally not clear who is responsible for a certain link of the chain which can cause friction between parties. It can also be seen how varying organisations have different work cultures with some very response orientated and operating 24 hours whilst others are not. Also worthy of notification is that private companies, such as recovery services, are profit-driven and therefore very aware of the amount of time for which they are involved and the resources they apply.

To improve incident management and clarify individuals' roles and responsibilities cross agency organisational training and debriefs must be held. This would highlight areas for improvement and identify stakeholders to drive the process forward.

With the wide variety of organisations involved in incident management on motorways it shows how important communication, coordination and cooperation are. Multiple strategic partnerships must be undertaken to reduce the impact of incidents and increase safety for motorists and responders.

2.4 M25 – London Orbital Motorway

The M25 motorway, figure 2.4, is the orbital motorway that encircles London and is one of the world longest city bypasses. It is not quite a full circle - the only break is to the East of London, when it crosses the river Thames on the A282 via the Dartford Crossing (consisting of two tunnels and a bridge). The M25 is the strategic hub of Britain's motorway network and was designed as a bypass for London and the surrounding towns giving substantial traffic relief for communities, particularly from heavy goods traffic.

It is approximately 118 miles in length and is dual three lane carriageway or dual four lane carriageway and by Christmas 2005 will be dual five lane between

junctions 12 and 14 and dual six lane between junctions 14 and 15. It also has left lane hard shoulders over the majority of its length and thirty two junctions. There are approximately 500,000 yards of crash barrier, 234 bridges over and under the motorway and 452 emergency roadside telephones on the M25.



Figure 2.4 Map of the M25 London Orbital Motorway. (Highways Agency, 2004c).

Since its completion in 1986 it has become one of the busiest motorways in Europe, coming under ever increasing strain with demand often outstripping capacity. More than 700,000 daily journeys are made on it and the busiest south western section of the M25 regularly carries over 200,000 vehicles per day (Department for Transport, 1998). The M25 accounts for approximately 6% of the mileage of British motorway network, but carries 14% of all motorway traffic (Department of Transport, 1990). Today only 30% of road users on the motorway actual use it as a bypass, starting and finishing outside the M25, 60% use it as a part of their journey, crossing from outside to inside, and the remaining 10% of users start and finish within the M25. Of all the traffic that uses the motorway in the morning peak approximately 50% are journey's to work and the average car occupancy is very low at 1.15. The average distance

driven on the M25 is only two to three junctions. The usage of the M25 is partly due to the design, with many junctions installed as an inducement to local communities to allow its construction allowing local traffic to use what was intended as a long distance route.

As one of Europe's busiest motorway, congestion is a major problem. Each year, traffic congestion leads to millions of hours of vehicle delays and causes significant losses in productivity, increases in fuel consumption and environmental pollution (Department for Transport, 1998).

The famous congestion on the M25 has inspired jokes- "The world's biggest car park", "the road to nowhere" and "The world's largest roundabout" (Clarke, 1986) - songs- Chris Rea's "The road to hell" and the following tongue-in-cheek theory (Wikipedia, 2005):

"Many Phenomena – wars, plagues, sudden audits – have been advanced as evidence for the hidden hand of Satan in the affairs of man, but whenever students of demonology get together the M25 London orbital motorway is generally agreed to be among the top contenders for exhibit A."

- *Good Omens* by Terry Pratchet and Neil Gaiman.

2.4.1 M25 History

In 1854 Joseph Paxton, engineer and architect of the Crystal Palace for the 1851 Great Exhibition, submitted plans for an 11 mile long ring road around London, following roughly the route of today's London Underground Circle Line, later built in the 1880s. He proposed a covered arcade 72 feet wide ring road for pedestrians and carriages that was bordered by multi-level houses and shops with eight track railways above. His proposal was ultimately turned down by Parliament (Evans et al, 1986).

Another idea for a London city bypass was discussed in 1905 when the Royal Commission on London Traffic suggested a ring road solution to London's building

traffic problems, proposing a ring about 12 miles in radius from central London (Department of Transport, 1986).

In 1934 the then Minister of Transport Leslie Hore-Belisha instructed a comprehensive and systematic survey of highway developments required in the London Traffic Area to be investigated, which produced the first coherent proposal for an orbital road around greater London, drawn up by Sir Charles Bresssey and Sir Edward Lutyens. The route of their south orbital road plans actually follow closely the route of the M25 as it is today, starting at the Dartford Tunnel (which opened in 1963) and carrying on round to between Addlestone and Egham. Their North route however was rather different and incorporated a number of existing stretches of road which had been built in accordance with a plan by Colonel Hellard in 1910, who was the chief engineer of the Board of Trade Traffic Branch in the London area (Motorway Archive Trust, 2005).

In 1944 the Greater London Plan by Sir Patrick Abercrombie was published where he proposed a series of five rings around London:

- “A Ring”: a sub-arterial route encircling an extended central area,
- “B Ring”: an arterial for fast traffic to Earls Court in the West, the Isle of Dogs in the East, Islington in the North and Dulwich in the South,
- “C Ring”: a sub-arterial formed of the north and south circulars,
- “D Ring”: an express arterial just outside the built up area,
- “E Ring”: a sub-arterial comprising the North and South orbitals.

Much work had been undertaken on the issue of relieving London of traffic and many proposals put forward but very little progress was made mainly due to the fact that there was no central government control until the 1946 Trunk Road Act extended the Ministry of Transport's jurisdiction. Also, the plans had to wait for the 1947 Town and Country Planning Act and the Special Roads Act 1949 to provide suitable legislation. Despite the passing of the acts, little was done to implement the plans (Motorway Archive Trust, 2005).

It was not until the 1970s however that increasing traffic demanded government action into plans to create a high capacity bypass for London, at one time a combination of an inner (A406 North circular upgrade to M15) and outer road (M25) as recommended by the Greater London Development Plan. In 1975 the then Minister of Transport, John Gilbert, announced the consolidation into a single ring London orbital road, to be known as the London Orbital Motorway, the M25, to be made from separate relief roads North (M16 outer orbital) and South (M25) of London. At its closest (junction 24, near Potters Bar) the proposed M25 was approximately 13 miles (21 km) and at its furthest (junction 5 and 28, Sevenoaks and Brentwood) 22 miles (35 km) from Charing Cross.

The first section of the now combined M25 to be opened in 1975 was a 2.7 mile (4.3 km) stretch from the A1 to the A111. By January 1984 with the completion of the section between junctions 25 (A10) and 27 (M11) meant that there was now a continuous 43 miles (70 km) stretch between junction 23 (South Mimms) and junction 3 (Swanley). Another milestone was the completion in October 1985 of the section between Reigate and Wisley which completed the south-western section, providing a direct motorway link between Heathrow and Gatwick airports. Finally in October 1986 the concluding 8 mile (13 km) section of the M25 between Mickfield Green and South Mimms was completed and the Orbital was finished. The new road now provided a direct motorway link between the M1, Heathrow, M40, M4, M3, Dartford tunnel and access to the Channel ports (Department of Transport, 1986). The M25 was estimated to have cost £1,000 million to construct in 1986.

In total there were some 39 separate Public Inquiries into the route, compulsory purchase of land and treatment of subsidiary roads, which lasted for more than 700 sitting days. The inquiries resulted in a delicate balance between the advantages of the road to the community against the disadvantages to individuals and groups. A number of changes to the design of the road also resulted from the enquiry, including a greater use of cuttings and false cuttings to hide the road from view (Department of Transport, 1986).

There is extensive literature detailing the planning, design and construction of the M25 London Orbital Motorway: Jones (1982), Evans (1984), Evans and Lawrence (1985), Allinson, et al (1985), Hooper and Rushton (1985), Watts (1986), Langdon (1986), Peters and Roe (1986), Richardson, A. F. (1986), Salt and Hart (1987), Peters and Welton (1990) and McLeod and Clark (1999)

2.4.2 M25 Future

The Highways Agency recently announced a £1.6 billion scheme to upgrade all of the remaining dual three lane sections of the M25 to dual four lane. This accounts for approximately two thirds of the M25 road network. It is not an option however to continually build a way out of congestion on the M25 and a sustainable solution must be found for the long term to ensure safer and less congested journeys.

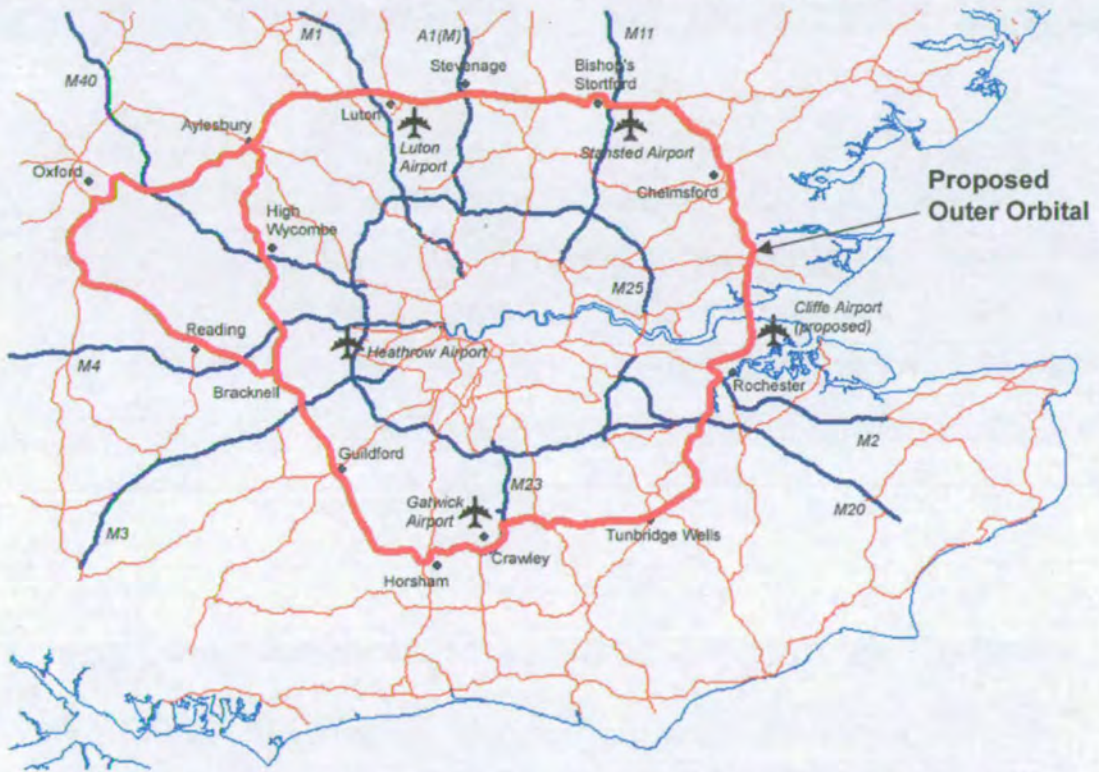


Figure 2.5 Proposed Outer Orbital Motorway Map (Transport 2000, 2005).

To relieve the congestion on the M25 an outer M25 was suggested in the governments "Roads for Prosperity" programme in 1989. The new route, shown in figure 2.5, would go from a new Thames crossing at either Canvey Island or Gravesend and orbit the capital to the North of Chelmsford, Stansted Airport and

Luton, to the West of High Wycombe and Bracknell, and to the South of Guilford, Crawley, Gatwick and Sevenoaks, eventually returning to the new crossing.

2.4.3 M25 Sphere

The M25 Sphere (figure 2.6) or Highways Agency area 5, is the HA area that contains the M25 motorway. It consists of the M25 motorway as well as additional motorways and trunk roads in and out of London including the M1 in the North, M4 in the West and the M20 and M26 in the South-East. Since September 2001, for the first time, a single team consisting of the managing agent, Mouchel Parkman and term maintenance contractor Carillion plc has been operating the area on behalf of the HA.

Area 5 facts:

- 500 Km (310 miles) of routes
- Over 2500 Km total lane length
- At least 80% of M25 Sphere is Motorways
- Total length of safety barriers is over 780,000 metres
- Over 520 foot, road and rail bridges and 5 tunnels
- Over 1,000 SOS telephone boxes
- The length of grass verges is at least 1,035,000 metres
- Approximately 224,000 coloured road studs

Responding to incidents is only a small part of the tasks carried out by the M25 Sphere Management team. As part of their contract they must also perform the following operations:

- Incident Response Service
- Highways, Footways & Cycleways General Maintenance
- Bridge General Maintenance
- Street Lighting & Road Sign Maintenance
- Winter Salting & Snow Clearance
- Verge & Landscape Maintenance
- Highway Improvements & Safety Measures

- Traffic Management
- Authorising Skips & Scaffolding
- Approving Abnormal Load Movements
- Technical Surveys
- Liaising with Police, Local Authorities & Statutory Undertakers
- Liaison with Residents & General Public

All these tasks are essential so the day to day operation of the M25 sphere runs as smoothly as possible



Figure 2.6 Map of Roads Within the M25 Sphere (Highways Agency, 2003).

2.5 Highways Agency

The Highways Agency (HA), established in 1994, is the Executive Agency of the Department for Transport (DfT), who operate, maintain and improve the strategic

road network in England on behalf of the Secretary of State for Transport. The Secretary of State is responsible for overall Government policy on motorways and trunk roads in England and determining the financial resources and the strategic framework within which it operates.

The HA's purpose is to provide safe and reliable long distance journeys by managing the traffic using the country's strategic routes. They aim to deliver a high quality service to their road users by reducing congestion, improving journey reliability and along with road safety, improving management of incidents and road works, providing better motorist information and respecting the environment.

The HA's road network includes various types of roads, ranging from motorways carrying up to 200,000 vehicles per day to single carriageway trunk roads carrying fewer than 10,000 vehicles per day. These roads comprise some 4,818 miles (7,754 km) of routes which carry a third of all road traffic in England and two thirds of all heavy freight traffic, with over 170 billion vehicle kilometres of journeys undertaken each year.

It has been estimated that incidents account for approximately 25% of all congestion on the trunk road network, with road works accounting for 10% and the remaining 65% due to recurrent congestion. All of this congestion is estimated to cost the British economy approximately £3bn (\$5.25bn) a year (National Audit Office, 2005).

2.6 Incident Support Units

A key objective of the HA is to reduce congestion and increase the reliability of journey times. One way to do this is to work with the Police to provide a faster response to incidents and quicker clearance of blocked lanes. The Incident Support Unit (ISU) was developed to support the effective management of incidents and increase co-ordination between the HA's service providers, the Police and other Emergency Services. ISUs are operated on the HA's routes by contractors.

With sections of the M25 motorway carrying an average of 200,000 vehicles a day even a minor incident can bring traffic to a halt very quickly. To help mitigate the impact of incidents on the road users of the M25, a new joint initiative by the Highways Agency and Carillion plc has been implemented. A fleet of sixteen ISUs are on standby 24 hours a day, 365 days a year to solve problems on the M25 and adjoining roads (known as the M25 Sphere). These vehicles are dedicated maintenance vehicles that do minor maintenance activities on the network, but are available whenever an incident occurs or their presence is requested by the emergency services. The ISUs are placed at strategic locations around the road network and are monitored by GPS, allowing the nearest vehicle to be dispatched. They are manned by specialist two man crews, equipped with cones, warning signs, environmental protection packs and suitable equipment to deal with most situations and carry out emergency maintenance and repairs. ISUs are neither allowed nor responsible for removing vehicles from travel lanes, but do provide emergency traffic management to protect incident scenes. At incident scenes they free up police resources, allowing them to concentrate on their investigation, while the ISU expedites the roadway clearance. The aim is to work together as an integrated team with the aim of clearing incidents and opening lanes at the earliest opportunity.

ISUs are now in use on the majority of trunk roads and motorways in England. One of the key benefits of the ISUs is that the response time to incidents, contractually 20minutes, is greatly improved as prior to the service response times were anywhere up to 1.5 hours.

The aim of this service is to provide assistance to the emergency services and reduce the impact of an incident on the road network by providing a safe and timely response and quicker clearance of blocked lanes. The role of Carillion's ISUs is to:

- Provide immediate response to incidents on the road network,
- Provide emergency, short term lane closures,
- Deal immediately with minor, incident related debris,
- Undertake minor repairs to highway infrastructure damaged by an incident,

- Assess the incident scene and request attendance of additional or specialist resources when the task is beyond that of the ISU's capabilities,
- Provide a communications link between the incident site and the network control centre,
- Patrolling, monitoring and reporting on the network.
- Undertaking routine maintenance,
- Making safe defects to the highway infrastructure.

To date, on the M25 Sphere road network, from the start of Carillion's contract in September 2001, ISUs have been involved with more than 38,000 incidents.

2.6.1 ISU Operative Training

The ISU operatives must complete specialised training. This training is both classroom and practical "hands-on" based, including "ride-a-longs" with experienced ISU crews. Training is continuous and ISU operatives must pass refresher courses. Examples of some areas covered in training are shown below.

- | | |
|--------------------------------|--------------------------------|
| • Functions of ISUs | • Scene management |
| • Road network familiarisation | • First aid |
| • Health and Safety | • Hazardous chemical awareness |
| • Driver training | • Fire awareness |
| • Traffic Management | • HIAB/Loading shovel |
| | • Communication skills |

2.6.2 ISU Vehicles and Equipment

The ISUs are equipped with traffic management, environmental protection packs and suitable equipment to deal with most situations and carry out emergency maintenance and repairs. A detailed list of the minimum contractual required equipment is shown in table 2.1 but additional equipment may need to be carried to reflect the nature and frequency of incidents within particular areas.

Table 2.1 Minimum ISU Equipment

Installed Equipment	
<ul style="list-style-type: none">• Halogen work lights• Two-way radio• Mobile Data Terminal•	<ul style="list-style-type: none">• Warning Lights• Electric light arrow and crash cushion (some vehicles)
Traffic Management Equipment	
<ul style="list-style-type: none">• Reflective traffic cones (minimum of 30)• Cone Lamps (minimum of 15)• Diverted traffic signs• Road narrow signs	<ul style="list-style-type: none">• Keep right/left (610) arrows• Road closed signs• Flooding signs• Traffic lights inoperable signs• Sandbags
Tools	
<ul style="list-style-type: none">• Sandbags• Disc cutter + PPE• Hand saw and bow saw• Manhole lifting keys• Sledge hammer• Brushes• Shovels• Safety fence spanners•	<ul style="list-style-type: none">• Sharps box• Electronic data capture device• Drain rods and stoppers• Pickaxe• Washing facility• Dog-pole• 9kg dry powder extinguisher
Materials	
<ul style="list-style-type: none">• Pot hole repair material• Oil absorbing granules• Oil absorbing boom• Carcass disposal bags• Lamp batteries• Marker paint.	<ul style="list-style-type: none">• Cutting discs• First aid kit• Temporary fencing• Gully seals• Fence nails and staples
Personal Equipment	
<ul style="list-style-type: none">• Fluorescent reflective jacket and trousers• Mobile phone• Flashlight• Gloves• Reporting forms	<ul style="list-style-type: none">• Route maps and plans• Generic Risk Assessments• Method Statements• ISU Operations Manual• Diversion route plans• Contact telephone list

There is no national standard for the type of vehicle operated by the HA's contractors but they must all be capable of completing all contractual duties safely. Contractors' vehicles include panel vans, open flat bed trucks and even full traffic management vehicles with crash cushions, which are usually operated on the busiest routes. All vehicles must however be liveried in the HA's corporate livery with examples shown in figure 2.7. The main purpose of the livery is safety, with retro reflective material covering as much of the vehicle possible. A national consistent brand vehicle livery also helps to build recognition and customer confidence in the HA and its services



Figure 2.7 Examples of ISU Vehicles and Livery.

2.7 Highways Agency Traffic Officers

Traditionally the HA and its contractors have built and maintained the English road network whilst police forces have provided the operational side, primarily addressing unplanned incidents. The Association of Chief Police Officers (ACPO) and Highways Agency roles and responsibilities review (Highways Agency, 2005a) made recommendations to transfer some of the operational roles over to the HA. The Highways Agency Traffic Officer (HATO) concept was developed as an on-road support service where civilian HA personnel will perform a number of general traffic and road management tasks previously undertaken exclusively by the police. For example when an incident now occurs the police still retain responsibility for investigation of criminality and, for major accidents, will be in charge at the scene and in control offices but the HATOs will concentrate on managing the traffic.

The HATOs will:

- Stop and direct traffic
- Place road signs
- Undertake high visibility patrols
- Help and protect drivers in distress
- Support the Police in their duties
- Provide mobile/temporary road closures
- Clear debris from carriageways
- Arrange removal of damaged or abandoned vehicles.

The role of the HATOs has been developed in cooperation with the police and will enable the police to focus on their core roles of tackling crime, investigating collisions and enforcing the law. HATOs are not permitted to offer mechanical assistance to motorists but will arrange for assistance/recovery and stay with the motorist until it is safe for them to leave.

The first HATOs started in the West Midlands region of England, around the city of Birmingham, in April 2004. This was the start of their staged rollout across the whole of the HA's strategic road network, due for completion by the end of 2005. Eventually there will be approximately 1,200 Traffic Officers and 300 Regional Control Centre staff working to keep traffic moving and improving safety.

HATOs started operating on part of the M25 motorway around London on the 1st of August 2005. Initially they will patrol between junction 2 and junction 14 on the M25 as well as some stretches of the M23 and M3 under the control of the South East Regional Control Centre (RCC) at Godstone. Six double manned vehicles will patrol this section with more staff and vehicles being added when more road sections come under the control of the South East RCC with eventually more than 150 HATO's and supervisors operating 14 patrols over the whole area.

As the Traffic Officer position was completely new and some police powers were to be transferred, several laws had to be changed and amended to provide them with new powers such as:

- Stop traffic and close roads, lanes and carriageways
- Direct and divert traffic
- Place and operate traffic signs
- Manage traffic at traffic surveys.

On 22nd July 2004 the Traffic Management Bill received Royal Assent after successfully completing the Parliamentary process, becoming the Traffic Management Act 2004. This new legislation provided them with special powers so that they are able to perform certain traffic management tasks previously carried out by the police. This now means that it is an offence not to comply with the directions of a HATO. Further secondary legislation is also being sought to further extend the HATOs powers.

2.7.1 HATO Training

All HATOs, supervisors and control room staff receive comprehensive and professional training at each level, with a summary of the on road HATOs training shown in table 2.2. Supervisors receive an additional 4 days training which includes trauma diffusion, media skills and Performance and Development Plans (PDP). The training is delivered through both classroom instruction and hands-on exercises.

Table 2.2 Traffic Officers and Supervisors Training

Subject	No. of Days	Subject	No. of Days
Induction	2	Supervisors:	
Familiarization	3	Trauma Diffusion	½
People Skills	2	Media Skills	½
Health & Safety	3	PDP/ILM	3
Highway Patrol	11		
Driving	7		
First Aid	1		
HABIT	1		
		Total Days = 30 or 34	

The training is provided both internally and by external partners and contractors. Some external courses include: first aid training provided by the Red Cross, driving by Police driving schools and health and safety by Fire service colleges. Once all initial training is completed the traffic officers receive an accredited qualification, the “Certificate in Traffic Management”, which is externally verified by City and Guilds. The HATOs will also be continually assessed to ensure competency of staff.

2.7.2 HATO Vehicles and Equipment



Figure 2.8 Examples of HATO Vehicles and Livery.

The HATO vehicles are all large and powerful four-wheel drive and are fully liveried, with examples shown in figure 2.8. These vehicles were chosen as they were thought to be the most flexible for the role: good safety for occupants, power for towing/dragging vehicles from the carriageway and all weather capabilities. They are marked very similar to motorway traffic police vehicles which use blue and yellow “battenburg” rather than the black and yellow used by HATOs. These contrasting colours, on the vehicle sides increase conspicuousness and were chosen to increase safety. The material used is retro reflective (florescent and reflective) which gives good results both day and night. The HATOs similar colours to the police also assist with their duties as motorists consider their driving habits more when they believe they are in the presence of the police. The fully marked vehicles are also comforting to vulnerable motorists as they can easily tell who has pulled up behind them.



Figure 2.9 Examples of HATO Equipment and Storage.

Table 2.3 HATO Standard Equipment, Tools, and Supplies.

Installed Equipment

- Rear tow ball
- Halogen work lights
- Two-way radio w/repeater
- Electronic Message Sign
- Warning Lights

Portable Equipment and Tools

- Tow straps
- Reflective traffic cones (minimum of 20)
- Cone Lamps
- Dog-pole
- Portable traffic control signs
- Push brooms, shovels and scoops
- Camera
- Pry bar
- First aid kit
- Emergency escape hammers
- Hazardous spill kit

Supplies

- Water (16 litres)
- Tape
- Safety area tape
- Fire extinguishers
- Fire blanket
- Area maps
- Wipes
- Emergency thermal blankets (minimum of 10)
- Emergency ponchos (minimum of 10)
- Refuse bags
- Face masks
- Spare batteries

Personal Equipment

- Fluorescent reflective jacket and trousers
- Mobile phone
- Flashlight
- Searchlight
- Portable two-way radio
- Gloves
- Binoculars
- Manuals and guidebooks
- Reporting forms

The HATO vehicles carry the majority of equipment that would allow them to quickly deal with minor incidents or reduce the impact of larger incidents. An example of the equipment carried is shown in figure 2.9 and an example list is shown in table 2.3.

2.8 International Incident Management Programme Comparison

2.8.1 Introduction

To assist with the evaluation and optimisation of the incident support service on the M25 several international incident management programmes were contacted and a review is presented below.

2.8.2 Background

To mitigate non-recurrent congestion, rapid response and clearance is essential. In the US, many incident management programmes have been developed in recent years with freeway service patrols (FSP) playing a major role (Roper, 1990). FSPs are usually roving vehicles that are intended to detect, respond to and clear incidents, in partnership with other emergency responders, facilitating the quick removal of incidents (Skabardonis et al, 1998). They typically offer a broad range of services including motorist assistance, debris removal, vehicle clearance, first aid and traffic control (ITS, 2000). All services rendered by FSPs are generally free and often include: minor mechanical repairs, water, air and fuel. They were initially used at spot locations such as bridges or tunnels where incidents would have a great impact on traffic flow. An extensive introduction to FSPs is given by McDade (1990). Roving patrols were introduced at first only on a temporary basis during holiday periods or in heavy tourist areas in peak seasons. The first regular roving patrol was the Chicago Emergency Traffic Patrol (ETP) which commenced operating in 1960 (Fenno and Ogden, 1998). Today there are in excess of 70 FSP programmes in operation in the United States.

In the United Kingdom, FSPs are not operated. In England, in 2000 the Highways Agency deployed fleets of Incident Support Units (ISUs) on some of the most congested roads. Also, in the spring of 2004 Highways Agency Traffic Officers (HATO) commenced operating on motorways and trunk roads in the West Midlands. ISUs and HATOs have been discussed in Section 2.6 and 2.7

A selection of four FSP programmes in the United States are detailed below.

2.8.3 Florida Department of Transportation Road Rangers

Florida Department of Transportation (FDOT) operates an incident management programme over the busier roads in the state. The service patrol concept is a service of FDOT and its partners and was initially used for the management of vehicle incidents in construction zones, during the 1980's. The units were known as "Highway Helpers". This programme has since been renamed to "Road Rangers", and expanded, to respond to all types of incidents. It has become one of the most effective elements of the Department's incident management programme. The Department began funding the state-wide service patrol in December 1999. Funding for the programme comes from State maintenance funds for Intelligent Transportation Systems (ITS) projects.

The goals of the programme are to:

- Reduce secondary collisions (In Florida, 33% of all accidents were secondary);
- Improve responder safety;
- Improve response and clearance times;
- Reduce incident congestion and delay;
- Decrease economic impact of incidents.

The Road Rangers are roving vehicles that patrol congested areas and high incident locations of the urban freeway and are fully equipped to deal with most situations. Their main role is to assist the general public, keep roads open and increase safety

for road users. The vehicle operators are mechanics, fully qualified first-aiders, and are trained in incident management practices.

The benefits of the programme have been as follows:

- The reduction of accidents;
- The reduction of incident duration by assisting the Florida Highway Patrol (FHP);
- Assistance to stranded or disabled motorists;
- Keep traffic moving, reducing delay;
- The removal of road debris;
- Reduced response times to incidents, (41 minutes for FHP, Road Rangers on 20 minute loop);
- Increased safety for road users.

All of the Road Ranger vehicles carry the minimum of the follow equipment:

- | | |
|--|--------------------------|
| • Towing Straps, | • Brooms, |
| • Rubber push-bumper, | • Shovels, |
| • Spot lights, | • Flares, |
| • Power outlets and jumper cables, | • Cones (15 each), |
| • Arrowboard, | • 2 ton jack, |
| • Fully equipped tool box, | • Compressor, |
| • Fuel (diesel and unleaded) (minimum 10 gallons of each), | • Torches, |
| • Motor oil, | • Trash can, |
| • First aid kit, | • Absorbent material, |
| • Fire extinguishers, | • Drinking water, |
| • Radiator water, | • Disposable camera, |
| • Car belts, | • Mobile phones, |
| • Wood blocks, | • Tire repair kit, |
| | • Public address system. |

In central Florida there are two main Road Ranger programmes operating. Firstly the FDOT, district 5, programme which operates on Interstate 4 from County Road 532 in Osceola County to Saxon Boulevard in Volusia County. The second service is a partnership between FDOT and the Orlando-Orange County Expressway

Authority (OOCEA) who provide a service on toll roads around the central Florida area.

FDOT Interstate 4 Programme.

Interstate 4 (I-4) is one of the busiest roads in Florida. It runs from Tampa in the West to Daytona Beach in the East. The district 5 Road Ranger programme runs from the Osceola/Polk county line to the Seminole/Volusia county line on approximately 53.6 miles of I-4. The service is operated under contract by LYNX. The contract is for one year and is worth \$500,000 (£343,077).



Figure 2.10 Road Map of Central Florida.

Six service patrol vehicles patrol 5 zones on a twenty minute loop. Each assists in incident management, including incident detection, traffic control and the removal of disabled vehicles from travel lanes. The vehicles are manned by one operator and have all the tools and equipment necessary for making minor vehicle repairs, pushing vehicles involved in non-injury incidents out of travel lanes, securing incident scenes and removing debris from the roadway. The operators also have the necessary training to complete the above tasks. They provide fuel and radiator fluid, change flat tires, replace/repair belts and hoses and offer other simple repair services that can typically be completed in less than 15 minutes, all at no cost to the motorist. If repairs are not possible, the use of a mobile phone is offered to allow the motorist to contact a tow company or a relative. Operators remain with motorists pending the arrival of towing company. On average the I-4 Road Rangers have 30 assists per day.



Figure 2.11 Line-up of LYNX I-4 Road Ranger Vehicles.

All vehicles are all full size, heavy duty, 1/2 ton long bed pickup trucks with crew cabs, capable of easily carrying all necessary equipment. Each vehicle is fitted with a full lighting package which also includes a Radar Safety Warning System, to warn approaching motorists, with radar detectors, of road hazards ahead. The system is activated whenever the vehicles lightbar is turned on.



Figure 2.12 LYNX Road Ranger Vehicle.

The service operates 8 hours a day: between 6am-10am, 3:30pm-7:30pm weekdays. Additional hours at weekends and for special events are also scheduled. Whenever an operator stops to provide assistance, the motorist is given a postage paid comment card and requested to return at their convenience. Up to the end of March 2002, 1443 responses had been received. From this feedback there has only been one negative answer- free petrol was refused to one motorist who had been given petrol three previous times.

It is proposed to expand the central Florida Road Rangers to a 24 hour service on weekdays and 9:30am-6:30pm at weekends. The number of patrol vehicles would be expanded to nine from the current six and ten more operators would be hired.

OOCEA / FDOT partnership programme.

The motorist assistance services, provided by the Orlando and Orange County Expressway Authority (OOCEA), are operated under contract by Martin Petroleum Corporation of Florida. The contract is for a three year period, with a one year option, and is worth \$1,511,100 (£1,036,846). These vehicles are mainly funded through toll charges.



Figure 2.13 OOCEA / FDOT Road Ranger Vehicle.

The Road Rangers' patrol 96 miles of the expressway system including State Road 408 (East-West Expressway), State Road 417 (Central Florida Greenway), and portions of State Road 528 (Bee Line Expressway). These roads are separated into five patrol sectors. Each sector is patrolled by one road ranger vehicle during peak periods (6am-10am, 3.30pm-7.30pm) 365 days a year.

The expressway authority vehicles are all full size, heavy duty, 1/2 ton long bed pickup trucks with extended cabs and all vehicles are equipped with Nextel cellular mobile telephones and Florida Highway Patrol (FHP) radios. Every vehicle is fitted with either a Dynamic Message Sign (DMS) or lightarrow board for traffic control. Each vehicle is manned by one fully trained operator who makes on average 7-8 assists a day. At every assist a postage paid response card is issued- to date over 1000 returned of which all were very positive.

Service provided by operators include:

- Attempt minor repairs, not exceeding 15 minutes;
- If not corrected, motorists are allowed three, 3 minute phone calls to make arrangements for further service;
- Move disabled vehicles;
- Provide minimum amount of fuel to reach closest fuel station;
- Follow directions of law enforcement personnel;
- Protect accident scene;
- Clear debris;
- Change flat tires;
- Give jump starts.

Every operator must complete an incident log after every assist. The log should include:

- The date of log entry;
- The following times;
 - Time when advised of incident;
 - Time of arrival at scene;
 - Time of departure from scene;
- The nature of each incident;
- Whether incident was detected by normal patrol or dispatch;
- Incident location - Mile marker and lane(s) located and direction of travel;
- Vehicle make, model, body type, license plate number;
- Nature of problem;
- Disabled vehicle driver's name;
- Type of assistance provided;
- Any damage evident before moving of vehicle;
- Was additional assistance required;
- Service patrol vehicle operator's name and vehicle license number;
- Service patrol vehicle odometer reading at beginning and end of each shift;
- Weather conditions.



Figure 2.14 Examples of OOCEA / FDOT Road Ranger Vehicle with DMS Activated.

Other FDOT Road Ranger Programmes

FDOT's Road Ranger programme is not limited to District 5, all other districts run similar styled services. There are at present 85 service vehicles in the state of Florida.



Figure 2.15 Examples of FDOT District 4 Road Ranger Tow Truck Vehicle.

FDOT District 4, which covers Ft. Lauderdale and Palm Beach, has a fleet consisting completely of small tow trucks. These vehicles are used primarily to move disabled motorists from the roadway to a safe area or next available exit ramp. Once in a safer location, repairs will be attempted. When the current contracts are renewed, it is planned to expand the vehicle fleet to include pickups equipped with Dynamic Message Signs (DMS). The plan is to have the Road Rangers work in teams of four with three wreckers and 1 pickup per team operating on one beat.

Road Ranger Programme Summary

FDOT now operate their freeway service patrol, the Road Rangers, in all of their districts across the state of Florida. To date they have assisted thousands of motorists and supported the emergency services at many incidents, improving traffic conditions and safety across the whole state.

The Road Ranger programme has been expanded very rapidly, almost doubling in size. They are becoming first responders, often arriving at incidents prior to the emergency services. In the future, to support their activities, all vehicles will be fitted with automatic vehicle locators (AVL), 25% units to be equipped with DMS and 25% units to be tow trucks to allow faster quick clearance and motorists' information, without the need to wait for assistance from another party. Operative training will be improved and more advanced training will also be given. The Road Rangers will centrally dispatch to provide a more integrated programme with the emergency services.

FDOT's "Open Roads Policy"

In an effort to provide the travelling public of the State of Florida a cost effective, high quality, transportation infrastructure, the Florida Department of Transportation has implemented their "Open Roads Policy" for quick clearance, safety and mobility, to make travel in Florida safer and more efficient (FDOT, 2005).

The "Open Roads Policy" is an agreement between the Florida Highway Patrol (FHP) and the Florida Department of Transportation (FDOT) and establishes a policy for FHP and FDOT personnel to expedite the removal of vehicles, cargo and debris to restore, in an "urgent manner" the safe and orderly flow of traffic following a motor vehicle crash or incident on Florida's roadways (FDOT, 2005). Roadways will be cleared as soon as it is safe to do so and it is understood that damage to vehicles or cargo may occur as a result of using this quick clearance policy. While reasonable attempts to avoid damage will be taken, the major concern is to restore the roadway to normal conditions as the cost of incident induced congestion is

considerably greater than the salvage value of an already damaged vehicle and its cargo.

As part of the policy when requested by FHP or other emergency agency, FDOT have agreed to respond and deploy resources at traffic incidents 24 hours a day, 7 days per week. Each individual FDOT District will also develop and implement response procedures to meet the goal of providing initial traffic management on scene within 30 minutes of notification during normal working hours and 60 minutes after hours and on weekends.

Ultimately FDOT and FHP's aim is to have roadways cleared as soon as possible, with the goal that all incidents should be cleared from the roadway within 90 minutes.

To support the strategy detailed in the "Open Roads Policy" legislation has been introduced which limits liability during quick clearance. This eliminates liability for FDOT, fire fighters, police officers, etc. to remove a vehicle and its cargo off the roadway when it presents a safety hazard.

RISC Incentive Towing Contracts

Consistent with the Open Roads Policy, Florida's Turnpike Enterprise, who maintain Florida's toll roads, has adopted an innovative clearance strategy by implementing the Roadway Incident Scene Clearance (RISC) Programme in order to significantly reduce the time it takes to clear major accidents and incidents. The programme involves an enhanced contract with recovery operators that include incentives for quick clearance and disincentives for delayed clearance. Previously recovery operators were paid by the hour for their service with some unscrupulous operators "dragging their heels" to get paid more, which was not conducive to quick clearance.

As part of the new contracts the recovery operator should respond to requests for vehicle recovery and clearance services within fifteen minutes, 24 hours a day, 7 days a week. Once the recovery agent confirms the request they must arrive at the

incident scene with all contractual equipment, personnel and vehicles within one hour. All RISC contractors are specially qualified with very heavy duty recovery equipment and highly trained operators who know how to safely and quickly clear roadways. The RISC programme is in addition to the normal rotational tow list currently used by FHP for typical incidents on the Turnpike system.

A full summary of the RISC incentive towing contract is given in appendix A.

2.8.4 Tennessee Department of Transportation HELP Freeway Service Patrol

Stage implementation of Tennessee Department of Transportation's (TDOT) new freeway service patrol, known as HELP, began in June 1999 in the cities of Knoxville and Nashville. One year later, the service was expanded to cover the cities of Chattanooga and Memphis. The HELP patrols operate on some of the highest volume roads of these four cities, with traffic volumes on their patrol routes ranging from 80,000 to 120,000 annual average daily traffic (AADT). The HELP mission statement gives a good introduction to the programme:

“The mission of HELP is to minimize traffic congestion, promote the safe movement of people and products, and improve the travel environment. We work in partnership with emergency response agencies and other TDOT units as part of a highway incident management team. We are committed to performing our duties in a professional manner.”

The lime yellow, specially equipped HELP trucks operate on designated patrol routes. Normally, the patrols cover approximately 198 miles in the four cities combined, with some patrols overlapping where traffic volumes are the highest. The patrolling supervisors can authorise responses to off-route locations when requested by law enforcement agencies.

The uniformed HELP operators are very aggressive in dealing with incidents and restoring traffic to normal conditions as soon as possible. The HELP trucks operate as emergency vehicles, and the four-wheel drive vehicles are equipped to quickly

push, pull or drag disabled vehicles from the travel lanes. HELP operators and supervisors receive nine weeks of initial training and “quick clearance” is an important part of the training. Each operator has two-way radio communication with a HELP dispatcher and the other operating personnel and each shift supervisor has a police radio to facilitate coordinated response to incidents. The operators and patrolling supervisors are all certified as emergency medical First Responders.

The HELP programme operates with three shifts and has 66 specially equipped trucks, 52 operators, 16 supervisors and 17 dispatchers. All HELP personnel are TDOT employees. During a regular week, at least four and as many as seven HELP trucks are on patrol during each shift in each city for weekdays. At weekends, there are normally fewer trucks on patrol. Most of the capital and operating expenses for the first three years of the HELP programme were paid with federal dollars, matched by the state, under either the Congestion Mitigation and Air Quality (CMAQ) programme or the Surface Transportation Programme (STP). HELP began with the expectation that state funds would be used to continue the services beyond the first three years and 100% state funding for the Knoxville and Nashville services will begin during the 2002-2003 fiscal year. The HELP programme costs annually approximately \$5.1 million resulting in an estimated benefit-cost ratio of more than 6:1 (TDOT, 2005).

TDOT HELP Training

All HELP operatives receive comprehensive training, with initial training on a wide range of topics lasting nine weeks. The training is completed through classroom instruction and hands-on exercises. Trainees also “ride along” with experienced operators at different stages of the training.

An outline of the topics covered in the HELP training course is shown in table 2.4, along with the approximate number of hours allocated to each topic. TDOT managers participate in many of the training activities, and TDOT managers and training staff members deliver some of the instruction.

To a large extent TDOT has put together courses and material from already existing sources, in some cases adapting or customising the original course or material to be more meaningful for the HELP programme. Most of the human resource courses are provided through the state Department of Personnel. The Tennessee Highway Patrol teaches the self defence and verbal judo course, and the Tennessee Emergency Management Agency teaches hazardous material awareness. The State Fire Marshal's office provided the initial instruction on vehicle fires and use of fire extinguishers, but that training is now provided by a HELP supervisor who is a retired fire chief.

Table 2.4 Initial Training Modules and Approximate Number of Training Hours for HELP Operators and Supervisors

Subject	Aprx. Hours	Subject	Aprx. Hours
Organization and Procedures		Human Resource Skills	
HELP Orientation	4	Sexual Harassment Prevention	3
TDOT Orientation	4	Diversity	6
Organizational Policies and Practices	12	Self-Defense/Verbal Judo	3
ITS Awareness	2	Working In Teams	3
HELP Administrative Procedures	4	Speechcraft	4
Drug Testing Awareness	3	Public Relations - Working with the Media	6
Legal, Liability, and Safety Issues	4		
Operational Skills		Operations	
CPR	8	HELP Mission	3
First Responder (Medical)	60	HELP Operating Procedures	4
Mechanical Trouble Shooting	8	Traffic Incident Management (NHI)	12
Radio Communications	4	Proper Operation and Use of Vehicle	3
Hazardous Material Awareness	4	Traffic Management at Incident Scenes	8
Vehicle Fires and Fire Extinguishers	3	Supporting Other Incident Responders	2
Emergency Vehicle Operations	8	Individual Check Rides	1
Orientation to HELP Trucks and Equipment	8	Scheduled "Ride Alongs" - Partnered Training	80
Traffic Control	8		
		Total Hours* = 282	

All of the trainees also participate in a National Highway Institute (NHI) Incident Management Workshop, and TDOT has arranged for the NHI instructors to present additional material specifically for the HELP operators. Usually, one of the NHI instructors accompanies each new operator on a "check ride" for personal coaching. The HELP first-line supervisors receive the same training as the operators, plus

supervisory training. All of the HELP dispatchers receive at least 40 hours of training through the Association of Public Safety Communications Officials (APCO), and many of the dispatchers have participated in parts of the operator training. Several of the Region HELP managers have participated in the training. Three of the current managers are certified as medical First Responders.

Finally, training is a continuing process for all HELP personnel. The most structured part of recurrent training is to help operators maintain their First Responder certification, but TDOT frequently arranges special courses and guest lectures. Difficulties in communicating with Spanish-speaking customers prompted TDOT to also arrange special language classes for the HELP personnel.

TDOT HELP Vehicles and Equipment

The first-rate vehicles and equipment comprise a major part of programme. The HELP vehicles and equipment have met or exceeded all expectations and have allowed the operators to accomplish their work quickly and safely. Some of the most frequent comments from law enforcement officers and other emergency responders relate to the excellent quality of the vehicles and equipment.

The HELP operators' trucks are heavy duty, four-wheel drive vehicles, with dual rear wheels and an ambulance-type enclosed box (canopy) mounted on the chassis. The mounted box has outside compartments for storage of gear and supplies as well as inside shelves and room for tools, equipment, and supplies. The trucks are powered by turbo diesel engines and equipped with heavy duty cooling systems and suspensions. HELP supervisors drive heavy duty, four-wheel drive pickup trucks, also painted lime yellow with much of the same equipment as the operators. The pickups have extended cabs for transporting passengers.

Table 2.5 lists the standard equipment, tools, and supplies found on the HELP trucks.

Table 2.5 HELP Standard Equipment, Tools, and Supplies.

Installed Equipment

- Oversized front push bumper
- Rear trailer ball
- Air compressor
- 20-foot self-retracting air hose
- 3500 watt generator
- Halogen work lights on telescoping poles
- Portable flood light, cab-mounted spot light
- Retractable arrow or message board (roof mounted)
- Exterior quick connect jumper receptacles
- Two-way radio w/repeater
- CB radio
- Police radio (supervisors)
- Front-facing video camera (some vehicles)
- Emergency vehicle package (lights, siren, PA system etc.)

Portable Equipment and Tools

- Tow straps and chains
- Reflective traffic cones (minimum of 20)
- Portable traffic control signs
- Roadway flares
- Fluorescent traffic control flags
- Stop/slow traffic control paddles Camera
- Standard and metric tools, including sockets, wrenches, screw drivers and vice grips
- Ball pen hammer, sledge hammer, pry bar, hack saw and chisel
- Air impact wrench, lug-lock removal tool
- Portable air hose
- Jacks, wheel chocks
- Tire patch kit
- 25-foot jumper cables
- Battery booster pack
- Push brooms, shovels and scoops
- Five-gallon bucket
- 300-foot measuring tape
- Leaf blower (some vehicles)
- Radiological monitoring device

Supplies

- Gasoline and diesel fuel
- Water
- Fire extinguishers
- Marking paint
- Electrical tape, duct tape, mechanical wire
- Assorted fuses, hose clamps, nuts, bolts, clips
- Absorbent material
- Paper towels and hand cleaner
- Area maps and phone directories

Medical

- First aid/trauma kit
- Oxygen kit
- Eye wash kit
- Blankets, flat cloth sheets
- Automated external defibrillator

Personal Equipment

- Reflective vest and Jacket
- Binoculars
- Cell phone
- Portable two-way radio
- Flashlight
- Quick entry tool
- Gloves (leather and rubber)
- Manuals and guidebooks
- Reporting forms
- Motorist comment cards



Figure 2.16 TDOT HELP Operator, Truck, and Equipment.

2.8.5 Washington State Department of Transportation Incident Response Team

In the State of Washington, as in the UK, roads are operating at or above capacity. The majority of all congestion is caused by accidents, broken down vehicles, spills and other events that obstruct the normal flow of traffic. With the average Washington motorist spending approximately two weeks of every year stuck in traffic, it is easy to see how important the Incident Response Teams (IRT) are in keeping Washington state moving.

Since 1963, Washington State Department of Transportation (WSDOT) tow trucks have been clearing blockages on the Interstate 90 Mercer Island floating bridge. In 1989, IRT was highlighted as a pilot programme during the Goodwill Games in Seattle. This pilot programme coupled with the tow trucks on the floating bridges has grown today into a state wide programme with 44 IRT units roving thirty-five highway sections.



Figure 2.17 WSDOT Incident Response Team Vehicles.

IRT personnel provide “roving” coverage during “peak traffic periods”, also responding 24 hours a day, seven days a week to provide traffic control, traffic diverting, mobile communications for “real time” traffic reporting, and assist in incident clearance and clean up. Helping motorists with a flat tyre, jump starts, a gallon of fuel and many other types of motorist assistance are also included in the service, all completely free.



Figure 2.18 WSDOT Incident Response Team Vehicles.

IRT staff are specially trained WSDOT maintenance employees. They have to undertake intensive training before being allowed onto the roads: 2 days classroom training; ride-alongs with experienced IRT drivers; 1 day ride-along with a Washington State trooper; 1 day visit to WSDOT’s Traffic Management Centre (TMC) and Washington Highway Patrol’s Communication Centre.

2.8.6 Oregon Department of Transportation COMET Incident Response Programme.

In 1995, the Oregon Department of Transportation (ODOT) initiated one of the first documented incident management programmes in the rural United States. With the cooperation of Oregon State Police and several local agencies, ODOT administers the incident response programme on highways and interstates all over the State of Oregon. The incident response programme known as COMET (CORridor ManagEment Team) is ODOT's response to directly addresses traffic congestion and delays caused by traffic incidents.



Figure 2.19 ODOT COMET Incident Response Vehicle.

ODOT's COMET helps to keep traffic moving smoothly and safely. This is accomplished by pre-planned and coordinated responses that quickly and safely clear incidents while minimising disruption to traffic flow. The three main goals of the COMET programme are: Incident Prevention, Motorist Assistance, and Incident Management. COMET vehicles respond to an average of 1,200 incidents each month, including disabled vehicles, road debris, and accident/traffic control. They are normally first on the scene and can start incident cleanup operations. They can

initiate tow truck requests, call off responding emergency services when not needed, and set up safe traffic control.

ODOT uses different types of COMET vehicles throughout the state but the majority are 3/4 ton specially equipped trucks. They are equipped with nearly everything needed to get the job done quickly and efficiently, specifically hazmat kits, jumper cables, jack, shovel, gasoline, traffic cones, pry bar, water jugs, air compressor, tow strap, chain saw, roller magnet, rubber push bumper and numerous other tools. They also carry both standard flares and special electric detonating cap flares, which can be deposited on the move via a special launcher installed next to the cab. The trucks are fitted with a diesel transfer pump and holding tank, which allows leaking fuel tanks of Large Goods Vehicles (LGV) involved in incidents to be emptied prior to removal. Additionally, all COMET vehicles are fitted with LED portable variable message signs, rated to 90 mph. They can display any text message and many graphics such as arrows. The vehicle cabs are fitted with many radios including police and fire services. Responding emergency services contact the COMET personnel at incident scenes to ask incident information, best response access, coordinate response and best position for parking vehicles.



Figure 2.20 ODOT COMET Vehicle at an Accident Scene.

The smaller 3/4 ton trucks allow COMET vehicles to work and move well in the heavy congested urban areas. They are classed as emergency response vehicles which allow them to run with emergency lights and sirens enabling them to respond to incidents very rapidly. The emergency lights and sirens also help them respond through areas where there is little or no hard shoulder. The COMET vehicles may be small but they are very powerful and are capable of towing broken down heavy goods vehicles clear of travel lanes, with the current record being 54.5 tons.

COMET operatives are authorised under the law to forcibly remove wreckage and debris (private or commercial product or items that are now debris on the road) on the freeway. They can push trucks and loads into the ditch or side of the road regardless of what the company wants. Management can under the law ignore the owner's wishes and simply remove what's there even if more damage and destruction occurs to their truck and load.



Figure 2.21 Demonstration of ODOT COMET Vehicle's VMS.

The governor of the state supports the efforts of ODOT and has directed the police officials, fire departments officials, investigators, DOT, etc. that all incidents on the freeway system throughout the state be cleared in under 90 minutes. With the protection of the law behind them, first responders on scene can now take extreme measures to open the road.

The authorities are even looking at creating a unit of accident investigators that would be flown by helicopter to the incident scene to quickly conduct their investigation and have the road opened with the 90 minutes time window. When the governor says all incidents which closes a road will be reopened within 90 minutes,

and the law will protect your agency and individuals against lawsuits, departments and units quickly create new means of accomplishing that goal.

2.8.7 Programme Comparison

There are many differences between the US FSP programmes and UK HATOs and ISUs. A selection is shown in table 2.6.

Table 2.6 Comparison of US FSP Programmes to UK.

Programme	M25 ISU	M25 HATO	FDOT Road Rangers	TDOT HELP	WSDOT IRT	ODOT COMET
Hours of Operation	7 Days, 24 Hour	7 Days, 24 Hour	7 Days, Daytime Hours	7 Days, Daytime Hours	7 Days, 24 Hour	7 Days, 24 Hour
Crew	2	2	1	1	1	1
Motorist Assist	No	No	Yes	Yes	Yes	Yes
Scene Protection	Yes	Yes	Yes	Yes	Yes	Yes
Traffic Control Powers	No	Yes	Yes	Yes	Yes	Yes
Towing / Pushing	No	Yes	Yes	Yes	Yes	Yes
Debris Removal	Yes	Yes	Yes	Yes	Yes	Yes
Quick Clearance Legislation	No	No	Yes	Yes	Yes	Yes
Maintenance	Yes	No	No	No	No	No
Authorised Emergency Vehicle	No	No	No	Yes	Yes	Yes

The biggest difference observed between the programmes examined was that two different programmes, the HATOs and the ISUs, operate in the UK whereas in most states only have a single service encompassing both British roles.

The hours of operation, though different, may not have a great impact on the effectiveness of their respective programmes as it is very dependant on the type of roads and the traffic flow that uses the road. The presence of out-of-hours response can often replace full time patrol. It should be noted that incidents can and do occur at any time of the day or night and impact operations long after they have been cleared. Also, motorists generally have a greater level of distress if they breakdown during the night, particularly vulnerable motorists, which is when they would be most grateful for assistance.

One of the main differences noted between the US and UK are that the all FSPs and similar programmes are single crewed whereas the ISUs and HATOs operate with two crew members. This may be partially due to historical operations where in the UK the motorway police have almost always operated in pairs. There are many implications of single operator working, especially safety, particularly when working in rural areas.

When the HATO programme was being developed, there was fierce opposition to any form of motorist assistance being offered, mainly from automobile clubs, such as the Automobile Association (AA) and the Royal Automobile Club (RAC) as well as tow operators, who were concerned about losing their business. Motorist assistance, such as assisting to change a tyre or providing mechanical aid, was also not seen as a major issue by the HA as large numbers of motorists in the UK are members of automobile clubs who have an approximate response time of 30 minutes to their members on the motorways.

All examined programmes were capable of implementing emergency traffic management to protect incident scenes if required. All US programmes and HATOs are also authorised to direct traffic for traffic control purposes at incident scenes. In the UK only the police, police traffic wardens and now HATOs, following completion of the Traffic Management Act, are legally allowed to stop and direct traffic. ISU operatives are not allowed to direct traffic but can however close slip roads and carriageways under the direction of a police officer or HATO.

With exception of the ISUs all programmes used vehicles that are equipped to either push or tow incident involved vehicles from the carriageway. All examined US vehicles were fitted with push bumpers to allow quick and easy relocation of vehicles. The FDOT Road Ranger vehicles specifically used their bumpers to remove vehicles that had broken down at toll plazas. The push bumpers are most likely popular in the US as it allows one person to safely move the vehicle. HATOs are not equipped with push bars due to insurance issues over damage liability and the vehicles being leased, consequently push bumpers would invalidate their warranties. The ISUs are not permitted to remove vehicles from the carriageway and must wait for the attendance of the police or a HATO to remove a vehicle. The ISU will however protect the vehicle until their arrival.

All programmes were responsible for removing debris from the roadway. In the UK debris removal is typically done using an ISU and either a police vehicle or HATO providing a rolling road block to allow the ISU operatives time to safely move the obstruction.

Quick clearance legislation was in place for all of the US programmes which limits the liability of the programme operatives and encourages quick clearance. The roadways can be cleared rapidly without the risk of liability of further vehicle damage through quick clearance. It had been identified that any further damage to vehicles or cargo that were rapidly removed from the roadway was insignificant in comparison to the cost of delay many motorists experienced while care was taken. Many states also had laws prohibiting stopping in carriageways following incidents, such as “Steer it – Clear it” which reduced the initial impact of incidents as motorists legally should move their vehicles to the shoulder. There is no such legislation in the UK with care having to be taken when removing incident effected vehicles and cargo from the carriageway.

The ISU service was the only programme that also carried out maintenance as well as incident duties.

The vehicles in several US programmes are authorised emergency vehicles which are allowed to proceed to incident scenes with lights and sirens whereas in the UK, non emergency services, responders are only allowed to respond with the traffic, following all road traffic laws. This can greatly increase the response time of responders, especially when there is no hard shoulder available to aid travel to incident scenes.

A further difference between US and UK programmes is the amount and type of vehicle markings. Even though most vehicles are painted bright colours, such as white or lime yellow and have reflective logos they are a great deal less conspicuous than either the ISUs or HATOs, whose vehicles are fully liveried with retro reflective material.

2.8.8 Section Summary

There are both many similarities and differences between programmes operated in the US compared to the UK. Additionally experience from British programmes may prove useful and insightful for international practitioners and should be shared.

Points that can be drawn from the international comparisons include:

- Two programmes are used in the UK compared to a single in the US,
- All UK programmes operate with two crew members compared to single in US,
- No free motorist assist is offered in the UK,
- Hours of operation vary between programmes,
- UK incident vehicles are not authorised emergency vehicles,
- Most US states have quick clearance legislation in place to promote rapid clearance,
- Vehicle markings are much more conspicuous in the UK.

Current US practices that could prove beneficial to British incident management programmes include:

- Emergency authorised vehicles- Enabling ISUs and HATOs to respond faster to incidents by using emergency lights and siren, especially in areas with no, or discontinuous hard shoulders, would help reduce incident duration and improve safety. Traffic clearing equipment would also increase the safety of responders and other motorists as it would make the vehicles more conspicuous, in particular when passing stationary traffic.
- Motorist assistance- By providing free motorist assistance, similar to that offered by freeway service patrols, the duration of motorists' stoppages on the hard shoulder will be reduced, thus reducing the possibility of a more serious incident occurring and improving safety. Public relations could also be improved.
- Quick clearance legislation- Providing legal protection for incident responders from litigation with respect to additional damage caused to incident involved vehicles or cargo, will encourage faster clearance of travel lanes. This in turn will reduce delay experienced by motorists, reduce the exposure of incident responders to harm and lessen the possibility of secondary incidents.

2.9 Chapter Summary

This chapter has presented an examination of the motorway incident management process and a background into its operation on the M25 London Orbital Motorway.

The following was presented:

- The five stages of incident management- detection, verification, response, clearance and recovery- were detailed, with programme stakeholders identified and their roles and responsibilities at motorway incidents examined. This gives an understanding of an incident lifecycle in order to give context to incident analysis in subsequent chapters.
- An introduction to the M25 London orbital motorway was presented, including the history, future and current maintenance and management arrangements.

- Incident Management practices on the M25 motorway were examined in detail including the Highways Agency's role and their response capabilities through Incident Support Units and Traffic Officers. This has introduced the British approach to incident management.
- An international incident management programme comparison was also presented which highlighted the differences between the programmes on UK motorways and those of four US states. Several points were drawn and identified as areas of potential future benefit.

3 A Qualitative and Quantitative Review of the Incident Support Unit Programme on the M25 Sphere

3.1 Introduction

The Incident Support Unit (ISU) service, like any new programme, must be regularly evaluated to allow for continual improvement and facilitate an improved understanding of the programme benefits and effectiveness. As part of the evaluation both quantitative and qualitative analysis must be performed. Measuring the benefits of such incident management programs is however complex.

This chapter will present a review of the ISU service on the M25 motorway, operated by the HA's service provider, Carillion plc, including quantitative (analysis of incident data) and qualitative examinations (via questionnaire survey), and a benefit-cost estimation. An analysis of ISU attended incidents, an estimation of ISU benefits and qualitative police and ISU operative survey results will be presented.

This chapter is structured as follows:

- **Section Two.** A background is firstly presented including estimated benefits of the Incident Support Service on the M25 Sphere. A literature review on previous benefit estimations is also shown.
- **Section Three.** An examination of historical ISU records is undertaken to reveal an insight into the activities of ISUs on the M25 Sphere road network.
- **Section Four.** The results of a qualitative questionnaire survey of ISU operatives and police officers regarding the benefits of the ISUs are presented.
- **Section Five.** The cost effectiveness of the ISU service is investigated using an incident impact computer programme, IMPACT. A benefit-cost value for the service on the M25 is derived and presented.
- **Section Six.** Chapter summary and conclusions.

3.2 Background

The longer an incident is on a motorway, the more of a problem it becomes. According to traffic engineering theory incident delay increases as the duration squared. Therefore incidents must be cleared from the roadway as quickly as possible, reducing incident duration (Petty, 1997).

A key objective of the HA is to reduce congestion and increase the reliability of journey times. One way to do this is to work with the Police to provide a faster response to incidents and quicker clearance of blocked lanes. The ISU was developed to support the effective management of incidents and increase co-ordination between the HA's service providers, the Police and other Emergency Services.

3.2.1 Estimated Benefits of ISUs

Unfortunately due to the lack of pre ISU operational data, on the M25 Sphere, an accurate quantitative analysis can not be achieved. However, a qualitative estimate of the impact of the ISUs and their expected benefits can be examined.

Through consultation with the Police, Highways Agency and Carillion plc (service provider) the following is an example of who benefits from the service and the expected benefits of the ISUs.

Who benefits from the ISU service:

- General Public,
- Highways Agency,
- Emergency Services,
- Carillion plc (Service provider),

Estimated benefits of the ISU service:

- Faster detection of incidents,
- Faster response to incidents,
- Faster incident clearance times,
- Restoring traffic lanes faster,
- Risk of secondary incidents reduced,
- Better traffic flow,
- Increased safety:

- Debris removal,
- Barrier damage,
- Potholes,
- Boundary fencing securing,
- Improved level of service,
- Freeing up of emergency services,
- Timely reporting of motorway conditions,
- Increased motorist safety and security,
- Extra equipment arriving quicker,
- Homeland security,
- Reduction in vehicle operating hours,
- Reduced fuel consumption,
- Reduced emissions,
- Improved air quality,
- Reduced motorist delay,
- Vitalising local economy,
- Small maintenance jobs done quicker and at night,
- Fewer Police tyre punctures,
- Environmental improvement due to spill control,
- Reduced motorist stress, anxiety and discomfort,
- Increasing network mobility,
- Assistance to drivers – accident victims and stranded motorists,
- Reporting of damages to crown property.

Benefit Estimation

There have been no evaluations previously carried out on the Incident Support Service. There have however been many evaluations of US Freeway Service Patrols (FSPs).

A study by Fambro et al (1976) was the first published evaluation of a Freeway Service Patrol programme. The programme studied had been operating in Houston, Texas since 1973 and utilised three tow trucks that operated on 64 miles of freeway. The benefit-cost ratio for the service was computed as 2:1.

In 1990 Cambridge Systematics (1990) reviewed various incident management programs in five major metropolitan areas in the US. They also conducted a full evaluation of Chicago's FSP, the Minuteman programme, returning a benefit-cost of 17:1.

The Massachusetts Motorist Assistance Programme (MAP) was evaluated by Stamatiadis et al (1998) in 1995. They found that for every dollar spent on the programme it returns an average saving of \$19. This saving was estimated using a simulation package and representative incidents and accounts for the reduction in delay, fuel consumption and vehicle emissions. They also identified a 13.8% to 2.3% reduction in secondary incidents which was not included in the financial calculation.

One of the most comprehensive studies conducted to date was done by Skabardonis et al (1995) in 1993. They evaluated the FSP operation in the San Francisco Bay area and uniquely attempted to measure all of their data in the field. Data was collected both before and after the deployment of the FSP programme from probe vehicles (instrumented vehicles that provide information on traffic speeds and travel times) with average headways (vehicle spacing) of less than 7 minutes and from loop detectors. They then used this information to directly measure the incident induced delay. The evaluation compared the average delay before and after the FSP implementation and achieved a final benefit-cost of 3.4:1.

Another study by Skabardonis et al (1998) evaluated the FSP on a 7.8 mile stretch of Interstate 10 in Los Angeles. They again examined comprehensively data from the field using probe vehicles and loop data to estimate incident delays. Their study was conducted for six hours per day over 32 weekdays. Overall they estimated a benefit-cost ratio of 5:1 based on delay and fuel savings.

The Maryland State Highway Administration's (MSHA) Coordinated Highways Action Response Team (CHART) Emergency Traffic Patrols (ETP) and Emergency Response Units (ERU) were evaluated by COMSIS in 1996 (COMSIS, 1996). This incident response evaluation examined the delay and fuel savings due to their FSP's, reporting an annual public saving of \$30.5 million. This saving equates to a benefit-cost ratio of 7.5:1.

In 1997 Presley and Wyrosdick (1998) examined the benefits for Navigator, Georgia's Intelligent Transportation System. For the entire Navigator transportation management system including their HERO FSP service they returned an estimated benefit of \$44.6 million giving a benefit-cost ratio of 2.3:1.

Latoski et al (1999) evaluated the Indiana Department of Transportation's (INDOT) the Hoosier Helper FSP programme under two different operating regimes- daytime patrol and 24 hour. They estimated a benefit-cost ratio of 4.71:1 for the daytime operation and 13.28:1 for a 24 hour operation. This increase in estimated benefits motivated the change of the service to fully 24 hour.

Donnell et al (1999) evaluated the Penn-Lincoln Parkway FSP in Pennsylvania, USA. By comparing the effectiveness of the new service to prior implementation data obtained from the State Police they estimated a projected benefit of \$6.5 million per year giving a benefit-cost of 30:1.

An evaluation of Michigan Department of Transportation's FSP in Southeast Michigan in 2002 estimated a benefit-cost saving of 9.2:1 (SEMCOG, 2003). This figure only accounted for travel-time savings for motorists and was thought to be very conservative. Previous evaluations in 1998 and 1996 of the same programme returned benefit-cost figures between 14.1:1 and 17.1:1. These figures are higher than the 2002 analysis which they attributed to increased operating costs such as higher fuel costs, increased operative wages as well as acquiring different and more advanced types of FSP vehicles.

Morris and Lee (1994) produced a summary article reviewing statistics of 32 different service patrol programs. They also summarised calculated benefit-cost ratios for six studies.

Another summary article by Fenno and Ogden (1998) evaluated the state of the practice of FSP programs in the United States. They surveyed managers of fifty-three programs in twenty-two states to derive organisational, operational and

institutional programme information in 1996. It was found that FSPs had proven to be one of the most successful aspects of an incident management programme for reducing detection time and duration producing benefit-cost ratios ranging from 2:1 to 36.2:1. They recommended that an extensive public awareness campaign was essential to ensure the success of any FSP programme. Similarly Denholm et al (2000) provided a summary of nineteen US agencies FSP programs. Each programme was critically analysed and evaluation guidelines developed.

Table 3.1 Examples of Freeway Service Patrols in the United States

Patrol Location	Patrol name	Date of Evaluation	Benefit - Cost
Houston, TX	Metro Freeway Service Patrol	1976	2:1
Chicago, IL	Emergency Traffic Patrol	1990	17:1
Oakland, CA	Freeway Service Patrol	1991	3.5:1
Charlotte, NC	Incident Management Assistance Patrol	1993	3:1 to 7:1
Los Angeles, CA	Highway Helper	1993	11:1
Charlotte, NC	Motorist Assistance Patrol	1993	7.6:1
San Francisco, CA	Freeway Service Patrol	1993	3.4:1
Houston, TX	Metro Freeway Service Patrol	1994	6.6:1 to 23.3:1
Dallas, TX	Courtesy Patrol	1995	3.3:1 to 36.2:1
Detroit, MI	Freeway Courtesy Patrol	1995	14:1
Fresno, CA	Motorist Assistance Program	1995	12.5:1
Minneapolis, MN	Highway Emergency Local Patrol	1995	5:1
New York and Westchester Co., NY	Safety Service Patrol	1995	23.5:1
Norfolk, VA	Freeway Service Patrol	1995	2:1 to 2.5:1
Orange Co, CA	Freeway Service Patrol	1995	3:1
Riverside Co., CA	Freeway Service Patrol	1995	3:1
Sacramento, CA	Freeway Service Patrol	1995	5.5:1
Boston, MA	Motorist Assistance Patrol	1995	19:1
Denver, CO	Mile High Courtesy Patrol	1996	20:1 to 23:1
Detroit, MI	Courtesy Patrol	1996	15:1
New Jersey, NJ	Emergency Service Patrol	1996	11:1
New York, NY	Highway Emergency Local Patrol	1996	26:1
Baltimore, MD	Emergency Traffic Patrol	1996	7.5:1
Atlanta, GA	HERO	1997	2.3:1
Gary, IN	Hoosier Helper	1998	4.7:1 to 13.3:1
Los Angeles, CA	Freeway Service Patrol	1998	5:1
Penn-Lincoln Parkway, PA	Freeway Service Patrol	1999	30:1
Detroit, MI	Courtesy Patrol	2002	9.2:1
Bay Area, CA	Freeway Service Patrol	2002	11:1
Fresno, CA	Freeway Service Patrol	2002	2:1
Los Angeles, CA	Freeway Service Patrol	2002	15:1
Monterey, CA	Freeway Service Patrol	2002	5:1
Orange, CA	Freeway Service Patrol	2002	6:1
Riverside, CA	Freeway Service Patrol	2002	5:1
Sacramento, CA	Freeway Service Patrol	2002	15:1
San Diego, CA	Freeway Service Patrol	2002	7:1
San Joaquin, CA	Freeway Service Patrol	2002	13:1
Santa Cruz, CA	Freeway Service Patrol	2002	9:1

A summary of FSP examinations and estimated benefit-cost ratios is shown in table 3.1.

It can be seen from previous US studies that Freeway Service Patrols are very beneficial to the motorists that they serve. Reported benefit-cost ratios ranged from the modest 2:1 to an astonishing 36.2:1. The majority of studies just examined the reduction in delay experienced by motorists due to the quick clearance of incidents by FSPs but some also included the pollution reduction and fuel savings from the reduced delay. One study even included the benefit to the individual motorist involved in the incident, which most studies neglected as it is such a small value compared to the overall delay saving.

3.3 ISU Historical Records

3.3.1 Introduction

To understand the activities of Incident Support Units on the M25 Sphere road network a quantitative examination of historical ISU data was conducted. This would reveal what the ISUs actually do on the M25 Sphere daily.

This section will present the results of an examination into the actions of ISUs on the M25 Sphere road network.

3.3.2 Background

The computer aided dispatch (CAD) data for Carillion's ISUs on the M25 Sphere road network included 17,450 incidents for the first two years of their contract between September 2001 and August 2003. On the M25 motorway alone there were 11,857 incident requests. The CAD data is recorded at the M25 Sphere Hatfield Network Control Centre (NCC) where ISUs are centrally dispatched. Operators at the NCC receive telephone requests for an ISU from the emergency services or Mouchel Parkman route steward and then using the Global Positioning System (GPS) installed in each vehicle dispatch the nearest ISU to the incident location. The vehicles are dispatched electronically using mobile data terminals but the ISU crew

are also usually informed of additional information with a short wave radio or mobile telephone call.

Incident Data Summary

When an incident support request is notified to the M25 Sphere NCC, the following information is recorded on incident characteristics:

- Incident Number,
- Location (Road, junction no.),
- Type (Type of location- SOS box, M/P, gateway, etc.)
- M/P (Marker Post +/- metres),
- Track (A / B),
- Reported by,
- Symptom of Incident,
- Cause of Incident,
- Type of Work (Immediate / Non-Immediate),
- Priority (Day / Night),
- W/RS (Weather / road surface conditions (Weather condition Fine/Rain/Fog/Snow, Road Surface Dry/Wet/Ice/Snow)),
- Area (North / South),
- Engineer (Which ISU was dispatched),
- Start Date/Time,
- Arrive Date/Time,
- Close Date/Time,
- Comments (including- damage to crown property, actions carried out by ISU crews, materials used, etc.)

3.3.3 Results

An examination of incident frequency, location and timings is shown below.

For the period between September 2001 and August 2003 there were 17,450 recorded incidents. This equates to an average of 24 incident requests per day for the study period on the M25 Sphere road network. The number of incident requests per

day was however very variable with the maximum number in one day being 76 on 29th April 2003.

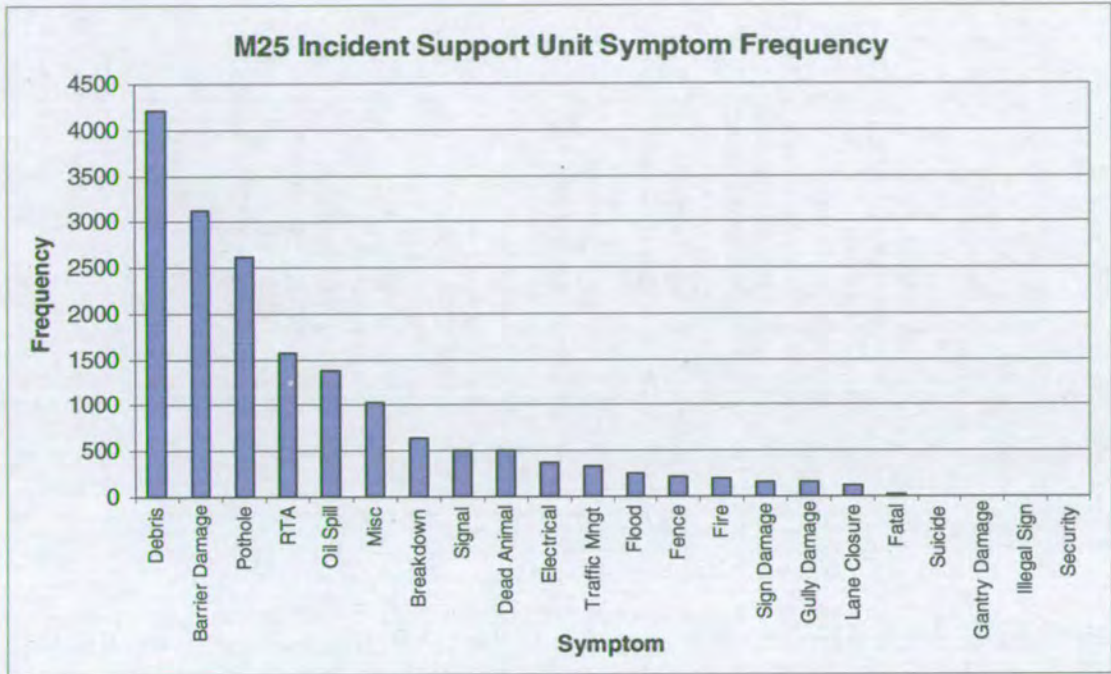


Figure 3.1 Breakdown of Incident Request Types.

Figure 3.1 shows a breakdown of recorded ISU requests by symptom of the initial call. The request symptom describes the initial reason for requesting an ISU’s presence at an incident. This may differ from the type of incident attended, which would be completed at the close of the call in the incident cause field if different. For the first two years of ISU operations on the M25 Sphere the majority of calls requesting the support of an ISU were to deal with debris both in the carriageway and on the hard shoulder. There were 4,217 debris ISU requests which accounted for 24% of all incident requests and on average 5.8 support requests per day. Debris was followed by barrier damage with 3,115 requests (4.3 per day), potholes with 2,621 (3.6 per day) and road traffic accidents with 1,563 (2.1 per day). The remaining 34% of incident requests included broken down vehicles, dead animals, boundary fence damage and fires.

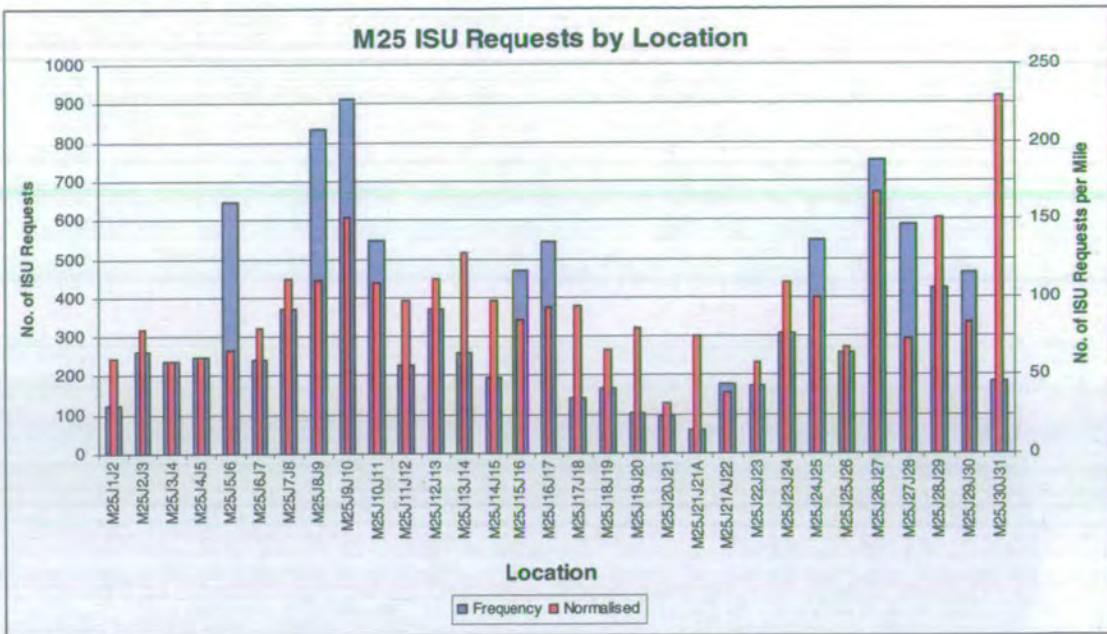


Figure 3.2 Incident Request Locations Organised by Junctions.

The location of each incident was recorded in the CAD data as either a marker post, SOS box (emergency roadside telephone) or feature on the side of the carriageway. Marker posts are spaced at 100 meter intervals along the full length of the M25 and all on-road features are referenced using GPS. The spatial distribution of incidents, organised by junctions for the M25 motorway only, is shown in figure 3.2 both by frequency and normalised by distance. Normalising by distance allows request rates by link to be established giving a clearer view of high incident frequency locations. It can be seen that the highest ISU requests occurred between junctions 9 and 10 and the highest rate was between junctions 30 and 31. The highest request rate between junctions 30 and 31 is mainly due to the short length of the link. It should be noted that the M25 is controlled by six different police forces who all use the ISUs differently. For example Surrey police, who control between junctions 6 and 14 on the M25, are very proactive in the deployment of an ISU whereas Hertfordshire police, who control junctions 17 to 24, are the complete opposite. This discrepancy in ISU deployment may explain the fewer incident requests in certain areas compared to others.

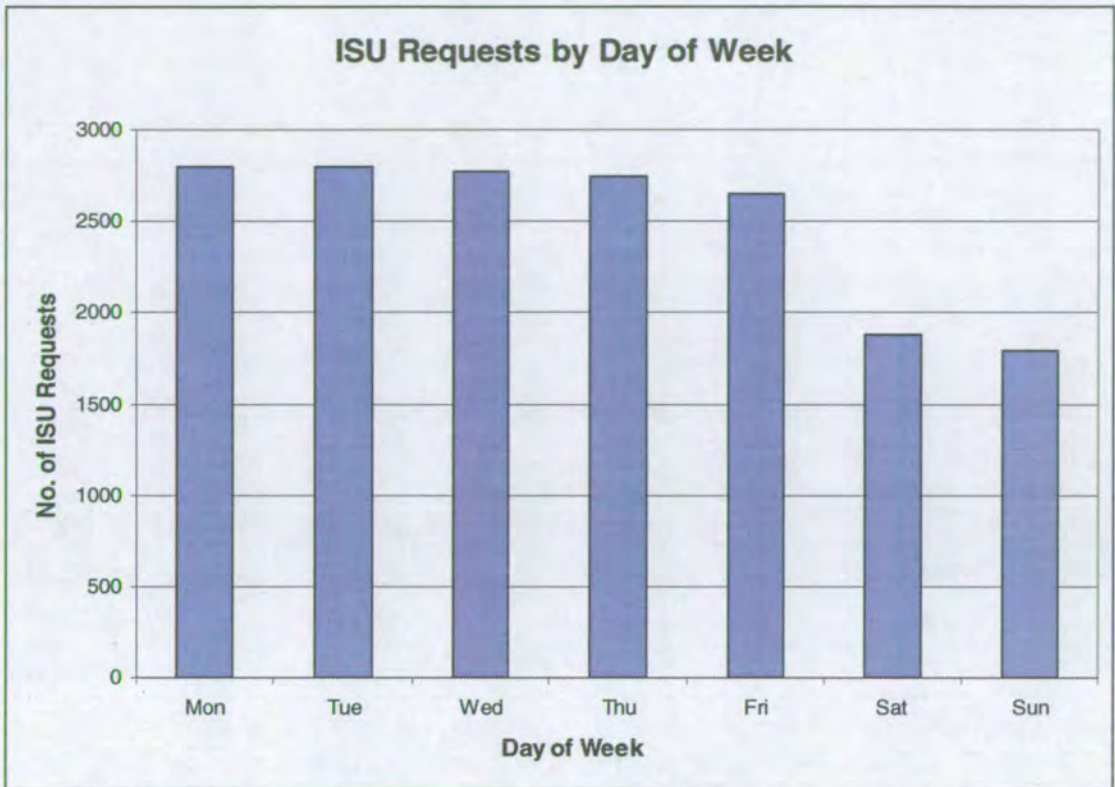


Figure 3.3 Incidents by Day of Week.

Figure 3.3 shows the variability of recorded incidents by days of the week. The plot of data shows, for weekdays, that the larger numbers of incidents occurs on Mondays with 2,803 incident requests or 16% of all incidents in the study period. The weekday distribution is fairly constant with only a 155 request difference between the highest (Monday) and the lowest (Friday). As expected there are fewer incident requests at the weekend as there are lower traffic volumes on the road network.

The distribution of incident requests by month, shown in figure 3.4, is not as straight forward as it first appears. From the recorded data July experiences the most incident requests, with nearly 36 support requests per day. The ISU service first started in the month of September so understandably initially the service was not fully employed by the emergency services and artificially skews the results. It can be seen that the demand for ISUs has increased over the study period. Future examination of a larger data set or a data set excluding the first year would be needed to properly evaluate any patterns of ISU requests by month.

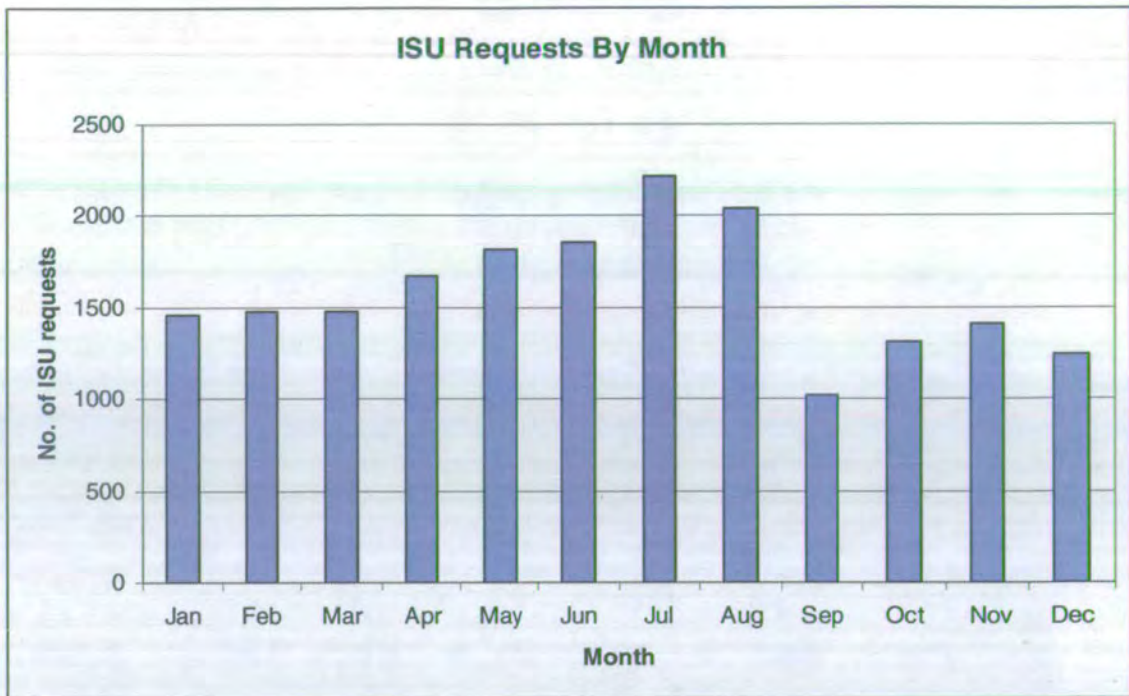


Figure 3.4 Incidents by Month of Year.

The frequency of incident requests varies throughout the day and generally corresponds to the number of vehicles on the road, with the majority of all requests when the road network is near or exceeding capacity, shown graphically in figure 3.5. It can be seen that the greatest number of ISU requests are between 11:00 and 12:00. It can also be seen that the majority of incident requests occur between 7am and 7pm. This information will allow the optimisation of ISU operative shift patterns to provide the greatest coverage of incidents and improving the response to incidents.

Figure 3.6 shows the average response times for each of the sixteen M25 Sphere ISUs. It can be seen that the average response times vary greatly between vehicles by as much as 7 minutes. The average for all vehicles was 12.5 minutes which is well within the contractual 20 minutes response time. GPS tracking data and CAD dispatch logs must be examined more closely to fully understand the reasons for the differences in ISU response times.

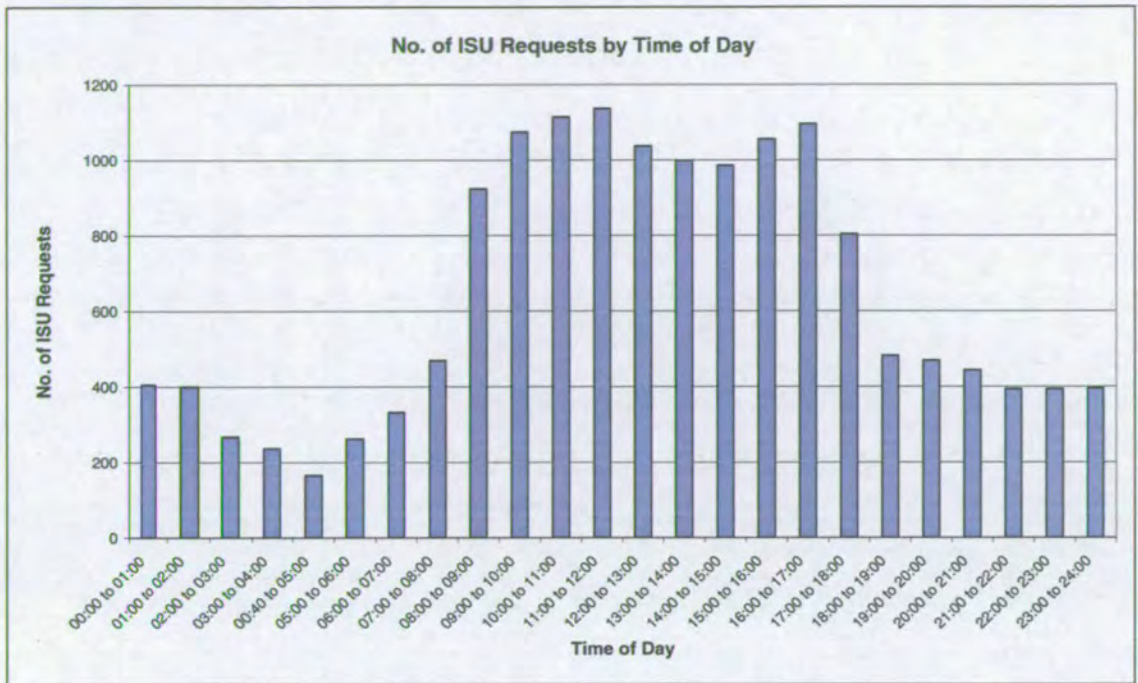


Figure 3.5 Incident Requests by Time of Day.

It was not possible to analyse incident durations from the M25 Sphere CAD data as the closing time of incidents was when the job was finally closed at the NCC once all work had been completed. The durations could also be influenced by the fact that the CAD data is only concerned with the activities of the ISUs and therefore the incident may continue for some time following the ISU departure from the scene.

ISUs do not attend every incident that occurs on the M25 Sphere road network as their presence is not always required by the emergency services. A previous study by University of Edinburgh (Rodgers et al, 2005) showed that ISUs were requested to attend 21.33% of all incidents during the study period. They attended 44% of all accidents, 5% of breakdowns and 63.41% of debris incidents. After being requested, the ISUs had an average response time of 12 minutes over 96 incidents.

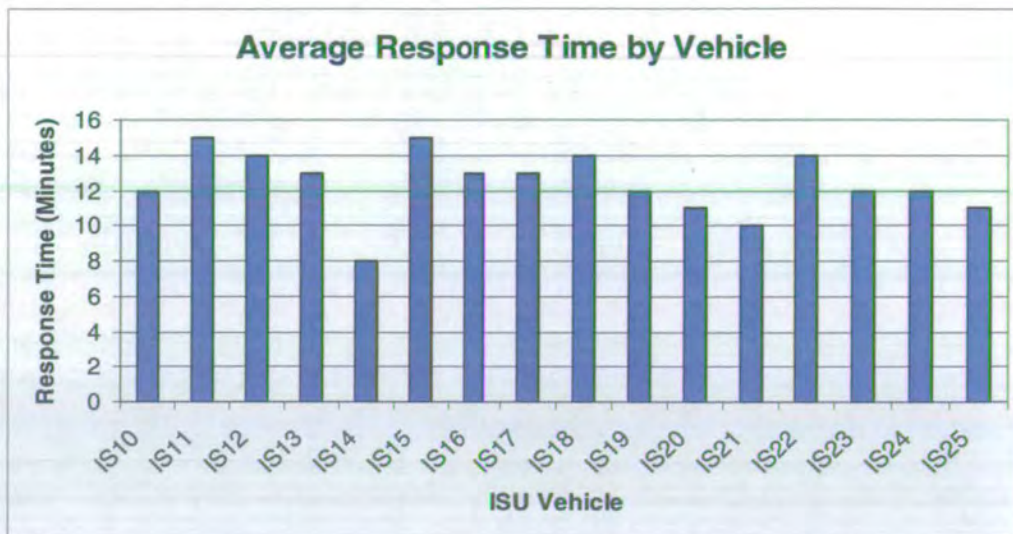


Figure 3.6 Average ISU Response Time by Vehicle.

3.3.4 Section Summary

An overview of the characteristics of incidents attended by Incident Support Units, on the M25 Sphere road network for the period between September 2001 and August 2003 has been shown. Incident frequency, timings and locations were examined.

It was found that:

- A total of 17,450 incidents were observed resulting in an average frequency of 24 incidents per day for the M25 Sphere.
- Most ISU requests, 24%, were for debris clearance.
- The highest ISU requests occurred between junctions 9 and 10 and the highest frequency was between junctions 30 and 31.
- Most incidents, 16%, occurred on a Monday albeit there was little variance on weekdays and there were fewer at the weekend
- July experiences the most incident requests however ISU requests have grown steadily since they were introduced.
- The greatest number of ISU requests is between 11:00 and 12:00.
- The average response time for all ISUs was 12.5 minutes.
- It was not possible to examine incident durations with the available data.

3.4 Police and ISU Operative Surveys

3.4.1 Introduction

As well as quantitative analysis of the Incident Support service a qualitative analysis can also provide valuable information regarding the benefits of the service.

A survey of police officer's within the M25 Integrated Policing Group, police control room staff and Carillion's ISU operatives, who have actually worked with or observed ISUs at an incident scene was conducted in late 2003 and early 2004.

The purpose of the survey was to:

- Determine the opinions of the service while it was still relatively new,
- Establish a baseline of opinions of the service for future year comparison,
- Compensate for the lack of hard data on certain benefits of the service,
- Request comments and suggestions to help enhance and improve the ISU service.

The survey was constructed in five different formats:

- Statements,
- Rating questions,
- Fill in the blank question,
- Open ended questions,
- Comments and suggestions.

The statement questions were designed to allow the respondents to indicate their level of agreement or disagreement with the question: 1=Strongly Agree, 2=Agree, 3=Neither Agree or Disagree, 4=Disagree, 5=Strongly Disagree. The ratings questions allowed respondents to rate various aspects of Carillion's ISU service using the following scale: 1=Excellent, 2=Good, 3=Adequate, 4=Fair, 5=Poor. The survey had 26 statements, 9 rating questions, 1 fill in the blank question, and 2 open ended questions, giving a total of 36 questions.

This section will present the results of the questionnaire survey of ISU operatives and police officers regarding the benefits of the ISUs.

3.4.2 Survey Design

A survey is a method of collecting information from people about their ideas, feelings, plans, beliefs and social, educational, and financial background (Fink and Kosecoff, 1985). They usually take the form of questionnaires or interviews and are used to help assessors, planners, researchers and policy makers. There are many reasons for conducting surveys- planning of a programme, setting of policy, and programme evaluations are just three examples.

Questionnaire and Interview Design

Interviews and questionnaires are the most frequently used type of surveys. Questionnaires and interviews share many of the same features, with both relying on getting information by asking people questions. Questionnaires let people work at their own speed and when and where they want to. Interviews require more structure. Interviews can produce more reliable information than questionnaires due to the set order and time for completion. Interviews can contain a built in bias because people react to the interviewer and not just the questions (Alreck and Settle, 1995)

Survey Design

The design of a survey is critical. It must be designed in such a way that it will result in the data that is required. There are several key points to designing surveys:

- Type of Survey,
- Length,
- Content,

The type of survey must be chosen to enable the best result data to be collected. Telephone interviews, face-to-face interviews and questionnaires are three examples of surveys. Each different survey method will be suitable to an individual survey's requirements but may be completely wrong for another (Oppenheim, 1992).

The length of a survey depends upon what you need to know and how many questions are necessary to collect the required data. The length is also dependant on how much time the respondents have available for completing the survey (Fink, 1995).

The content should be directly related to the aims and purpose of the survey, especially the first question (Fink and Kosecoff, 1985). All questions should be independent and unbiased and should have just one thought. Questions should be well defined and not be open to respondents personal definitions (Hague, 1993).

Types of Questions

Survey questions typically take the form of either closed or open ended (Fink and Kosecoff, 1985).

Closed ended questions (also known as “forced choice”) are those where respondents answer multiple choice questions, where the answers are predetermined. For example a person could be asked to indicate their level of agreement or disagreement on a list of pre-selected alternatives. Closed ended questions can be more reliable and efficient as they are easy to use and mark. As all respondents have the same options to choose from, the resulting data is uniform.

Open ended questions are questions that respondents answer in their own words. Answers are inevitably hard to interpret as each responder has a different view. These questions can however allow respondents to express their own opinions, providing greater insight into respondents’ thoughts.

Pilot Testing

Reliability and validity of a survey are established by pilot testing. The survey should be trialled extensively by choosing respondents similar to the ones who will eventually complete the survey (Gillham, 2000). As many people as possible should be enlisted.

Pilot testing enables the survey to be modified if the testers do not understand the survey instructions and directions. To help reliability there should be focus on the clarity of questions and general format of the survey.

Testing also aids design issues such as providing enough space for responses and identifies any failures to answer questions. Poorly worded questions, responders providing several answers or writing comments in margin are also discovered thanks to pilot testing.

Sample

When a survey is conducted it must be decided whether to include everyone or just a sample of the population. There are several issues that must be addressed when looking at the size of samples (Alreck and Settle, 1995):

- How quickly is the data needed - If you survey everybody in the population then the data will take a long time to collect and analyse.
- What type of survey is planned – A telephone survey or self-administered questionnaire would be quicker than personally interviewing everybody in the population.
- How credible will your results be – Enough people must participate in the survey to ensure that it is representative.

There are two basic methods of sampling used for surveys: probability and non-probability sampling.

Probability Sampling Method

A probability sample is one in which each person in the population has an equal chance of being selected and is said to be representative. It should be a miniature version of the population to which the findings are going to be applied. The sample should be representative of the general population as the people selected are thought to be the same as the people who are not. Three commonly used methods of probability sampling are:

- Simple random sampling,
- Stratified random sampling,
- Simple random cluster sampling.

Simple Random Sampling

A simple random sample is one in which each person has an equal chance of being chosen for involvement in the survey. This method is the simplest and easiest to conduct. Examples of simple random sampling would be by selecting people names from a hat or by using a table of random numbers against names. This method can however produce greater errors than others and can not be used if it is required to split respondents into subgroups.

Stratified Random Sampling

Stratified random sampling is slightly different from simple random sampling as you first split the population into subgroups or strata and then select a certain number of respondents from each division to get a sample. For example the entire group could be divided into subgroups of males and females and then randomly choosing your sample from each subgroup, to give you an equal representation of males and females. Stratified random sampling is more precise than simple random sampling and it allows the surveyor to select a representative sample, of a variety of groups and patterns of characteristics in the required proportions. The method however requires more effort than the simple method and it requires larger sample sizes. It should be noted that the increase in the accuracy of the results found with stratification can usually be produced by increasing the sample size of a simple random sample.

Simple Random Cluster Sampling

Simple random cluster sampling is useful for when random selection cannot be used and is employed mainly for administrative ease, not to improve accuracy. Instead of randomly selecting individuals, groups or clusters of respondents are used. The method assumes that the population is arranged into natural or predefined clusters or groups. The method is unfortunately not mathematically efficient but is

administratively simple, as individuals are not required to be identified, and can be used when it is inconvenient or unethical to randomly select persons.

Non-Probability Sampling Method

Non-probability samples are those acquired by accident, such as the first one hundred people to return the survey. They are usually easier to draw than other probability samples, but increases in effectiveness frequently correspond to losses of accuracy. Three commonly used methods of non-probability sampling are (Fink and Kosecoff, 1985):

- Systematic sampling,
- Accidental sampling,
- Purposive sampling.

Systematic Sampling

Systematic sampling is done by selecting a number and then picking names off a list corresponding to that number. For example if three was picked, every third person on the list would be selected. The sample size is relative to total size of the list as you have to select a collection from it. Another example would be if you had a list of 1000 names and wanted to select 200 from it. A random number between one and ten could be selected, and then you would start at that random number and count every five until you had your 200 sample. If two had been chosen, the resulting selection would be the second name seventh, twelfth, seventeenth until 200 names were collected. Unfortunately lists of people are occasionally arranged so that certain patterns can be uncovered. If a patterned list is used then there will be a bias introduced into the sample. Any lists of names used for this method of sampling should be carefully examined and if any bias is suspected another method should be used.

Accidental Sampling

Accidental sampling is conducted by selecting people who are accessible. For example you survey the first 25 people that enter a shop or get off a bus. The convenience of an accidental sample is the main benefit but it can be very susceptible

to bias. If you only conducted the survey at a certain time of the day you would only get a certain type of people. People willing to do the survey may be concerned about the issues in the survey, may have a complaint or may be very satisfied thus not giving a complete general sample.

Purposive Sampling

In purposive sampling the sample is selected by the surveyor. The judgement of the surveyor is a major problem as they may be in error. If the choices, of the surveyor, can be justified there can be great value in purposive sampling.

Confidence Levels

The confidence level describes the probability that the chosen sample is representative of the population. The 95 percent confidence level is frequently used, but other levels such as 99 or 90 percent levels may also be employed.

Margin of Error

Unless a survey is conducted of an entire population there will be some errors. A sample is almost always different from the population by some margin of error, whatever sample method you use. For the sample to be accurate the error has to be minimised.

The accuracy of a sampling method can be measured by computing standard error of the mean (Fink and Kosecoff, 1985).

$$SE = \left[\frac{(N - n)}{(N - 1)} \right] \sigma^2 / n \quad \text{[Eq. 3.1]}$$

Where, SE is standard error, N is the total population size, n is the sample size and σ^2 is the variance.

The standard error is a good indication of how well the sample's response will reflect the total population. It can be seen that if you increase the sample size the sampling error is improved.

Sample Size

Once the sampling method has been chosen the sample size must then be established. The survey sample size should be large enough to satisfy the problem and enable the results to be properly analysed. To get credible findings, enough people whose views count must reply, so that the results will be representative of the population. When using statistical method to choose the sample size, three issues must be considered, as discussed earlier:

- Sampling error,
- Stratification,
- Confidence levels.

The formula used for statistically calculating the sample size is shown below (Fink and Kosecoff, 1985).

$$N = \left(\frac{z}{e} \right)^2 (p)(1-p) \quad [\text{Eq. 3.2}]$$

Where, N is sample size, z is the standard score corresponding to confidence level, e is proportion of sampling error and p is the estimated proportion of incidences of cases.

For a 90% confidence level $z=1.65$, for 95% $z=1.96$ and for 99% $z=2.58$. A satisfactory level of error is approximately plus or minus 10%, 0.10.

It is not always necessary to use statistical methods to obtain a sample size. As long as the sample size is sufficient in size as to yield useful data it is acceptable to just selected the size.

Response Rate

The response rate should be as high as is feasibly possible. The response rate being number of people who respond to a survey divided by the number who should have

responded. For example if 50 surveys were sent out and 40 were returned, then the response rate would be 80 percent. Error will be introduced, into the survey, if a number less than the chosen sample is returned, resulting in the survey not being as credible.

To try and improve response rates a high response technique such as face-to-face interviews should be used (Fink and Kosecoff, 1985). Over-sampling by selecting more people than initially required will allow non-respondents to be replaced easily.

3.4.3 Incident Support Unit Assessment Survey

Another way to estimate the benefits of the ISUs is to ask the people who use the service daily their opinions. This methodology was first used by Baird and Jacobs (2003) who assessed the Tennessee Department of Transportation's HELP freeway service patrols.

The participants were asked to either manually post return the survey or electronically complete the questions. It was thought that this format would be the most flexible and most convenient for the police officers.

Question Choice

Questions were chosen in discussion with police officers and ISU operatives to ensure relevance and to ensure that each question was meaningful to respondents. The questions were arranged in several different styles: open ended, ratings, statement and fill in the blanks. Open ended and fill in the blanks questions were chosen to enable the person being surveyed to answer the questions in their own words. It was hoped that the varied question styles and types would aid in the collection of an accurate set of results.

Following the choice of questions the questionnaire was trialled by serving police traffic officers, from several police forces, to ensure the reliability and validity of the results. These trials highlighted several issues with the survey that were addressed and another pilot performed.

Sample

It was decided not to use a sampling method, as the population was relatively low, therefore as many police traffic officers and ISU operatives as possible were asked to participate.

3.4.4 Survey Results

The results of the survey are shown in tables 3.2, 3.3 and 3.4, showing the average (mean) and most frequent (mode) of the responses to each question. The results are also split into three categories: all survey results, ISU operative results and Police survey results. 71 police surveys were returned and 66 ISU operative surveys were returned giving 137 in total.

Response Rate

The survey response rate is very difficult to establish as the number of operational police officers changed on a daily basis depending on their duties. The staffing numbers provided by police forces also included officers that were on leave, sick leave, court duties, training courses and secondments which also hindered the calculation of response rates.

Using supplied officer numbers and numbers of responses a conservative response rate can be estimated at 30% for police officers. For ISU operatives the response rate was considerably higher with an approximate response rate of 85%. Again due to sick leave, holidays and training a more accurate figure can not be established.

Another reason for a lower number of responses was that several officers from each police force were used for pilot testing the survey, thus reducing the sample size, and were not included in the analysis.

Table 3.2 ISU Survey Statement Question Responses

	Question	All Survey Results		ISU Survey Results		Police Survey Results	
		Mean	Mode	Mean	Mode	Mean	Mode
1	ISUs are an asset to police officers.	1.64	1	1.56	1	1.70	2
2	The ISU service has improved safety at incident scenes for emergency responders.	1.81	2	1.67	1	1.94	2
3	Roads patrolled by the ISUs are safer and less congested.	2.90	3	2.39	3	3.37	3
4	ISUs are an unnecessary duplication of services already provided.	4.16	4	4.39	5	3.94	4
5	The ISU service has resulted in a reduction of secondary incidents (either in queues from previous incidents or rubbernecking).	2.89	3	2.52	3	3.24	3
6	The ISU service has reduced traffic congestion caused by crashes and other incidents.	2.74	3	2.27	2	3.17	3
7	The police receive more accurate and timely information about incidents as a result of ISUs.	2.69	3	2.20	2	3.15	3
8	The ISU service is well coordinated with local agencies.	2.53	2	2.35	2	2.70	2
9	The ISU operatives work effectively with other responders at incident scenes.	1.85	2	1.65	2	2.04	2
10	An ISU should be requested immediately when an incident occurs.	1.96	1	1.56	1	2.32	2
11	The ISU service has enabled the police to better utilise its resources on the motorways for enforcement and emergency response.	2.21	2	1.70	1	2.70	2
12	The police now give lower priority to the motorways than before the ISU service started.	3.55	3	3.21	3	3.87	5
13	The ISUs arrive in a timely manner at incident scenes.	2.04	2	1.71	2	2.34	2
14	There would be extra benefit if the ISUs arrived at an incident faster.	2.44	3	2.35	2	2.52	3
15	ISUs carry all necessary equipment to deal with incidents swiftly.	2.36	2	2.24	2	2.46	2
16	There should be more integrated training between ISUs and the emergency services.	2.09	2	1.74	1	2.42	2
17	It is safer at an incident when a large, crash cushion equipped, ISU is at an incident scene.	1.72	1	1.61	1	1.82	2
18	ISU operatives can get in the way at incident scenes.	3.68	4	3.97	5	3.41	4
19	There is less debris on the hard shoulder since the ISUs started.	1.95	1	1.21	1	2.63	2
20	Direct radio communication with ISUs would be of benefit.	1.89	1	1.62	1	2.14	2
21	When an ISU is present at an incident scene, police officers can cut the time for normal investigations for collisions and minor injuries on the motorways.	2.68	2	2.11	2	3.21	4
22	The environmental impacts of incidents, from spills, are lessened due to the rapid initial response by ISU operatives.	2.15	2	1.59	2	2.66	2
23	ISUs are better equipped to help protect incident scenes.	1.94	2	1.89	2	1.99	2
24	The carriageway is cleared much quicker when an ISU is present.	1.91	2	1.39	1	2.39	2
25	All ISUs should be equipped with electric light arrows.	1.91	2	N/A	N/A	1.91	2
26	ISU mounted, portable variable message signs would be of benefit.	1.85	1	N/A	N/A	1.85	1

Table 3.3 ISU Survey Ratings Question Responses

	Question	All Survey Results		ISU Survey Results		Police Survey Results	
		Mean	Mode	Mean	Mode	Mean	Mode
1	How do you rate the general skills and expertise of the ISU operatives at	2.12	2	1.91	2	2.32	2
2	How do you rate the attitudes and professionalism displayed by the ISU operatives towards the emergency services?	1.83	2	1.50	1	2.14	2
3	How do you rate the attitudes and professionalism displayed by the ISU operatives towards the public?	2.07	2	1.67	2	2.45	2
4	How do you rate the ISU vehicle livery?	2.82	2	3.36	3	2.32	2
5	How do you rate the ISU vehicle lighting?	2.96	2	3.82	5	2.15	2
6	How do you rate the ISU equipment?	2.72	2	3.20	4	2.27	2
7	How do you rate the ISU operatives concern for safety?	2.26	2	1.77	2	2.72	2
8	Do ISUs attend the majority of incidents in an acceptable time from	2.09	2	1.82	2	2.34	2
9	How do you rate the overall ISU service?	2.00	2	1.76	2	2.23	2

Table 3.4 ISU Survey Fill-in-the-Blank Question Responses

	Question	All Survey Results		ISU Survey Results		Police Survey Results	
		Mean	Mode	Mean	Mode	Mean	Mode
1	Ideally, an ISU should arrive at an incident scene within _____ minutes.	17.55	20	18.03	20	17.12	15

Police Survey Responses

The first question “ISUs are an asset to police officers” received an average response of 1.7 (1=strongly agree, 5=strongly disagree, section 3.4.1), the most positive of all the responses to all of the survey statements and questions. More than 87% of officers agreed with this statement, with the other 13% neither agreeing or disagreeing. The majority of police officers (82%) also thought that the ISU service was not a duplication of services already provided, giving it an average of 3.9. More than 73% of responders also rated the overall ISU service as good or excellent.

The ISU operatives received a positive response from the police officers with good response to all questions related to them. They also received several positive remarks in the comments section. The statement “ISU operatives work effectively with other responders at incident scenes” received very positive feedback with 84.5% agreeing with it. Conversely when the police officers were asked “ISU operatives can get in the way at incident scenes” only 53.5% disagreed with the statement and

22.5% agreed with it. The most frequent chosen answer was 4 but respondents may not have fully understood or read the question properly. Two ratings questions on the professionalism of ISU operatives both received positive feedback. Their attitudes towards the emergency services and attitudes towards the public, received 2.1 and 2.45 with 77.5% and 59% of police officers rated them as good or excellent respectively. The general skills and expertise of the ISU operatives at incidents were also given a good rating of 2.3 with 69% of respondents rating them as good or excellent.

A number of questions were posed regarding the benefits of the ISUs in the eyes of the people who use the service daily. More than 53% of police officers agreed that there was less debris on the hard shoulder since the ISUs started giving it an average response of 2.6. The officers agreed with the statement “the environmental impacts of incidents, from spills, are lessened due to the rapid initial response by ISU operatives” with an average response of 2.6. The statement “the police receive more accurate and timely information about incidents as a result of ISUs” received varied responses with 42% neither agreeing nor disagreeing. It is thought the many officers on active patrol duties would never directly receive information from ISUs which may account for this response.

For the question about the police now giving lower priority to motorways than before the ISU service started, the most frequent response was 5, strongly disagree, but the average was 3.8. More than 61% of the officers selected strongly disagree but a small number, 12%, of respondents did believe that there had been a shift in priorities. On the other hand the previous statement question, “the ISU service has enabled the police to better utilise its resources on the motorways for enforcement and emergency response” was given 2.7 and 49% officers agreed.

The response time of the ISU vehicles is very important and feedback is valuable. More than 70% of police officers rated good or excellent that ISUs attend the majority of incidents within an acceptable time. They also thought that the “ISUs arrive in a timely manner at incident scenes”, giving an average response of 2.3 and

73% agreeing with the statement. The response to “there would be extra benefit if the ISUs arrived at an incident faster” was positive with an average response of 2.5 but only 46.5% agreed and 45% neither agree nor disagree. Some police forces only requested an ISU once an officer has started to clear an incident scene and realises that he needs more specialised assistance which is far from the ideal situation. As ISUs are not emergency vehicles it can take a long time to respond to an incident as they now have to contend with large tailbacks due to the initial incident. One way round this problem would be to request an ISUs presence immediately an incident occurs. More than 60.5% of officers agreed with an average response of 2.3.

All of the ratings questions relating to the details of the ISU vehicles and equipment they carry all received very positive responses. The most positive was the ISU vehicle lighting rating with an average of 2.1 and 75% of officers selecting good or excellent. The ISU equipment was also rated highly at 2.27 and 69%. Finally the ISU vehicle livery was rated as 2.3 and 67%. One statement question regarding ISU equipment – “ISUs carry all necessary equipment to deal with incidents swiftly”- received a slightly positive response of 2.5 and 59% of officers agreeing with the statement. Unfortunately none of the officers included suggestions for additional equipment so more information will be sought from officers to enhance the ISU service.

Improved Safety

The police officers provided very positive responses to statements and questions about safety at incident scenes. The statement question “The ISU service has improved safety at incident scenes for emergency responders” received an average response of 1.94 with nearly 79% agreeing with the statement but 10% also disagreed. They were not as positive about the statement question “Roads patrolled by the ISUs are safer and less congested” giving it an average of 3.37. A couple of officers noted in the comments section of the questionnaire that they would not know how to judge this. Officers also had a similar reaction to the question “The ISU service has resulted in a reduction of secondary incidents (either in queues from previous incidents or rubbernecking)” again stating that they would not know how to

judge this. The average answer was 3.2 with 52% of responders neither agreeing nor disagreeing. The police officers responded very strongly to the statement “it is safer at an incident when a large, crash cushion equipped, ISU is at an incident scene” giving it an average answer of 1.8 and nearly 82% of officers agreed with the statement. Another strong response of 84.5% of officers agreeing with the statement “ISUs are better equipped to help protect incident scenes” certainly shows one of the benefits of the ISUs. The officers were also asked to rate the ISU operative concern for safety at incident scenes giving an average response of 2.7. More than 50% of responses rated them as good or above but 21% did respond that they thought that they were poor. This has been fed back to the service provider and more regular training will now be given to all operatives to remind them of the dangers of working on live motorways.

Reduced Incident Duration

Three questions looked at the impact of the ISUs on the durations of incidents. In response to the statement “the carriageway is cleared much quicker when an ISU is present” more than 65% of officers selected agree or above with an average of 2.4. The responses to “the ISU service has reduced traffic congestion caused by crashes and other incidents” were not as positive with an average of 3.17. More than 40% of officers selected neither agree or disagree and some stated that again that they would not know how to judge this. Another question that received a varied response was “when an ISU is present at an incident scene, police officers can cut the time for normal investigations for collisions and minor injuries on the motorways”. This question was given an average of 3.2 with 44% of officers disagreeing with the statement and 28% agreeing.

Future work

Several questions were included in the survey regarding future enhancements to the ISU service.

When the survey was conducted, ISUs did not have any direct radio communications with police officers or police control rooms. The ISUs are in contact with their

Network Control Centre (NCC) who then contact the appropriate police control room who in turn control the officers on the ground. When direct communication was needed, for example with debris removal from a live lane with a police rolling road block, the control rooms would often pass direct mobile phone numbers for the police and ISU crews for safety reasons. When asked if “direct radio communication with ISUs would be of benefit” 72% of police officers agreed and the average response was 2.14. The HA are currently implementing airwave, a tetra based radio system, for their new traffic officers which is compatible with the police radio network and it is hoped will be used by the ISUs as well to improve on scene communications.

The use of vehicle mounted light arrows and variable message signs was examined. 76.5% of police officers agreed that “all ISUs should be equipped with electric light arrows” with the average response of 1.91. This is very positive as 4 of the large ISU vehicles are already equipped with light arrows but the benefits were not certain or supported. This result can be used as a justification for equipping the rest of the ISU fleet. An even more positive response was recorded for the statement “ISU mounted, portable variable message signs would be of benefit” with an average response of 1.85 and again 76.5% of responders agreeing. This response is also very constructive as a proposal can be prepared to justify equipping the ISUs with electronic variable message signs.

Training of emergency responders is arguably one of the most critical pieces of any traffic incident management programme. Currently there is minimal integrated training between the ISUs and the other emergency services. More than 59% of police officers agreed that “there should be more integrated training between ISUs and the emergency services” with an average of 2.4. There were many remarks in the comments and suggestions section, of the survey, regarding ISU operative training particularly regarding integrated training, with several officers offering their assistance.

Other Responses

Officers were asked a fill in the blank question about what ideally the response time of the ISUs should be. The most frequent answer was 15 minutes and the average was 17.12 minutes. This is quite close to their current contractual maximum of 20 minutes but is in fact higher than what the ISUs on the M25 currently achieve.

More than 40% of responders made comments or offered suggestions. A selection is shown below:

- “Improvement in integrated training would be of benefit to both ISU operatives and the police. Improved communications (direct radio) would improve the existing arrangement of passing messages via separate control rooms”
- “Very good - freeing of police time and equipment to concentrate on the job at hand”
- “ISU operatives should be better trained by operational traffic motorway officers. This would also assist in a good working environment. I would happily assist in training”
- “It would be extremely helpful for them to have police radios to assist communications”
- “More personal safety awareness training should also be given to ISUs whilst on the motorway. At times seem oblivious to the hazards”
- “ISUs are a great help at incidents”
- “Overall the service they provide is beneficial and I am generally impressed with what I have seen them do”
- “The ISU's on the M25 are very good, but their colleagues on the M3 leave a lot to be desired”
- “The service provided by the ISU's is extremely valuable and assist in the role that I perform. If the ISU's were not working on the motorway network I feel that my job would be made far more difficult and even minor incidents would take longer to complete”
- “I would like to state that I think they work bloody hard and don't get a lot of praise for what they do”

- “I can say I have thanked God they have been protecting RTC scenes when I have had to deal with them”
- “The crews that I have come in to contact with have been more than helpful to assist and have even taken the initiative in dealing with incidents”
- “They are a valuable resource”
- “I feel that it would benefit them if they did training with us so they can see what we are trying to achieve. This also puts names to faces and makes us one big team”
- “I think they do a damn good job”
- “ISU staff currently do their best to assist but lack the necessary equipment”
- “The ability of ISU vehicles to tow/drag disabled/crash-damaged cars & light vans from live running lanes onto the hard shoulder under the direction and supervision of police would be of great help since garage attendance times are generally much greater than ISU's”
- “This needs to be adapted and extended over all areas”
- “I am personally always thankful when they arrive at a scene especially one in the running lanes as their cones and lights provide the required level of safety to allow us to concentrate on the job in hand”

Two negative comments are shown below:

- “FORGET TRYING TO PATROL THE MOTORWAYS CHEAPLY - EMPLOY MORE POLICE OFFICERS AND THE PROBLEM IS SOLVED!”
- “During my patrol time on the M25 I have rarely seen the ISUs attend incidents. I was under the impression the ISUs were a temporary trial due to their lack of presence”

The first comment shows how emotional some of the police officers feel about their jobs on the motorways. It should be noted that the ISUs are in no way intended to take over any roles currently performed by the police but are intended to support the operational roles of the emergency services. The second comment is very

unexpected as there is identical ISU coverage all over the road network and the majority of respondents were positive about the response times and presence of the vehicles. These responses may be due to a lack of education about the ISU programme or training.

Police Force Comparison

On average, the responses from all four police forces that participated in the survey were reasonably constant. Of all the police forces, Essex police force were on average the most positive about the ISU service and Hertfordshire police force were the least positive. On average Hertfordshire police officer responses were approximately 0.6 units less positive than their Essex counterparts. It is unknown why there is such a discrepancy and further work would have to be conducted to establish a reason and strategies to mitigate it.

ISU Operative Response Comparison

Comparing responses from police officers to those of the ISU operatives shows understandably that the ISU operatives gave more positive responses. On average their responses were 0.47 more positive. Observations from first hand experience would suggest that the ISU operatives' pride in their work may have contributed to these more positive responses. This may also be because they are more aware of the system and what its aims are compared to police officers'.

There were however three negative responses from ISU operative: ratings question 4, 5 and 6. Ratings questions 4, 5 and 6 all pertained to the ISU vehicles livery, lighting and their equipment. On average the ISU operatives were 1.1 points less positive than police officers for these three questions.

3.4.5 Section Summary

A total of 137 police officers and ISU operatives were surveyed using questionnaires to establish qualitative information regarding the benefits of the Incident Support service. The opinions of police officers on the M25 have been captured at a time when the majority are still familiar with the operations prior to ISUs. Also, a

baseline of the officers' opinions has been established for future assessments. A better understanding of what police officers see as the programme's strengths, areas where officers are less convinced and specific suggestions for improvement are now known.

The following is a summary of the study findings:

- A qualitative questionnaire survey of police officers has elicited a valuable and positive response towards the ISU service on the M25.
- Overall feedback regarding the ISUs was positive and it can be concluded that the ISU service provided on the M25 is of benefit. In particular:
 - more than 87% of surveyed police officers agreed that “ISUs are an asset to police officers”.
 - more than 73% of officers also rated the overall ISU service as good or excellent.
 - more than 79% of officers believed that safety had been improved at incident scenes for emergency responders.
 - more than 65% of officers agreed that “the carriageway is cleared much quicker when an ISU is present”.
- Areas of improvement identified by police officers included:
 - 42% neither agreed nor disagreed that they receive more accurate and timely information about incidents as a result of ISUs. This is an opportunity to improve communication between ISUs and police officers and hence effectiveness.
 - 21% rated ISU operatives concern for safety at incident scenes as poor. This is now being addressed with further training being offered to ISU operatives.
- Significant feedback has shown that future developments should focus on (1) Improved direct communications; (2) Improved use of mobile variable message signs and electric light arrows; and (3) improved integrated training between the various emergency and response services.
- ISU operatives gave more positive responses in comparison to police officers.

3.5 IMPACT Benefit Prediction Model

3.5.1 Introduction

As the Highways Agency is a government agency it must justify its actions and the effectiveness of its programmes. The cost effectiveness of the ISU service must be established to ensure continued financially and politically support.

This section will utilise a piece of software, IMPACT, to estimate the delay saving benefits brought about by the Incident Support Unit service on the M25 Sphere. The estimated delay savings will be converted into a financial value and a benefit-cost ratio established.

3.5.2 Background

Due to the lack of pre Incident Support Unit operational data on the M25 it was not possible to estimate their influence on the delay experienced by motorists. Another method is to use an incident impact estimation model to approximate their effectiveness. Such a model was sourced from the United States called IMPACT which was developed under a research project from the US Federal Highways Administration (FHWA).

A thorough analysis of the IMPACT model was conducted to establish if it could accurately estimate the impact of incidents for the UK motorway system, in particular the M25 London Orbital Motorway.

The model was then be calibrated for British motorways using incident statistics relative to Incident Support Units. Once calibrated for local conditions the delay savings as a result of the ISUs was be converted into a monetary value to enable a benefit cost figure to be established.

The IMPACT model has previously successfully been used by Maas (1998), Maas et al (1998) and Miller and Abkowitz (2000). Maas (1998) and Maas et al (1998) utilised IMPACT to evaluate the benefits of implementing Intelligent Transportation

Systems (ITS) in Northern Virginia, in particularly CCTV, cellular phones in response vehicles, computer aided dispatch screens in response vehicles and global positioning system location for response vehicles. Using IMPACT they estimated that an additional 21 to 46 percent delay reduction is possible with full deployment of selected applications of ITS technology. Miller and Abkowitz (2000) used IMPACT as part of a decision support protocol for a highway incident management system.

IMPACT Model

IMPACT is an empirical computer model of incident occurrence, location and severity, intended for use to estimate the incident impacts expected for freeways, and to quantify the expected changes in incident impact corresponding to proposed alternative traffic and incident management procedures. From estimated delay, other traffic and economic impacts of incidents can be determined, such as increased air pollution and increased fuel consumption (Sullivan (1997), Sullivan and Champion (1995), Sullivan, Taff and Daly (1995)).

The IMPACT software was developed under contract between the Federal Highways Administration (FHWA), US DOT, and Ball Systems Engineering, later subcontracted to California Polytechnic State University at San Luis Obispo.

Designed for cost-benefit analysis and planning applications, IMPACT is a stand-alone Windows computer programme. The programme utilises standard Microsoft Windows file management and help screen facilities and is completely menu driven through the stages of input data specification, solution calculation and output of results. The developers generated the model by collecting and analysing the best available incident, highway geometry and traffic volume data from eight major US cities. A detailed statistical analysis of the incident data was conducted, with the analysis revealing considerable similarities in the patterns in incident frequencies and characteristics that were quantified for these cities. Variations among locations could be explained by variations in traffic conditions, incident response capabilities and other known factors. The empirical relationships captured in the model are

transferable to other locations. Even though IMPACT is fully calibrated, it is possible to substitute the current model calibration with locally suitable or the latest available relationships through the user interface.

The IMPACT model contains four sets of calculations:

- Road capacity,
- Incident rates,
- Incident location and severity,
- Incident duration and delays due to incidents.

The four sub-models join together to approximate the impact of each of seven classes of freeway incidents:

- Accidents and vehicle fires,
- Major mechanical and electrical breakdowns,
- Dropped loads and other debris,
- Vehicle stalls,
- Flat tires,
- Abandoned vehicles,
- Other.

The incident impacts can be viewed under any one of the five Incident Management scenarios:

- No Incident Management,
- Traffic management centre,
- Major incident response team,
- Freeway service patrol,
- User defined.

Calculations are conducted on a road section by section basis, with no spill over effects from one section to the next. Firstly, the incident rate sub-model estimates the number of incidents of each type and then the number is multiplied by the output from the location and severity sub-model. Subsequently each lateral locations and

incident, together with their reduction of capacity, is combined with four percentile values that represent the duration distribution of incidents of a given type, under the chosen incident management scenario. The collection of incident duration and capacity reduction is assessed in the delay sub-model and the annual number of hours of delay estimated for each type of incident.

IMPACT Model Inputs

The freeway section data is entered through the IMPACT user interface (figure 3.7), which provides a screen template, or by directly manually inputting files into the appropriate “.DAT” text file. The following section characteristics variables are required by the IMPACT model:

- Length: The length of the section along the centre line from junction to junction.
- Lanes: Number of lanes (each direction).
- AADT: 2 way Annual Average Daily Traffic flow.
- Peak Period: The total peak period each day, the time for both morning and evening rush hour combined.
- Percent Trucks: The ratio of the daily traffic flow, which is made up by Large Goods Vehicles as a percent.
- K: This is the percentage of the daily traffic which occurs in the peak hour of the day.
- D: This is the directional factor, i.e. the percent of the peak hour traffic in the peak flow direction will default, if not specified, to zero.
- AAWT/AADT: the AAWT is the Annual Average Weekday Traffic, this ratio will account for the fact that the AADT includes data obtained from the weekend.
- Shoulder: This indicates the type of hard shoulder in operation at the facility. IMPACT has four different options: no shoulder, left shoulder, right shoulder and shoulder on both sides of the carriageway. As the model was designed for the US, when choosing the correct shoulder for a UK motorway a right shoulder would be selected.

- **Management:** In order to carry out a cost benefit of a highway management system the model offers a number of different management types for the road network; these are:
 - None
 - Traffic Management Centre Surveillance
 - Incident Response Teams
 - User-Defined (which defaults to the same values as none, unless otherwise inputted)

In addition to the section characteristics a climate model must be calibrated which details the number of dry weather days, wet weather and snow as a percentage.

The basic road section characteristics were obtained from the Highways Agencies Annual report for Area 5 2000 (Highways Agency, 2000) and the HA were consulted regarding other required inputs. Any additional factors that are not available default to values contained as assumptions in the IMPACT model.

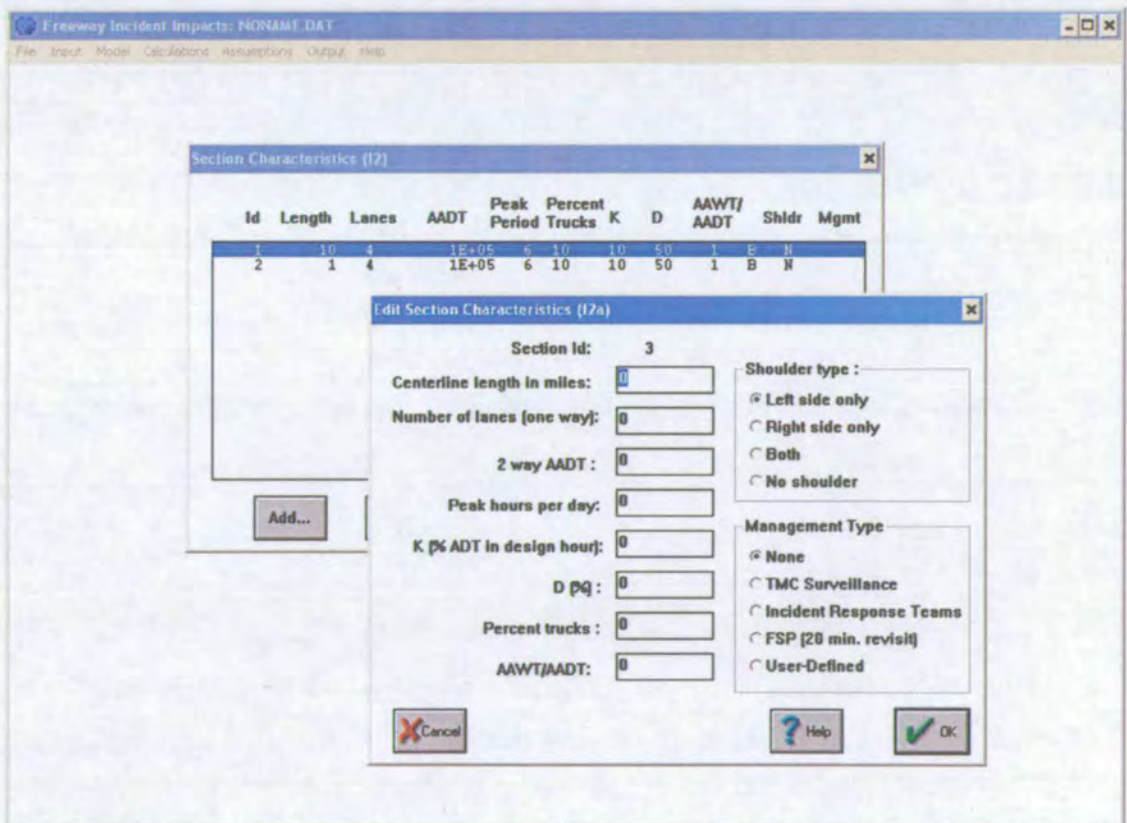


Figure 3.7 IMPACT User Interface

IMPACT Model Calculations

The IMPACT model uses four sets of relationships, which link together in series to estimate the delay impacts of incidents.

The four step modelling framework

1. Incident rate models- Freeway Capacity of a section is calculated which determines which incident rates are used to estimate the number of incidents by type in a time period (peak/off-peak) and weather condition.
2. Incident severity model- The incident severity model is used to estimate how severe an incident will be. It estimates the likelihood that incidents of a given type will block one or more lanes or occur on the shoulders and what the associated effects will be on freeway capacity.
3. Incident duration model- This is used to estimate how long it takes to resolve an incident of a given type and severity.
4. Incident impact model- The Incident impact model is used to estimate the delay due to incidents of a given type, severity and duration.

IMPACT Model Outputs

Each sub-model produces summary statistics that can be viewed independently to ensure consistency.

- The basic calculated capacity for each section.
- The severity model produces a number of incidents for the seven classes listed below:
 1. Abandoned vehicles
 2. Accidents and fires
 3. Debris on the highway
 4. Mechanical, electrical, fuel and cooling system failures – likely to be the most severe disablement's for which vehicles must be towed away

5. Stalled vehicles – largely including out of fuel and similar problems, which may be serious but where brief roadside attention can often get the vehicles going again
6. Tire problems
7. Other, this captures a variety of causes, such as pedestrians and providing information, as well as a host of other rare incident types.

The frequencies of these incidents occurring in each section for the desired time period is determined as well as a total for all the sections, which is summarised at the end of the output.

The severity report details a breakdown of each incident type, the resulting proportion of lanes blocked and the effect this will have on the remaining capacity for each section.

The final output is the delay report, for each section the vehicle/hour delay due to each incident type is detailed, totalling the delay in a summary.

3.5.3 IMPACT Model Calibration

Data Description

The IMPACT model was thoroughly run and compared with US data. The model has been shown to work well for the US highway system (Sullivan et al, 1995), however a comparison must be made to actual results from the M25 motorway. For the comparison the following data was used:

- Carillion ISU CAD data - This data is summarised in section 3.3 above. It details the section of road, incident symptom and date and time of received call. Although the information contains many incident symptoms, only the fields pertaining to accidents, fires, debris and breakdowns were utilised. There is no data on abandoned vehicles or flat tires from Carillion so these are neglected.

- STATS 19 - Road accident data for incidents that caused injury to any person and is completed by the police. It was obtained from the UK data archive at Essex University.
- Weather data - Obtained from the UK Meteorological office on the Heathrow weather station. This detailed rainfall on each day and temperature, fog etc. This allowed a climate model to be set up for IMPACT.
- MIDAS traffic flow data - Traffic flow data from the M25 between junctions 6 to 16 and a small section of the M4 and M40. The MIDAS data was obtained through Mott MacDonald, on behalf of the Highways Agency.
- Highways Agency Annual Report for Area 5 – This contains detailed traffic counts, including details of AADT, AAWT and percentage of LGVs on each section of road.
- DETR data - This is a series of equations that derive accident levels from the total vehicle miles of a particular section of roadway.
- Breakdown data - obtained from the RAC breakdown Service.
- Damage only accident data - obtained from Essex police.

Model Sections

The M25 Sphere road network was divided into individual road sections defined by a number. Each section was classed as each stretch of road between junctions. This was done for all sections of the M25 and the additional M25 Sphere sections.

3.5.4 Initial Run Results

Table 3.5 shows a summary of the IMPACT incident model results and comparison data following the initial model run.

Table 3.5 Initial Model Run Results and Comparison Data.

Incident Type	IMPACT results		Carillion results		DETR results		STATS 19/RAC
	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	
Vehicle-Miles	1.92E+08	9.87E+08					
Accidents and Vehicle Fires	651.59	2265.1	168	97	588.8	487.38	679
Mechanical and Electrical Breakdowns	1557.6	5670.7	77	26	454.548	376.25	487
Flat Tires	1085.7	3787.4			0	0	
Vehicle Stalls	992.28	3820.2			0	0	
Dropped Loads and Debris	222.76	521.73	544	182	1045.27	865.22	
Abandoned Vehicles	2751.3	2622.7			0	0	
Other	608.75	3171.5	224	57	0	0	
Totals	7870	21859	1013	362	2088	1728	1166
Daily Total	29729		1375		3817		1166

The IMPACT model generates far higher incident frequency than any of the comparison data which indicates that the standard incident generation model is not suitable and must be calibrated. This would suggest that the incident frequency is higher on US roads than in the UK roads.

Incident Frequency Calculation

IMPACT uses rates per million vehicle miles to develop the incident statistics. These ratings will differ according to the three following factors:

- Time of day: peak/off-peak.
- Road conditions: wet, dry and snowy.
- AADT/C factor: This falls into three areas <7, 7-10 and >10.
- C is capacity and is obtained using equation 3.3.

$$C = MSF \times N \times f_w \times f_{HV} \times f_p \quad [\text{Eq. 3.3}]$$

Where:

- *MSF* : Maximum Service flow, which is the ideal flow rate per lane under ideal conditions, which defaults to 2000 in the IMPACT model.
- *N* : Two way number of lanes.
- *f_w* : Lane width adjustment factor, which in all sections will be for a right shoulder in the US, a left shoulder in the UK, this defaults to 0.98.

- f_p : Population adjustment factor, which represents the reduction of capacity due to driver behaviour and defaults to 1.
- f_{HV} : heavy vehicle adjustment factor, determined from equation 3.4

$$f_{HV} = 1/(1 + P_i \times E_i) \quad [\text{Eq. 3.4}]$$

Where:

- P_i : Ratio of heavy goods vehicles to other vehicles operating on the section as a percentage.
- E_i : Truck equivalence factor representing the difference in capacity with a truck in comparison to a car.

Before a calculation involving the rates is carried out the model needs the volume of traffic for the peak and off-peak times on the section. These are determined using equations 3.5 and 3.6.

Peak volume of traffic:

$$V_p = AADT \times K \times N_h \times WDPY \quad [\text{Eq. 3.5}]$$

Where

- $AADT$: Annual average daily traffic flow in the section.
- K : Percentage of AADT, which occurs in the peak period.
- N_h : Peak period hours in a day, the am and PM rush hour times combined.
- $WDPY$: Number of weekdays in a year which are non holiday basically the number of recognised workdays a year. Defaults to 250 if ignored in the section characteristics.

Off-peak Traffic volume:

$$V_o = AADT \times (AAWT / AADT - K \times N_h) \times WDPY \quad [\text{Eq 3.6}]$$

Where:

- $AAWT / AADT$: Average annual weekday flow divided by AADT.

The step by step process continues with the final two calculations, which complete the calculation of incident volumes per section. Again there are different equations for rush hour and non-rush hour conditions.

Peak time incident levels:

$$I_{pi} = V_p \times L \times (R_{pci} \times C + R_{pri} \times R + R_{psi} \times S) \quad [\text{Eq. 3.7}]$$

Where:

- V_p : Result of equation 3.5, the peak volume distribution.
- L : Length of the section inputted in the section characteristics.
- C, R, S : ratios of days in the year which experience dry, wet and snowy road conditions respectively. The climate sub model contains this information and can easily be modified.
- $R_{pci}, R_{pri}, R_{psi}$: peak period incident rates for the weather conditions of dry, rainy and snowy respectively.

Off-Peak incident levels:

$$I_{oi} = V_o \times L \times (R_{oci} \times C + R_{ori} \times R + R_{osi} \times S) \quad [\text{Eq. 3.8}]$$

Where R_{pci}, R_{pri} and R_{psi} are off-peak period incident rates for the weather conditions of dry, rainy and snowy respectively.

Revised Incident Frequency

The Carillion data was collated into IMPACT symptoms which were then classed into the three factors (time, weather, AADT/C) which determined ratings. Following the determination of incident frequencies for each incident type and each factor, the following equation (Sullivan, 1995) was used to determine:

$$R = \frac{10^6 I}{D \sum_{S=1}^S (\alpha_S ADT_S L_S)} \quad [\text{Eq. 3.9}]$$

Where:

- R : Incident rate measured in incidents per million vehicle miles.

- I : Number of incidents of a given type that were listed in a group of road sections during peak or off-peak and some specified number of days.
- D : Number of days covered by the incident data.
- s : Number of road sections covered by the incident data.
- ADT_s : The AADT of each road section.
- α_s : the fraction of the AADT that occurs during the time period of chosen rating.
- L_s : the centre line length of the section.

3.5.5 Revised Model Run

The second model run was completed using revised incident rates based on Carillion CAD data. A summary of the revised run is shown in table 3.6.

Table 3.6 Comparison of IMPACT Initial Run and Revised Run.

Incident Type	IMPACT results		IMPACT results		Carillion results	
	Initial Run		Revised Run			
	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak
Vehicle-Miles	1.92E+08	9.87E+08	1.92E+08	9.87E+08		
Accidents + Fire	651.59	2265.1	140.47	115.33	168	97
Mechanical and Electrical Breakdowns	1557.6	5670.7	61.071	34.248	77	26
Dropped Loads & Debris	222.76	521.73	436.63	194.15	544	182
Other	608.75	3171.5	181.29	66.483	224	57
Totals	7870	21859	819.461	410.211	1013	362
Daily Total	29729		1229.672		1375	

The values provide significant improvement on the initial run but the section characteristics can still be modified to improve accuracy.

Section Characteristics Update

Using MIDAS traffic flow data enabled accurate K value and D value to be determined as well as a value for the AAWT. In addition rush-hour times were also verified (peak/off-peak times).

The D values obtained from MIDAS traffic flow data were obtained taking the average of 10 incident free weekdays of data for each section. Where a D value was

not available (i.e. section not with the MIDAS area), the average D value was used, for the M25 it was calculated as 53.81%. For all other sections of motorway the average D value was higher at 56.15%.

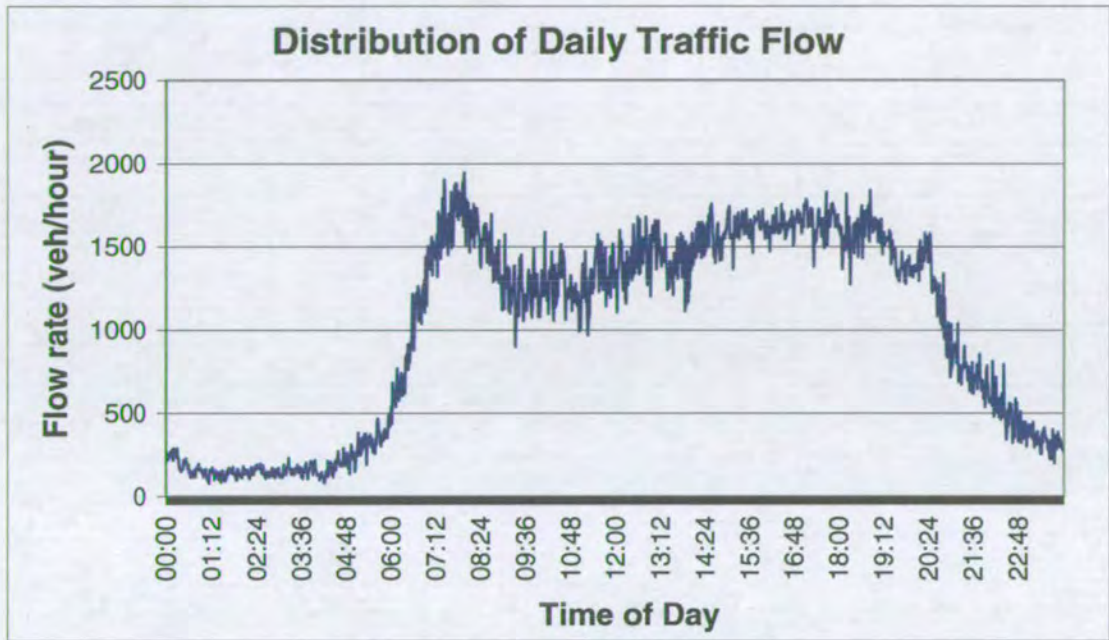


Figure 3.8 Graph of Traffic Flow Throughout The Day

The K values were taken as the average from 10 sets of incident free days. Where a K value for a section is not obtainable the average K value is used, for the M25, 6.6 and 7.5 for other routes.

The average AAWT/AADT value was calculated to be 1.04. This value was kept uniform throughout all sections and was obtained by analysing 4 weeks and 4 weekends of data.

Figure 3.8 shows the average flow for weekdays during the month of September obtained from MIDAS traffic flow data. This confirms the selected peak period.

Revised K, D and AAWT Values

The updated model run was performed with actual K, D and AAWT values determined from MIDAS traffic flow data and demonstrated a marked increase in comparison to the initial model run results. The revised run results are shown in

table 3.7 and demonstrate the improved match but also that considerable differences still remain.

Table 3.7 Comparison of IMPACT Model Runs

Incident Type	IMPACT results		IMPACT results		Carillion results	
	Initial Run		Updated Run			
	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak
Vehicle-Miles	1.92E+08	9.87E+08	1.30E+09	8.00E+08		
Accidents + Fire	140.47	115.33	153.07	93.533	168	97
Mechanical and Electrical Breakdowns	61.071	34.248	66.548	27.774	77	26
Dropped Loads & Debris	436.63	194.15	475.79	157.45	544	182
Other	181.29	66.483	197.55	53.915	224	57
Totals	819.461	410.211	892.958	332.672	1013	362
Daily Total	1229.672		1225.63		1375	

3.5.6 Incident Severity

The incident severity model determines how severe an incident is, with the severity defined as the number of lanes that are blocked by a certain incident.

This stage involves lookup tables, which comprises two parameters ALPHA₁ and ALPHA₂. These are used to redistribute incidents when there is no median or (US) right hand shoulder.

The three look-up tables are:

- Distribution of lateral locations of incidents
- Calibrated percentages of lanes blocked
- Percentage capacity remaining for different severity

Revised Severity Rates

As all road sections of the M25 Sphere analysed included a hard shoulder and did not have any median shoulders, the median shoulder value distribution was set to zero and both ALPHA values were set to 1.

Distribution of Incident Lateral Locations

The average percentage distributions of lateral locations of incidents refer to whether the incident took place in either the hard shoulder or in-lane. From the Carillion CAD data it was possible to revise the original values and these are displayed in table 3.8.

Table 3.8 Lateral Lane Locations of Incidents.

Incident Type	Carillion Data				Original IMPACT Values	
	Frequency		Percentage (%)		Percentage (%)	
	Shoulder	In-Lane	Shoulder	In-Lane	Shoulder	In-Lane
Accidents	138	663	17.23	82.77	60.6	39.4
Debris	1091	1006	52.03	47.97	26.4	73.5
Breakdown	122	97	55.71	44.29	90	10
Other	N/A	N/A	N/A	N/A	95	4.9

The “Other” incident category of the IMPACT model was not used, as there was no possible comparison data.

Percentages of Lanes Blocked

Table 3.9 shows the original values for the impact model regarding lanes blocked during incidents.

Table 3.9 Blocked Lanes During Incidents (Sullivan, 1995)

	# Incidents	1 lane	2 lane	3 lane	4 lane
Accidents	350	80.9%	15.8%	2.7%	0.7%
Debris	82	96.7%	3.3%	0.0%	0.0%
Mechanical	348	97.8%	2.0%	0.0%	0.0%
Other	53	94.3%	5.7%	0.0%	0.0%

As data regarding lane blockages was not available the original IMPACT data was assumed to be correct.

Percentage Capacity Remaining

It was chosen to modify the percentage capacity remaining figures to those reported by Huddart and Thompson (2001) as these were determined by analysing accidents on the M25. These figures are used by the delay model to estimate the volume of

traffic delayed dependent on the severity (number of lanes blocked) by an incident. The updated figures are shown in table 3.10.

Table 3.10 Capacity Reduction by Number of Blocked Lanes (Huddart and Thompson, 2001)

% Reduction	Number of blocked lanes				
	1	2	3	4	5
2x2	75	95			
3x3	60	85	95		
4x4	50	75	90	95	
5x5	40	65	75	85	95

Table 3.11 Indicates the revised capacity figures that were used with the severity sub-model of the IMPACT model. The rates for other incident types were not modified, except for the full lane blockage which was changed to 5%.

Table 3.11 Revised Capacity Remaining Values

Lateral Location	Original width of Roadway							
	4		3		2		1	
	Accident & Debris							
	IMPACT	Revised	IMPACT	Revised	IMPACT	Revised	IMPACT	Revised
Right Shoulder	85	80	83	80	81	80	79	79
1 lane blocked	62	50	53	40	39	25	0	5
2 lanes blocked	26.7	25	18.4	15	0	5		
3 lanes blocked	13.9	10	0	5				
4 lanes blocked	0	5						
	All other Incident Types							
	IMPACT	Revised	IMPACT	Revised	IMPACT	Revised	IMPACT	Revised
Right Shoulder	96	96	90	90	84	84	78	78
1 lane blocked	66.7	66.7	57	57	42	42	0	5
2 lanes blocked	28.7	28.7	19.8	19.8	0	5		
3 lanes blocked	14.9	14.9	0	5				
4 lanes blocked	0	5						

3.5.7 Incident Durations

When defining a road network without any kind of incident support service the IMPACT model used a combined detection and response time of 20 minutes for accidents and in-lane incidents while the remaining incident types have an average

25-minute detection and response time. Table XXX from Sullivan (1995) details the detection and response times for all traffic management scenarios.

Using values for total incident duration for different incident types enabled the generation of the mean and standard deviation values for the total incident duration. Total incident duration was defined as the sum of detection, response and clearance times. A selection of these values is shown in table 3.12.

Table 3.12 Mean and Standard Deviations for Detection and Response Times, Adapted From Table XXX in Sullivan (1995)

Incident Type	Traffic Management System	Incident Location			
		Shoulder		In-Lane	
		Mean	STD	Mean	STD
Accidents	None	39.72	33.35	47.09	40.17
	TMC	31.72	26.63	39.09	33.35
	IRT	31.72	26.63	39.09	28.35
Mech./Elec.	None	41.63	30.59	38.65	30.54
	TMC	31.36	23.2	30.65	24.22
	IRT	31.36	23.2	30.65	24.22
Other	None	38.19	36.14	34.69	26.56
	TMC	28.19	26.67	26.69	20.43
	IRT	28.19	26.67	26.69	20.43
Debris	None	31.29	39.46	29.64	33.98
	TMC	21.29	26.85	21.64	24.81
	IRT	21.29	26.85	21.64	21.09

It should be noted that the difference of in-lane standard deviation between Traffic Management Centre (TMC) and Incident Response Teams (IRT) for accidents and debris is due to a 15% factor introduced due to the result of improved traffic management, being introduced to ease traffic flow around major incidents (Sullivan, 1995).

To represent the differences in incident duration between various incident severities, four percentiles are calculated to model the incident duration, these are the 20th, 55th, 80th and 95th. These values represent the lowest 40%, the following 30%, 20% and finally the highest 10% of incident durations. Guiliano (1988) states that the characteristics of incident duration take the form of the lognormal distribution and this is the approach has also been adopted in the IMPACT model.

Incident Detection and Response Time

The average response time for the M25 was estimated by Essex police who stated that it took them 20 minutes to detect and respond to a motorway incident (Essex Police, 2003). Other than this data, the UK incident timing statistics are very limited in contrast to the United States.

A US Department of Transport report on incident Management (USDOT, 1998) stated that introducing incident response units on to a motorway system reduced detection and response times by, on average 20%. This value is supported by a report on incident response units implemented in San Antonio which also suggested a 20% reduction (TransGuide, 2001). A more conservative value for the implementation of active incident response units suggests a reduction in accident detection time of 2 minutes (Sreedev & Picado, 2001).

Incident Duration

Data on incident duration times is more easily obtainable. A summary of information from report cited by the Transportation Research Laboratory, TRL Report PR/TT/141/95 (Huddart and Thompson, 2001), is detailed in table 3.13. Unfortunately the standard deviation could not be obtained from this report as it only detailed mean and median.

Table 3.13 TRL Report on Incident Duration

Incident Type	Duration	
	Mean	Median
Accidents	38 minutes	15 minutes
Breakdown	20 minutes	11 minutes
Debris	12 minutes	10 minutes
Fire	101 minutes	43 minutes
Load shedding and spillages	70 minutes	40 minutes

The US also have large volumes of data on incident duration reduction due to freeway service patrols, a study in Atlanta showed a 38% reduction in incident clearance due to the implementation of Highway Emergency Response Operators (HEROs) (Presley and Wyrosdick, 1998).

Table 3.14 Revised Mean and Standard Deviation for Incident Detection and Response

Incident Type	Traffic Management System	Incident Location			
		Shoulder		In-Lane	
		Mean	STD	Mean	STD
Accidents	None	39.72	33.35	47.09	40.17
	ISU	37.72	31.67	45.09	32.69
Mech./Elec.	None	41.63	30.59	38.65	30.54
	ISU	36.36	26.72	36.65	28.96
Other	None	38.19	36.14	34.69	26.56
	ISU	33.19	31.41	32.69	25.03
Debris	None	31.29	39.46	29.64	33.98
	ISU	26.29	33.15	27.64	26.93

The percentiles were then re-calculated using the new incident duration values listed in table 3.14 and these are shown in table 3.15.

Maas (1998) stated a list of mean reductions in incident duration due to a range of technologies on board freeway service patrols and at the traffic management centres, in this case the Network Control Centre at Hatfield. With the technology on board the ISUs, the report stated a reduction of up to 9 minutes in mean incident duration.

After analysing all the information presented above, table 3.12 was revised to include updated incident duration mean and standard deviations and is shown in table 3.14. The base values of IMPACT for incident type “none” are used as a base reducing incident detection and response by 2 minutes for accidents and 5 minutes for other incident types. The mean was not altered with the TRL values above, as the duration times were not broken down into shoulder and in-lane.

Table 3.15 Revised Incident Durations Percentiles by Incident Type and Lane Blockage

Incident Type	Lanes Blocked	
	Shoulder	In-Lane
Accident and Fire		
20	0.230674	0.380656
55	0.502315	0.677446
80	0.89484	1.039014
95	1.711335	1.679565
Mechanical and Electrical		
20	0.297224	0.254517
55	0.540441	0.513494
80	0.842192	0.864373
95	1.385969	1.551185
Debris		
20	0.076285	0.126577
55	0.245176	0.323889
80	0.583019	0.650356
95	1.542144	1.422709
Other		
20	0.160523	0.24324
55	0.398892	0.470034
80	0.783735	0.766307
95	1.673141	1.326679

3.5.8 Incident Delays

The final part of the model uses the outputs of the three sub-models and estimates the total delay on the road network from a particular incident type for the desired time period. It uses the distribution shown below in figure 3.9 to model the queuing of traffic at a specific incident and hence obtain a delay time. This is obtained by first

generating the graph of traffic volume distribution, which is then converted to a cumulative volume/capacity (V/C) distribution. A nine-degree polynomial equation was developed to best describe the cumulative V/C distribution (the build up of traffic). The polynomial parameters are changeable and located in the assumptions sub-menu.

Equation 3.10 shows the 9 degree polynomial equation.

$$V(t) = a_0 + a_1t + a_2t^2 + a_3t^3 + a_4t^4 + \dots + a_9t^9 \quad [\text{Eq. 3.10}]$$

where:

- $V(t)$: cumulative value of traffic arriving at a time of the day t .
- a_0 : values that represent the polynomial parameters. Different parameters exist for different combinations of AADT/C and K*D values.
- t : evaluation time for which the above distribution is calculated. Each K*D value and off-peak/peak situation has different evaluation times.

For the original IMPACT data, in general it was found that the 9th degree polynomials achieved good approximations to the original cumulative distributions (Sullivan, 1995).

The evaluation times are the last of the assumption sub-menu's and these are selected to provide a representative sample of times of the day and the proportion of incidents that occur at these times, hence giving different delay impact consequences. Table 3.16 illustrates the original values for the K*D value <0.425.

Table 3.16 IMPACT Values for Evaluation Times and Proportion Ratings.

Off-Peak		Peak	
Evaluation Time (m)	Proportion of incidents	Evaluation Time (m)	Proportion of incidents
4	0.019	17	0.183
10	0.192	15.5	0.174
12	0.173	18.5	0.153
14	0.211	14.75	0.138
19.5	0.269	16.25	0.18
22.5	0.137	17.75	0.171

Traffic Volume Distribution K*D ≤ 425

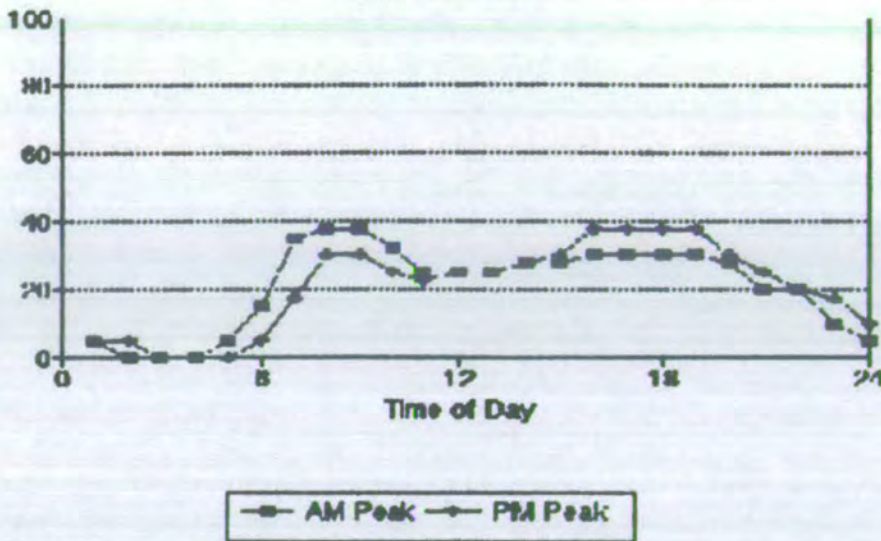


Figure 3.9 IMPACT Graph of Traffic Volume Distribution (Sullivan, 1995).

Using MIDAS traffic flow data it was possible to create traffic volume distributions, for comparison with the original IMPACT versions. Figure 3.9 shows the original IMPACT graph for $K*D \leq 0.425$ and figure 3.10 shows the graph from the M25 Sphere for the same $K*D$ value.

The two-graph peaks are at approximately the same points but the IMPACT graph does not maintain the same volume of flow between the two peak periods. Hence the polynomial parameters were refined, as this is one of the key characteristics on the M25 and will mean delay in this time period is subsequently underestimated using IMPACT values.

Due to the high flows in the M25 area of the MIDAS zone all sections fall within the range $K*D \leq 0.425$ and $AADT/C > 11$, apart from section 9 where $AADT/C$ is in the range of 7-11. The additional sections of network not on the M25 ring, have $K*D$ values which fall into the IMPACT defined ranges of $K*D \leq 0.425$ and $0.425 < K*D \leq 0.475$. These sections have $AADT/C$ values in all four ranges; in total seven new graphs to adjust the polynomial parameters were required. The

cumulative Volume/Capacity values could then be obtained from the new traffic volume distributions. Unfortunately these graphs were generated in Microsoft Excel where only a 6 degree polynomial equation could be produced. These values did still however generate acceptable results.

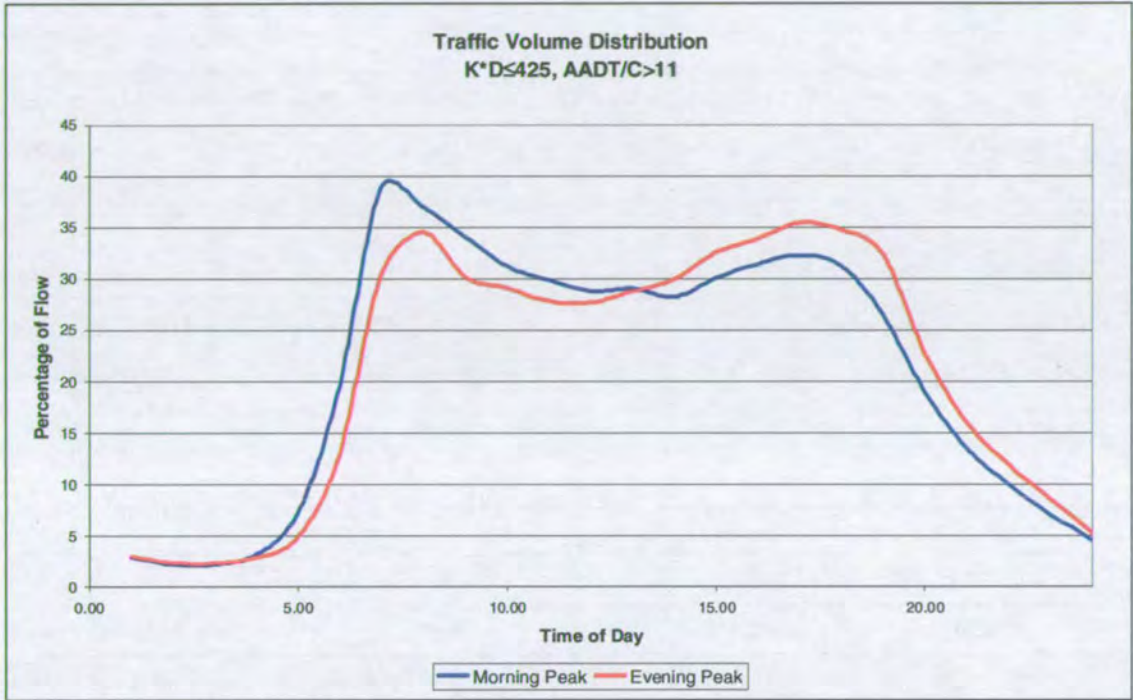


Figure 3.10 Example of M25 Traffic Volume Distribution.

The evaluation times were the final part that required modification. Table 3.17 details the new evaluation times derived for the $K \cdot D$ values of, ≤ 0.425 and $0.425-0.475$.

Table 3.17 Revised Evaluation Times and Proportions Ratings.

K*D, ≤ 0.425				K*D, 0.425 - 0.475			
Off-Peak		Peak		Off-Peak		Peak	
05:00	0.049	06:30	0.086	05:00	0.025	06:30	0.034
10:00	0.293	07:30	0.118	10:00	0.350	07:30	0.172
12:00	0.267	08:30	0.244	12:00	0.188	08:30	0.345
15:00	0.223	17:00	0.217	15:00	0.225	17:00	0.276
20:00	0.100	18:00	0.231	20:00	0.125	18:00	0.103
23:00	0.067	19:00	0.104	23:00	0.088	19:00	0.069

3.5.9 Model Error Identification

While analysing the initial runs of the IMPACT model an error was discovered. It was observed that sections with lower AADT and incident frequency were generating higher delay figures, which should not occur.

Following an extensive investigation into this it was discovered that the delay model was selecting the incorrect polynomial parameters from the lookup assumption menu. To remedy this, the lookup procedure was derived and polynomial parameters inputted into where the model would actually look for them rather than where it was supposed to look. This meant an analysis could still be implemented to create an accurate delay value. Table 3.18 details where the model actually looks for certain values.

Table 3.18 Actual Polynomial Parameter Lookup Table Locations

Actual Polynomial Parameters		Location	
K x D	AADT/C	K x D	AADT/C
<0.0425	> 11	0.0475 – 0.0625	< 5
<0.0425	7 - 11	0.0425 – 0.0475	< 5
<0.0425	5 - 7	<0.0425	5 - 7
<0.0425	< 5	<0.0425	< 5
0.0425 – 0.0475	> 11	0.0475 – 0.0625	5 - 7
0.0425 – 0.0475	7 - 11	0.0425 – 0.0475	5 - 7
0.0425 - 0.0475	5 - 7	< 0.0425	7 - 11

3.5.10 Final Model Run and Incident Delay Estimation

The final model runs were performed in two stages for the two management types- “none” and “user defined” values. The summary of expected motorist delay is shown in table 3.19.

Table 3.19 Comparison of Incident Delay.

Incident Type	No Incident Management		With Incident Support Units	
	Off-Peak	Peak	Off-Peak	Peak
Accidents and Vehicle Fires	6.90E+05	2.71E+05	6.10E+05	2.48E+05
Mechanical and Electrical Breakdowns	7.95E+04	1.78E+04	7.31E+04	1.65E+04
Dropped Loads and Debris	5.61E+05	1.06E+05	4.87E+05	9.59E+04
Other	9.03E+04	8.51E+03	8.13E+04	7.75E+03
Totals	1.42E+06	4.03E+05	1.25E+06	3.68E+05
Daily Total	1.82E+06		1.62E+06	

The total delay with no incident management was estimated as 1.82×10^6 veh./hours. The total delay with Incident Support Units was estimated as 1.62×10^6 veh./hours. Therefore a saving of 200,000 vehicle/hours per year is obtained, which is equivalent to an 11% reduction in delay due to incidents on the M25 Sphere.

3.5.11 Benefit-Cost Estimation

Now that a motorist delay saving due to Incident Support Units has been estimated using the IMPACT model a monetary value for this can be established. The average cost of delaying a vehicle is taken as £7.84 (Huddart and Thompson, 2001), based on 1994 prices. This figure has been sourced from Department for Transport survey figures for the whole of Britain, detailing the costs of travel. To convert this value into 2005 prices the Retail Price Index (RPI) was used as an efficient rate to base an updated value on. Therefore:

- Retail Price Index (RPI) in 1994 was 144.1,
- Average RPI value so far for 2005 is 191.06 (Wolfbane, 2005)

Therefore the cost saving from Incident Support Units on the M25 Sphere can be calculated as:

- The approximate cost for delaying a vehicle for an hour in 2005 will therefore be: $(191.06 / 144.1) \times 7.84 = \text{£}10.40$
- Hence, the total saving as a result of Incident Management on the M25 Sphere for 2005:

$$= 10.40 \times 200,000$$

$$= \text{£}2.08 \text{ Million per year.}$$

The contractual cost to the Highways Agency of providing the Incident Support Service on the M25 Sphere is £1.6 million. Using this value, the Benefit-Cost ratio of providing the Incident Support Service is 1.3.

This value represents a 30% return on the investment in the ISU service on the M25 Sphere. The figure is however considerably lower than those established for US incident management programs.

Further investigation would be required to understand exactly why this difference exists but possible reasons include:

- Differing capital costs- vehicle costs are less in the US and additionally smaller and cheaper vehicles are generally used in the US.
- Running costs including fuel price and operative costs differences,
- Differences in the relative delay values,
- Different service objectives- for example the benefits gained by assisting broken down motorists in US,
- Limitations of IMPACT model,
- Over-estimation of benefits in US assessment methodologies,
- Underestimation of ISU services- for example benefit of additional road maintenance undertaken while on patrol.

3.5.12 Discussion

Incident Frequency Model

The model has been used to predict incident frequency on sections of highway through out the Unites States, however in application to the UK road network there appears to be limitations:

- When IMPACT is run with no modifications to its parameters, the results show the model greatly over-estimates the number of incidents. This would be expected when compared to the Carillion CAD data, as this is not the actual number of incidents that occurred on the network, but merely those incidents that their ISUs attended. The case is the same with the STATS19 data and RAC breakdown data, as only accidents involving

injured persons are logged in STATS19 and the RAC attend approximately 34% of breakdowns on the M25 Sphere. The DETR data is the one accurate source for the UK road system, the comparisons here are poor, with only the off-peak accident volumes similar. Interestingly the DETR values for debris are larger than IMPACT, but agrees with the Carillion CAD data rates.

- The results of the initial run would imply that the level of incidents on American roads is considerably higher than in the UK and certainly additional literature would support this view.

The revision of the model was carried out in two stages: first the ratings that generate the volume of incidents were modified; and secondly the section characteristics were updated as accurately as possible, using the MIDAS traffic flow data. The ratings were altered using the Carillion CAD data and hence any comparison of output results would be against this data. As was expected, this revision of ratings produced far more suitable incident volumes, which related closely to the original Carillion values in terms of the total M25 Sphere. The updating of the section characteristics had the effect of generating better results for each individual section, but the total number of incidents on all sections stayed constant.

Incident Severity Model

Two types of changes were made to the severity model: capacity remaining values were updated to values from more recent and suitable studies and the values were adapted to fit the types of incidents that ISUs attended.

One of the biggest alterations made to the severity model was in the incident locations (hard shoulder or in-lane). The primary reason being ISUs are far more likely to be notified for an incident which is in-lane and causing a much greater delay.

Although the model deals with reduction in capacity in the carriageway that is affected by the incident, it does not account for the reduction in capacity, through

rubbernecking, to the opposite carriageway during an incident. This will be a result of curious drivers slowing down for a closer look and this figure has been quoted as high as 30% for major incidents (Huddart & Thompson, 2001). A recommendation in the IMPACT user guide (Sullivan, 1995) suggests that capacity remaining is revisited and hence the determination to update these values with a more recent report in this case Huddart and Thompson (2001).

Incident Duration Model

The incident duration sub-model is the section where the effects of different types of incidents are modelled. Their duration will decrease with quicker and more efficient incident management.

Incident Delay Model

The most significant issue with the delay model is with regards to the model incorrectly looking up the polynomial parameters. This is unfortunate, as it undermines what is essential a good procedure for determining traffic delay. The problem was corrected and the model was run using the correct polynomial parameters.

The M25 only really has one peak period and that is from 6 am to 7pm. The traffic flow only drops slightly after morning rush hour, but effectively there is a 13-hour peak period on the M25. This means the cumulative traffic distribution will rise more steeply and requires updating. Again, the fact that the polynomial parameters are arranged in the class of AADT/C means that the majority of M25 sections will fit easily into the top bracket. This gives further reason to suggest that the IMPACT model results reduce in accuracy when dealing with highway sections that have a very high traffic flow.

If the model was to be used to analyse separate sections and the operator had access to MIDAS traffic flow data or the equivalent, it would be possible to model individual sections with individual polynomial parameters. This would increase the delay result accuracy. While analysing the individual sections it was found that

several sections have very different cumulative traffic distribution, but both would fall under the same category in the IMPACT model.

There is no way to compare the delay figures for ISU attended incidents, for two main reasons. Delay is particularly hard to record, and any values that are available will be for all incidents - so it is difficult to put a figure on the proportion of incidents ISUs attended.

It must be emphasised that the delay value reductions are thought to be very conservative and the resultant delay reduction is therefore probably considerably lower than actual results. The reduction in incident duration as a result of implementation Incident Support Units is thought to be particularly conservative.

IMPACT Model Limitations

The first issue which has to be addressed is the problem with the incorrect lookup of the polynomial parameters. This initially caused considerable problems and a new user without knowledge of the model may not identify the problem.

It was felt that the original incident rates are not suitable for any area of UK roads, even if every actual incident that occurs is to be modelled.

Impact only works for 250 days when Incident response units in this country are available all the time, 365 days a year.

Incident Support Units will not attend every incident and it is safe to assume that this is also experienced in the US yet no facility in the model is available to enter a percentage of total incidents attended. This would also enable the evaluation of for example a reduced service on the weekends.

IMPACT takes no account of traffic build up it effectively models each section as one road and delay build up in adjoining motorway sections is not taken into consideration.

3.5.13 Section Summary

Using statistical trends between freeway incidents in the United States a model for estimating incident induced delay, IMPACT, was developed. This US model was modified and updated for use on the British motorway network and an analysis completed, detailing the impact of Incident Support Units on the M25 Sphere.

The following conclusions were drawn:

- IMPACT can be successfully adapted for use on the UK motorway network.
- It was estimated that ISUs reduced delay due to attended incident on the M25 by approximately 200,000 vehicle hours, or 11%.
- This estimated delay saving equates to £2.08 million savings per year and an approximate benefit/cost ratio of 1.3:1. This shows that the ISU service is beneficial and that deployment and support of this service should be continued.

3.6 Chapter Conclusions

This chapter has presented a review of the ISU service on the M25 Sphere, operated by the HA's service provider, Carillion plc, including quantitative (analysis of incident data) and qualitative examinations (via questionnaire survey) and a benefit-cost estimation. Conclusions for each section are detailed below.

Section Three

An examination of historical ISU records was undertaken to reveal an insight into the activities of ISUs on the M25 Sphere road network. The following are the key points that can be concluded from the analysis undertaken:

- An overview of the characteristics of incidents attended by ISUs on the M25 Sphere road network for the period between September 2001 and August 2003 has been shown. Incident frequency, timings and locations were examined.

- ISUs attended on average 24 incidents per day. However a maximum of 76 support requests were received on one day, showing the variability of demand.
- Most ISU requests, 24%, were for debris clearance.
- The average response time for all ISUs was 12.5 minutes. This is considerably shorter than the contractually required 20 minute response time.
- The frequency of support requests from the emergency services has steadily increased since the introduction of ISUs in September 2001. This shows the increasing recognition given to the ISUs by the emergency services.

Section Four.

The results of a qualitative questionnaire survey of ISU operatives and police officers regarding the benefits of the ISUs were presented. The opinions of police officers on the M25 have been captured at a time when the majority are still familiar with the operations prior to ISUs, allowing a baseline of the officers' opinions to be established for future assessments. A better understanding of what police officers see as the programme's strengths, areas where officers are less convinced and specific suggestions for improvement are now known. In particular, the following can be drawn:

- A positive response towards the ISU service on the M25 was received from the surveyed police officers.
- Overall feedback regarding the ISUs was positive and it can be concluded that the ISU service provided on the M25 is of benefit.
- Improvements could be made between ISU operatives and police officers, thereby improving efficiency and effectiveness. Additionally further training will now be offered to ISU operatives to improve safety.
- Significant feedback has shown that future developments should focus on (1) Improved direct communications; (2) Improved use of mobile variable message signs and electric light arrows; and (3) improved integrated training between the various emergency and response services.

- It is suggested that future work should include a repeat of the presented survey to continually assess performance.

Section Five

The cost effectiveness of the ISU service was investigated using an incident impact computer programme, IMPACT, which utilised statistical trends between freeway incidents in the US to estimate incident induced delay. The model was modified and updated for use on the British motorway network and an analysis completed, detailing the impact of ISUs on the M25 Sphere. The following can be drawn from the analysis:

- IMPACT can be successfully adapted for use on the UK motorway network.
- It was estimated that ISUs reduced delay due to attended incident on the M25 by approximately 200,000 vehicle hours, or 11%.
- This estimated delay saving equates to £2.08 million savings per year and an approximate benefit/cost ratio of 1.3:1. This shows that the ISU service is beneficial and that deployment and support of this service should be continued.

The ISU service has been reviewed and evaluated to facilitate an improved understanding of the programme benefits and effectiveness allowing for continual improvement, and in summary, it has been found that there is both a qualitative and quantitative material benefit to the ISU service.

4 Analysis of Incidents on Motorways

4.1 Introduction

The activities of Incident Support Units on the M25 Sphere were examined in chapter 3, but what is not known is their involvement in relation to all incidents that they are not required to attend. To fully understand the influence and role of ISUs on the M25 Sphere a detailed study of all incidents which occur on the road network was undertaken. To enable this, motorway incident data was collected by the author through observing motorway operations at a police control room.

This chapter will involve the collection and examination of motorway incident data.

This chapter is structured as follows:

- **Section Two.** A background and literature review is presented on incident analysis on motorways and freeways.
- **Section Three.** The collection and analysis of motorway incident data from Surrey Police's Godstone motorway control room is examined to establish an accurate representation of incidents on motorways.
- **Section Four.** To provide a larger data set for the analysis of incidents, historic matrix signal activations were examined and an analysis presented.
- **Section Five.** Chapter summary and conclusions.

4.2 Background

There is limited literature on incident analysis on motorways in Britain, with the exception of Roberts et al (1994). Their study, in 1992 and 1993, provides a review of incidents on British motorways. They assessed incidents at 10 motorway control rooms, to establish incident rates and durations on motorway links for the then U.K. Department of Transport. Multi-channel time-lapse video from CCTV cameras and historical police records were used.

There is more information available on US freeway incident characteristics (Pal et al (1998), Skabardonis et al (1997), Giuliano (1989), Jones et al (1991), Golob et al

(1987), Skabardonis et al (1999) and Bertini et al (2004)). Other studies for major cities in the US have been useful sources of information as reported traffic conditions are similar to that of the M25. However, many were carried out in the 1960's and 1970's (Skabardonis et al, 1997) when drivers and vehicles were very different. More recent studies into the characteristics of incidents were undertaken in Seattle (Jones et al., 1991), Portland (Bertini et al., 2004) and Los Angeles (Skabardonis et al (1997), Giuliano (1989), Golob et al (1987), Skabardonis et al (1999)). These studies used archived incident records as data whereas Skabardonis et al (1997 and 1999) collecting comprehensive field data, using probe vehicles, to determine incident and accident patterns. This data will be referred to in more detail within the analysis and comparison.

4.3 M25 Motorway Incident Analysis

4.3.1 Introduction

Due to the lack of any recent motorway incident analysis in Britain a significant data set was collected and a comprehensive investigation undertaken. The following incident data was recorded by the author at a police motorway control room and the analysis presented below.

4.3.2 Godstone Motorway Incident Data

The data, for this study, were collected through observations, using closed-circuit television (CCTV), at Surrey Police's Godstone Motorway Control Room. A total of four weeks (28 days) of incident data was collected from between November 5th to December 11th. Every day, incident information was collected for a 12 hour period between 7am and 7pm. This time period was chosen as it covered the majority of the morning and evening travel peaks.

Godstone Motorway Control Room manages Surrey Police's strategic roads which include the M25, M23, M3 and other major trunk roads. This study is however only concerned with incidents that occurred on their section of the M25, between Clacket Lane Motorway Services (marker post 4335) and junction 14 (marker post 4919) and is approximately 58.4 kilometres (36.3 miles) long. The road section under

examination can be seen in figure 6.17. The annual average daily traffic (AADT) over the study area ranged from 140,000 to 200,000 vehicles per day.

The complete survey area is covered by an extensive network of CCTV cameras, emergency roadside telephones (ERT), gantry matrix signals for speed and lane controls and variable message signs (VMS). The matrix signals are used by the Motorway Incident Detection and Automatic Signalling (MIDAS) system. The MIDAS system covers the area between junction 6 and junction 16 and uses information on flows, speed and occupancy from a large number of inductive loop detectors, spaced at approximately 300 and 500 metres, to trigger and impose speed limits on that section through the overhead gantry matrix signals and VMS. This is known as the variable speed limit zone and attempts to “smooth-out” the traffic flow, thereby reducing the stop-start and wave effect brought on by heavy traffic flow. In theory, this should create a more efficient network, keep congestion at a minimum and improve safety. The data recorded from loop detectors used by the MIDAS system have also been collected. Prior to data collection an extensive survey of previous incident management evaluation studies was conducted to evaluate the data requirements. Certain data fields that were sought were unfortunately prohibited by Surrey police due to data protection and security issues.

When an incident was notified to the control room or found by them, the following information was recorded on incident characteristics:

- Time of notification,
- Type of incident (Breakdown, Accident, Debris, Vehicle Fire, Animal, etc.),
- Time travel lanes were cleared,
- Time incident was cleared,
- Day of week,
- Method of notification,
- Location (Marker post, direction, junctions, lane),
- Number of lanes blocked,
- Weather conditions,
- Light conditions,

- Road conditions,
- Length of queue (if available),
- Occurrence of secondary accidents,
- Whether an ISU was required,
- Time of ISU request and arrival,
- Type and number of vehicles involved,
- Any other relevant details (times of matrix signal activations and settings, VMS messages and timings, Type, number and timings of emergency and recovery vehicles at incident scene, etc.).

For the duration of data collection period a total of 732 incidents were notified to the control room and recorded. As this study is only interested with incidents that occurred within Surrey police's section of the M25, only these incidents will be examined, giving a total of 450 incidents for the study area throughout the study period.

4.3.3 Incident Data Analysis

The data collected and described above can be investigated and analysed to provide greater insight into the occurrence of incidents on the M25. This data can be investigated in four separate areas:

- Incident Frequency,
- Incident Durations,
- Incident Locations,
- Incident Support Unit Involvement.

Each of these four areas will be discussed below providing conclusions where applicable.

Incident Frequency

The incident records were analysed to derive the incident type proportions and summary statistics are shown in table 4.1 and figure 4.1.

Table 4.1 Overall Incident Type Frequency and Locations

Type of Incident	H/S	%	In-Lane	%	Slip Road	%	Unknown	%	Total	%
Breakdowns	247	84.9%	39	13.4%	5	1.7%	0	0.0%	291	64.7%
Accidents	49	53.8%	41	45.1%	1	1.1%	0	0.0%	91	20.2%
Debris	3	7.3%	35	85.4%	1	2.4%	2	4.9%	41	9.1%
Pot Holes	0	0.0%	9	100.0%	0	0.0%	0	0.0%	9	2.0%
Animals	1	20.0%	3	60.0%	0	0.0%	1	20.0%	5	1.1%
Vehicle Fire	2	40.0%	3	60.0%	0	0.0%	0	0.0%	5	1.1%
Medical	3	100.0%	0	0.0%	0	0.0%	0	0.0%	3	0.7%
Pedestrian	2	100.0%	0	0.0%	0	0.0%	0	0.0%	2	0.4%
Abandoned Vehicles	0	0.0%	0	0.0%	1	100.0%	0	0.0%	1	0.2%
Obstruction	0	0.0%	1	100.0%	0	0.0%	0	0.0%	1	0.2%
Suicide	0	0.0%	1	100.0%	0	0.0%	0	0.0%	1	0.2%
Total	307	68.2%	132	29.3%	8	1.8%	3	0.7%	450	100.0%

Figure 4.1 shows the breakdown of incident types. For the study period there were 291 breakdowns that accounted for approximately 64.7% of all incidents and were followed by accidents at 20.2% and debris with 9.1% of the total 450 incidents. The estimated incident rate for the study area was 2.32 incidents per million vehicle km (3.74 incidents per million vehicle miles). In comparison, in the US, Bertini et al (2004) found that breakdowns accounted for 50% and accidents accounted for 15% of all incidents and Skabardonis et al (1999) found 86.6% of incidents were breakdowns and 6.5% were accidents. As Skabardonis et al (1999) used probe vehicles, patrolling the highway looking for incidents, instead of CCTV, for data capture, they would have witnessed more breakdowns than this study. On the M25 only breakdowns notified to the control room were logged, hence the smaller number of breakdowns. This highlights a difference in the recording of the incident data.

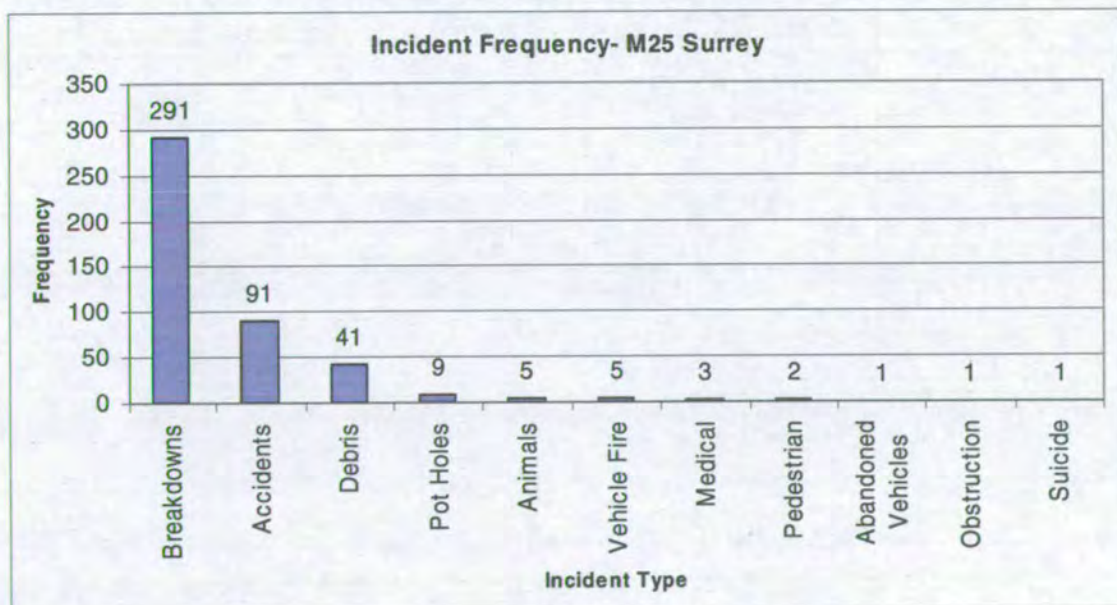


Figure 4.1 Breakdown of Incident Types.

Table 4.1 illustrates the type and the lateral locations of incidents on the carriageway. The locations are classified as to where the incident was first observed. Incidents may have occurred in the live lanes but by the time it was detected and verified the incident may have cleared to the shoulder. It can be seen that the predominant incident type recorded was breakdowns on the hard shoulder, approximately 55% of all incidents. In-lane accidents accounted for 45.1% of all accidents and 9.1% of all incidents. Approximately 29.3% of all recorded incidents occurred in-lane and had the potential to cause delay to motorists. The majority of accidents, 61.6%, involved only two or less vehicles and 80.2% of accidents involved three or less vehicles. A total of 50.5% of accidents involved a Large Goods Vehicle (LGV) and 34% of all accidents included a foreign LGV, which is very concerning as they comprise less than 10% of the LGV traffic. Foreign LGV's however only accounted for 1.37% of all breakdowns with LGV's accounting for 5.84%.

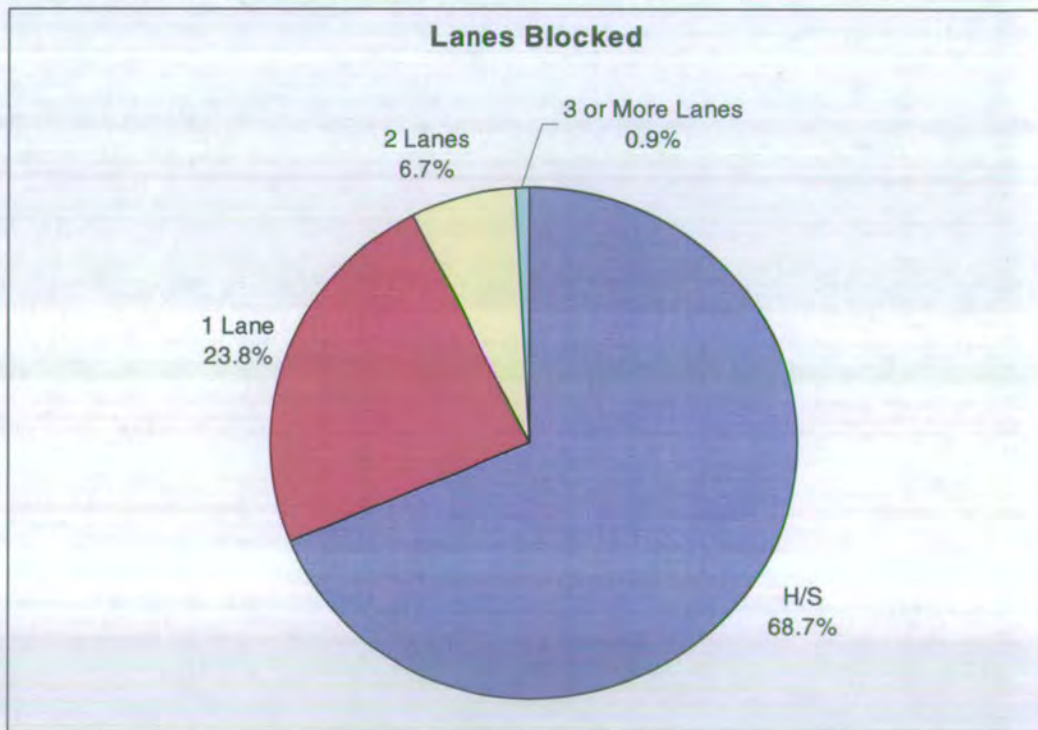


Figure 4.2 Lanes Blocked by Percentage.

In contrast, in the US, Skabardonis et al (1999) observed that the proportion of in-lane incidents was approximately 10.7% on I-10, Skabardonis et al (1997) on I-880 showed 4.6% occurred in-lane and FHWA (Lindley (1986)) also presented values of approximately 4%. Bertini et al (2004) however observed 29.3% in-lane incidents

using historical data from the Portland area. Roberts et al (1994) estimated that 6% of incidents occurring on the motorway network had the potential to interfere with free-flowing traffic in the running lanes. Skabardonis et al (1997) do admit that if CCTV had been used to observe incidents, rather than probe vehicles, the number of in-lane incidents would have been higher.

The percentage breakdowns of lanes blocked by noted incidents are shown in figure 4.2. As shown, 69% of incidents blocked only the hard shoulder and only 7.6% of lane blocking incidents blocked two or more lanes. Less than 1% of incidents blocked 3 or more lanes which is much lower than Bertini et al (2004) who reported that 3% of incidents blocked all lanes.

An average of 16.1 incidents/day were observed during the study period, within the study area, with an average of 10.39 breakdowns and 3.25 accidents per day. For each collection day there were on average 2.32 incidents per million vehicle-km (3.73 incidents per million vehicle-miles). The number of incidents was approximately the same for each direction of the study area with only 3.5% difference between clockwise and anti-clockwise carriageways.

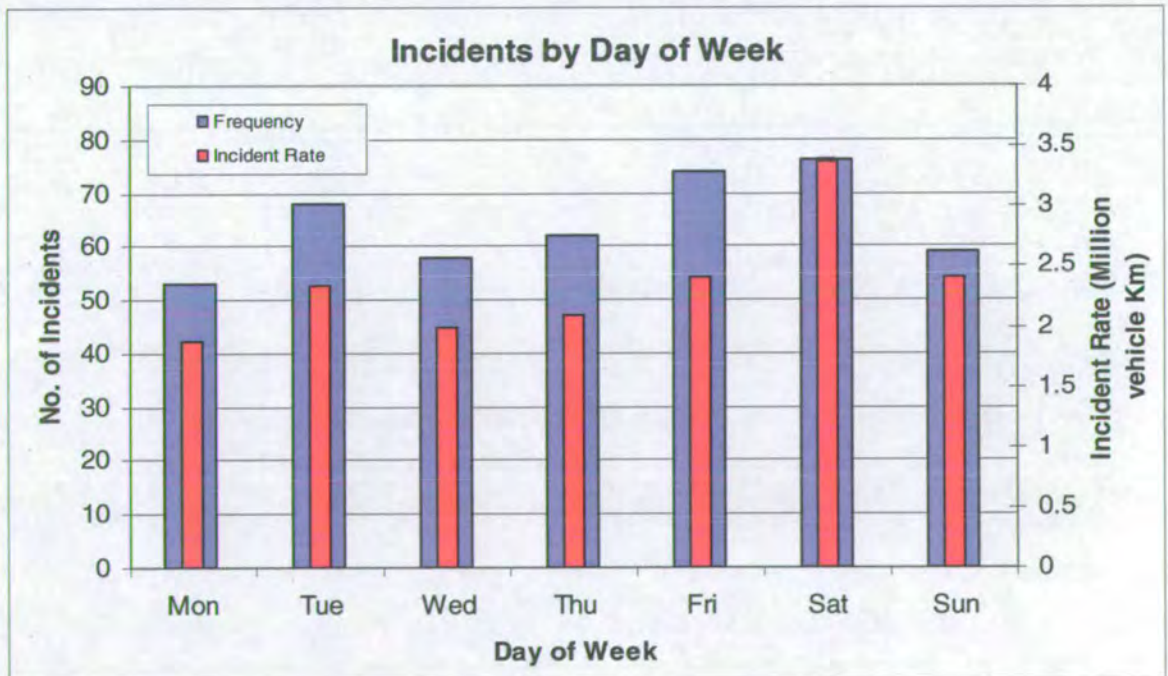


Figure 4.3 Incidents by day of Week.

Figure 4.3 shows the variability of recorded accidents by days of the week. The plot of data shows, for weekdays, that the larger numbers of incidents occur on Fridays with 74 incidents or 16.4% of all incidents in the study period. This is expected as more vehicles use the M25 on a Friday than on any other day and gives an incident rate of 2.41 incidents per million vehicle-km (3.88 incidents per million vehicle-miles). It can also be seen from figure 4.3 however that, unexpectedly, there are more incidents on a Tuesday. This requires further investigation with a larger data set to fully understand the influence of days of the week on the frequency of incidents.

Also unexpectedly there are more incidents on Saturdays than any other day of the week giving an incident rate of 3.36 incidents per million vehicle-km (5.42 incidents per million vehicle-miles). With Sunday also very high compared to weekdays, this may be due to the fact that motorists using the M25 at the weekend may be less prepared or experienced for driving on an extremely busy motorway, in comparison to weekday commuters. It should also be noted that the majority of incidents on weekends were breakdowns, 72% of all incidents compared to an average of 61.5% on weekdays. Even though there were more incidents at weekends, fewer occurred in-lane: on average 21.8% of incidents in-lane compared to 35.4% on weekdays. Vehicle fires also occurred more often at weekends than on weekdays, possibly confirming that less well maintained vehicles were being used at the weekend.

The rate of incident occurrence changes throughout the day and generally corresponds to the number of vehicles on the road, with the majority of all incidents when the road network is near or exceeding capacity, shown graphically in figure 4.4. There are however two exceptions to this between 11:00 – 12:00 and 14:00 – 15:00 where the incident rates are higher than expected. Further work has to be undertaken on the timings of incident occurrence, as the discrepancies occur in uncongested low flow periods. The temporal variation in the occurrence of incidents can be used to enhance the ISU program by optimising staffing shift patterns.

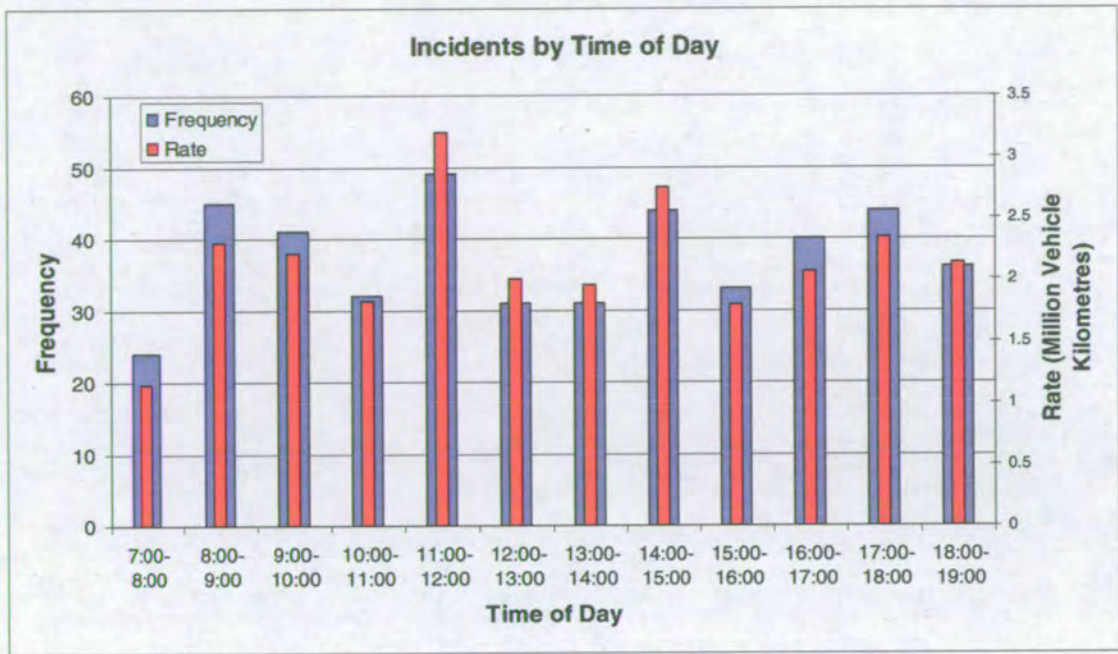


Figure 4.4 Incidents by Time of Day.

Figure 4.5 illustrates the different ways that incidents were notified to the motorway control room. As can be seen, emergency roadside telephones (ERT) are the most frequent method of notification with 236 uses or 52.4%. This is then followed by 999 (British emergency number) emergency calls with 25.1% and then police patrols with 5.8%. The remainder of incidents were either observed by CCTV from the control room or reported by the Highways Agency, including ISUs, other emergency services or various breakdown agencies.

For the entire study period there were only 4 secondary accidents and all were very minor damage only accidents. Other incident types however had even fewer secondary effects with only two debris incidents struck before clearance. This may be a result of the MIDAS system quickly reducing speed limits following incidents, and stopping other vehicles meeting stationary queues at high speed.

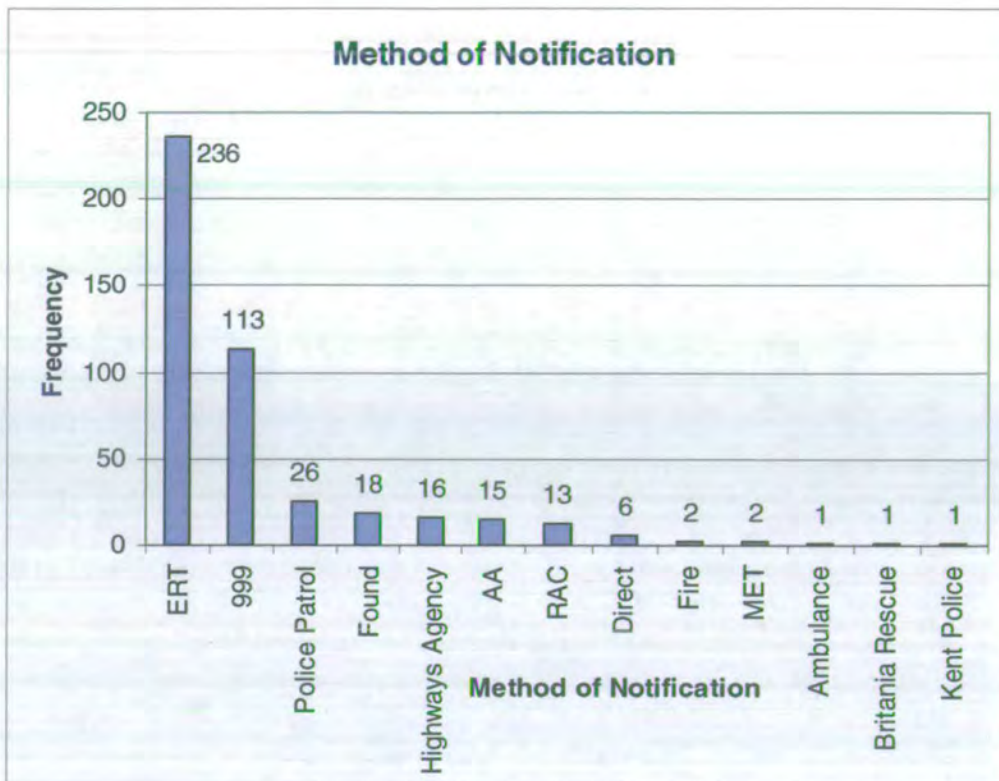


Figure 4.5 Method of Notification.

Incident Durations

For the 450 incidents observed, the total incident duration was calculated as the difference in the time from when the incident was first observed until all lanes, including the hard shoulder were cleared. The average duration of all incidents was 1 hour, 9 minutes. This duration is approximately three times that of Skabardonis et al (1999) incident duration of 20.7 minutes and double the duration of Bertini et al (2004) study in Portland at 33 minutes. The British study by Roberts et al (1994) found the average incident duration of 46 minutes for several UK motorways. This longer duration may be due to many locations on the M25 being rural and having longer distances between junctions compared to other study areas - as emergency and recovery vehicles have to travel further to an incident scene. The average duration of a travel lane being blocked was 32 minutes. The longest incident duration, and travel lane blockage duration, observed was 6 hours 40 minutes and involved extensive infrastructure damage that had to be repaired immediately for safety reasons. Accidents had the longest durations of all incidents, at 81 minutes, approximately 6 minutes longer than breakdowns, at 75 minutes. Debris incidents in general lasted 19

minutes and all other incidents, including vehicle fires, animals and pedestrians, lasted approximately 49 minutes on average.

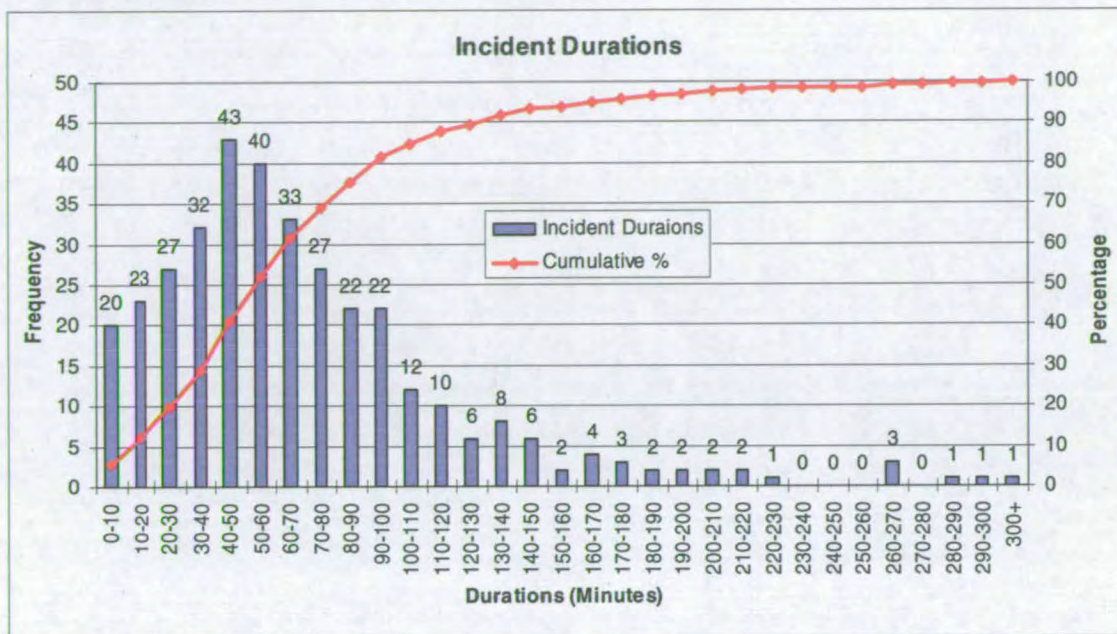


Figure 4.6 Distribution of Durations for all Incidents

Figure 4.6 shows the distribution of durations for all incidents. The distribution shows that approximately 50% of all incidents last less than 60 minutes, 75% of all incidents last less than 90 minutes and 90% of all incidents last less than 140 minutes.

During a day the average duration of incidents varies by as much as 37 minutes, as shown in figure 4.7. Also shown in figure 4.7 are lane closure durations throughout the day with the period between 13:00-14:00 hours having the greatest average duration of 58 minutes. The duration of an accident was affected by the number of lanes blocked (severity) with one lane accidents having an average duration of 85 minutes and lane closure duration of 29 minutes. Two lane accidents had an average duration of 92 minutes and lane closure duration of 39 minutes. Three lanes and over accidents had an average duration of 283 minutes and lane closure duration of 209 minutes though the sample size was very small for more severe accidents.

As this study was constantly observing traffic flows, using CCTV, several incidents were actually observed before the control room had been notified. This enabled

approximate detection times to be established. For the incidents that were discovered there was on average 5 minutes between the incidents occurring and the control room being notified.

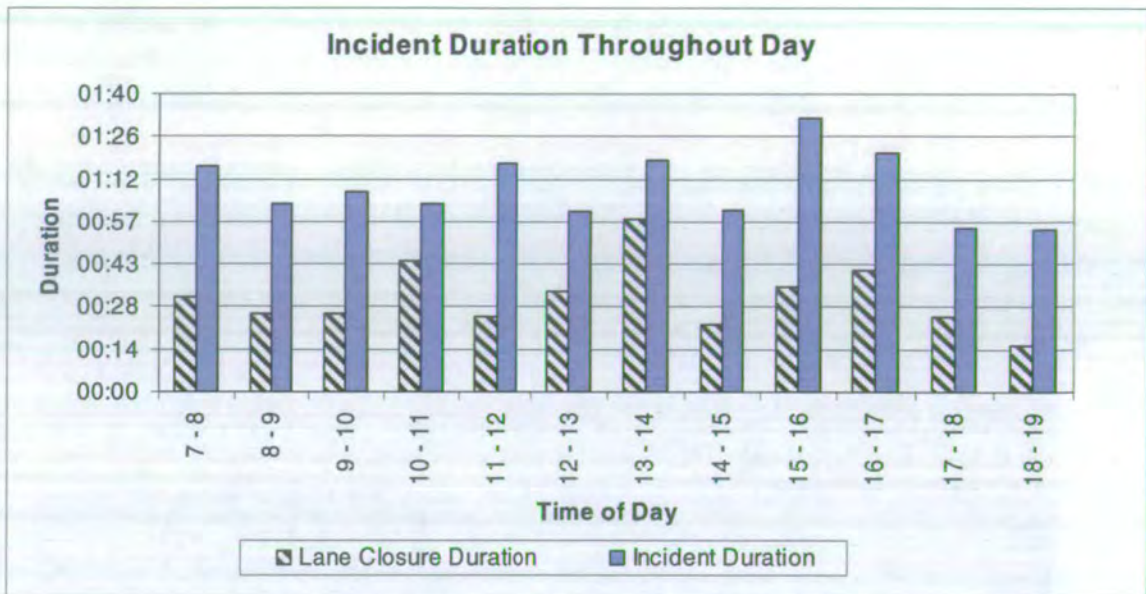


Figure 4.7 Graph of Average Incident Duration and Lane Closure Duration Throughout the Day.

Incident Locations

The location of each incident was recorded to the nearest marker post. These are spaced at 100 metre intervals along the full length of the study area. The spatial distribution of incidents, organised by junctions, is shown in figure 4.8.

It can be seen that for a straight count of incidents, that the section between junctions 8 and 9 has the highest occurrences of incidents. However, when incident rates are considered, the section between junctions 9 and 10 has the highest rate of incidents at 2.87 incidents per million vehicle km (4.63 incidents per million vehicle-miles). This information can be used to enhance the ISU program as the standby locations can be altered in relation to the spatial locations of incidents.



Figure 4.8 Incident Locations Organised by Junctions.

Incident Support Unit Involvement

Incident support units were requested to attend 21.3% of all incidents during the study period. They attended 44% of all accidents, 5% of breakdowns and 63.4% of debris incidents. After being requested, the ISUs had an average response time of 12 minutes over 96 incidents. Further research will have to be conducted to fully understand the influence of ISUs on the M25 road network.

Comparison between UK and US Incident data

Table 4.2 shows a comparison between this study's findings regarding incident characteristics and three other studies: Roberts et al (1994), Skabardonis et al (1999) and Bertini et al (2004). It can be seen that there are few similarities between studies.

Average incident duration varies by as much 28 minutes between the M25 and Interstate 10. Durations in the UK are between double and triple those of the US. Does this imply that US incident management practices are better than UK practices?

Table 4.2 Comparison of Study Results

Title of Study	London-M25	British Motorways	Los Angeles I-10	Portland Metropolitan Area
Year of Study	2003	1992/1993	1996	2001
Average Incident Duration (Minutes)	69	46	20.7	33
Incident Rate (Incidents per million vehicle kilometres)	2.32	11.49	92.8	N/A
Percentage In-Lane Incidents (%)	31.1	6	10.7	29.3
Percentage Accidents (%)	20.2	4.7	6.5	15
Percentage Breakdowns (%)	64.7	78.6	86.6	50

Incident rates between Britain and the US are vastly different with an average incident rate of 6.91 incidents per million vehicle kilometres from Britain compared to 92.8 in the US. This may be due to different driving styles, vehicles, vehicle regulations, driving distances, weather and many other factors such as incident recording. The difference between percentages of in-lane incidents appears to increase with more recent studies. Very minor incidents may not have been captured in this study thus increasing the in-lane percentage. The percentage in this study and the Portland study (Bertini et al., 2004) are however both greater than the two older studies in the comparison. The differences could also be due to different traffic densities. The percentage of accidents could also be due to the age of the study - again with the two more recent studies having greater percentages of accidents occurring. The lower accident percentages may also be due to the total number of incidents as the studies with the higher incident rates have lower percentages. Again the age of studies may be the cause of the differences between studies as more modern vehicles are less prone to breaking down. The differences between studies may also have been due to the method of detection the incidents. This study recorded incidents reported to the police control room and through observations on CCTV whereas Skabardonis et al (1997, 1999) used probe vehicles and Pal et al

(1998), Giuliano et al (1989), Jones et al (1991), Golob et al (1987) and Bertini et al (2004) used historical operational data.

4.3.4 Section Summary

This section has presented an overview of the characteristics of incidents on the south western part of the M25 London orbital motorway for the period between 5th November and 11th December 2003 to enable an understanding of the influence and role of ISUs on the M25 Sphere. Incident frequency, durations, locations and ISU involvement were examined.

It was found that:

- A total of 450 incidents were observed giving an average frequency of 16.1 incidents per day or 2.32 incidents per million vehicle-km (3.74 incidents per million vehicle-miles) for the study area. The majority of recorded incidents, 64.7%, were breakdowns.
- 69% of incidents blocked just the hard shoulder and only 7.6% blocked two or more lanes.
- Saturday had both a higher incident frequency and rate than any other day of the week.
- Between 11:00 and 12:00 was found to have the highest occurrence of incidents and highest rate during the day.
- Emergency roadside telephones were the most frequent method of incident notification.
- The average incident duration for the study period was found to be 1 hour, 9 minutes. Approximately 50% of incidents lasted less than 60 minutes and the average travel lane blockage was 32 minutes. The longest incident durations were recorded between 15:00 and 16:00 and the longest lane closure durations were between 13:00 and 14:00
- The majority of incidents occurred between junctions 8 and 9 but between junctions 9 and 10 had the highest incident rate.
- Incident Support Units attended 21.33% of all incidents and had an average response time of 12 minutes.

- Incident characteristics between US and UK studies were compared and found to be different.

4.4 Archived Matrix Signal Setting Accident Analysis

4.4.1 Introduction

Personal data collection ensures that all data collected is accurate and consistent but the time and financial constraints limits the volume of data that can be recorded. To provide a larger data set for incident analysis and allow a better understanding of the occurrence of incidents on the M25, motorway matrix signal setting archives were examined. Historic motorway matrix signal setting archives would enable a very large analysis of data, not restricted by data collection times.

It was chosen to only analyse “accidents” within the motorway matrix signal settings archives as these incidents are some of the most frequent and often have the greatest impact.

This section details an analysis of historical accident motorway matrix signal settings and their frequency, locations, durations and timings.

4.4.2 Data Description

The data for this section was taken from matrix signal settings archives, in a database format, for two control rooms on the M25, made available by the Highways Agency. Godstone and Heston control rooms record signal settings for the southern part of the M25, between junction 2 and 17, covering approximately 62.5 miles in total length. The databases were supplied in monthly form with all signal activations recorded. In total the data covered all days from 1st January 2000 to 31st December 2002 – 1,096 days.

The signal settings archive databases contain all information relevant to the setting of the signal:

- Log counter,
- On date and time,

- Operator who set the signals,
- Signal location (Motorway, marker post, direction, lane)
- Signal setting,
- Reason for setting (Accident, congestion, incident, debris, etc.)
- Off date and time.

Queries were run on the settings archive databases and all activations for accident only reasons were extracted. The extracted data was then manually analysed and separated into individual accidents. In total, 38,755 accident matrix signal activations were examined and 3,399 signal accident activations were identified.

4.4.3 Accident Data Analysis

Accident Frequency

Analysis showed that for the period of the study, there were 3,399 recorded matrix signal accidents activations (table 4.3). In 2000 and 2001 there were 1120 accidents - exactly the same number. In 2002 however, the number of accident signal activations increased to 1,159.

Table 4.3 Comparison of Accident Data for Different Years.

	Year				
	All		2000	2001	2002
Total Number of Matrix Signal Accident Activations	3399		1120	1120	1159
Mean Duration (Mins)	01:01:22		00:59:28	00:59:34	01:05:04
Standard Deviation (Mins)	01:49:59		01:56:35	01:42:36	01:50:46
Median Duration (Mins)	00:33:26		00:30:08	00:32:49	00:37:22

The increase in the number of accidents is contrary to expectation as several incident management programs have been instigated or modified over the 3 year study period. The average accident frequency was found to be 1,133 per year, 94.42 per month and 3.1 per day for the study area. Over the 62.5 miles of the study area this equates to an average of 18.13 accidents per mile per year, 1.51 accidents per mile per month and 0.05 accidents per mile per day.

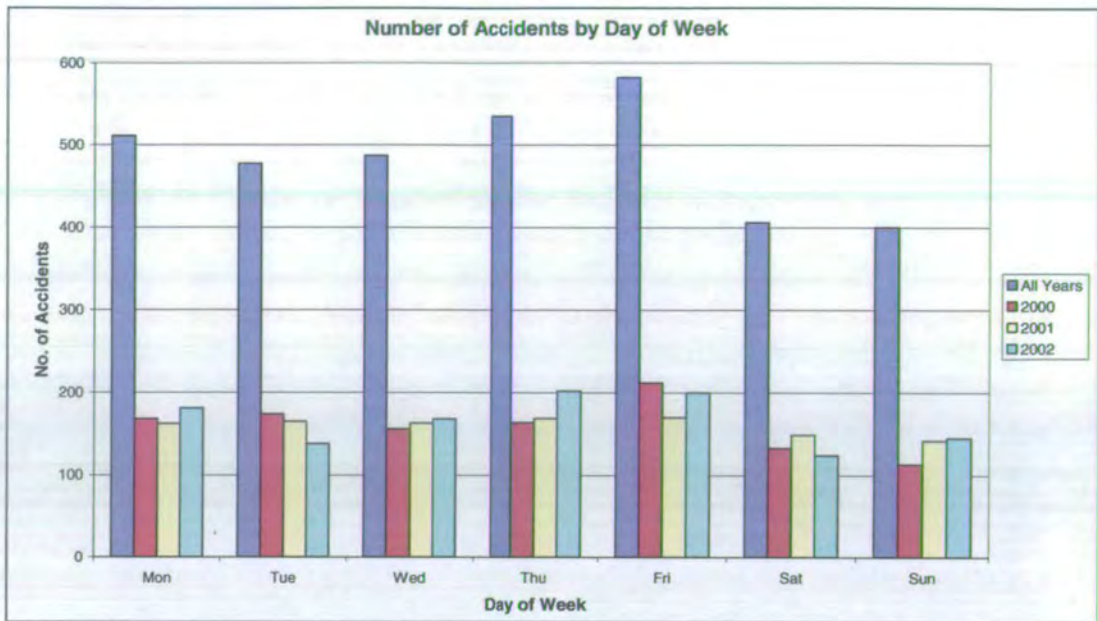


Figure 4.9 Graph of Accidents by Day of the Week.

Figure 4.9 shows the variability of recorded accidents by days of the week. The plot of data for all years shows that the larger number of accidents occurs on Fridays with 582 accidents or 17.1% of all accidents in the study period. It can also be seen from figure 4.9 that, as expected, there are fewer accidents on Saturdays and Sundays. This is because there are fewer vehicles using the motorway at the weekend. The individual years data, also plotted, is fairly consistent giving confidence in the combined data.

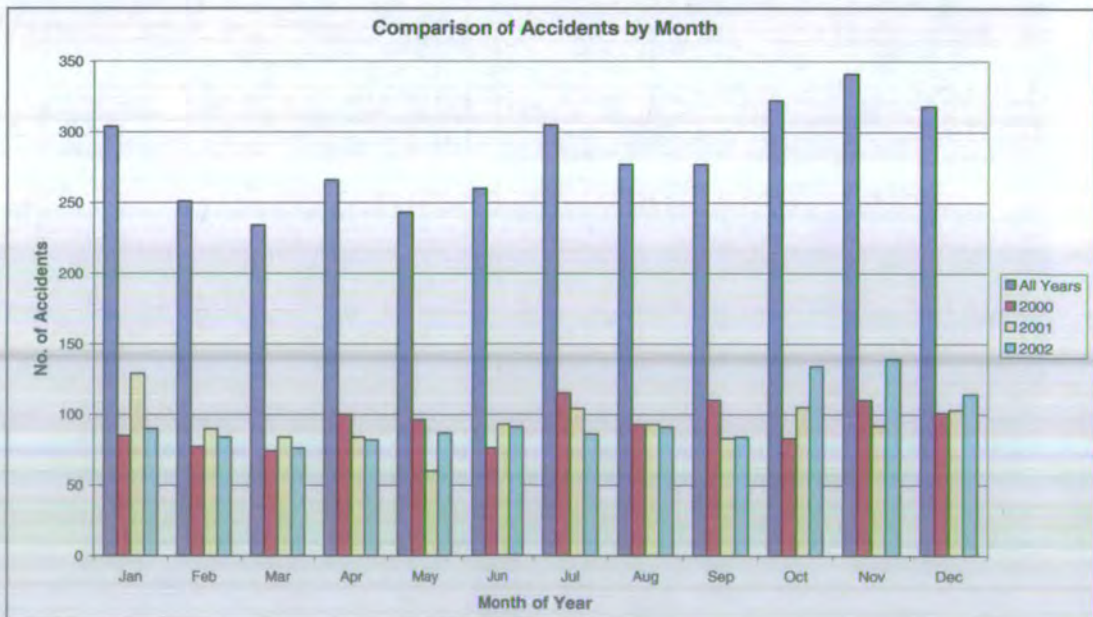


Figure 4.10 Graph of Accidents by Month.

Examination of the accidents by month showed some interesting variability, as shown in figure 4.10. The months in the spring season (Mar – May) were the lowest for the combined data with the period from October to January recording the highest number of accidents. Individual year's data shows greater variability however. In January there were 44 accidents between 2000's records and 2001's records. There were also 51 accidents between 2000 and 2002 in October. This variability requires further investigation as influencing factors, such as weather, were not available to this study.

A review of accident rates per year and per day for each day of the week and every month was carried out. It was found that the worst day for accidents was a Monday in December with an average of 21.67 accidents per year or 4.643 accidents per day for the study area of the M25. In contrast the minimum accident rate is a Saturday in May, with 5.67 accidents per year and 1.417 per day.

Table 4.4 Distribution of Accidents by Time of Day.

Time of Day	Total Number of Accidents	Average Accident Rate (Accidents per Day)
00:00 to 01:00	65	0.059
01:00 to 02:00	44	0.040
02:00 to 03:00	44	0.040
03:00 to 04:00	38	0.035
04:00 to 05:00	34	0.031
05:00 to 06:00	69	0.063
06:00 to 07:00	119	0.109
07:00 to 08:00	139	0.127
08:00 to 09:00	160	0.146
09:00 to 10:00	179	0.163
10:00 to 11:00	167	0.152
11:00 to 12:00	220	0.201
12:00 to 13:00	204	0.186
13:00 to 14:00	200	0.182
14:00 to 15:00	190	0.173
15:00 to 16:00	216	0.197
16:00 to 17:00	259	0.236
17:00 to 18:00	288	0.263
18:00 to 19:00	234	0.214
19:00 to 20:00	185	0.169
20:00 to 21:00	123	0.112
21:00 to 22:00	91	0.083
22:00 to 23:00	65	0.059
23:00 to 24:00	65	0.059

The number of accidents changes throughout the day. Table 4.4 and figure 4.11 show the variability of all accidents during the day. It can be seen that the higher

level of accidents occurred between 5pm and 6pm. The total of 288 accidents, or 8.5% of all accidents, during the evening peak period, has a rate of 0.263 accidents per day. The minimum number of accidents occurs between 4am and 5am with only 34 accidents over the study period. The data shown generally follows the number of vehicles on the road with the majority of all accidents when the road network is near or exceeding capacity. Further work could be done on the timings of accident occurrence, as the influence of traffic flows has not been examined.



Figure 4.11 Graph of Number of Accidents by Time of Day for All Years.

Accident Durations

For the 3,399 accidents, the total accident duration was calculated as the difference between the time that the first signal was activated until the last signal was deactivated. The average duration of all accidents was 1hour, 1minute and 22seconds. For the year 2000 the average accident duration was 59 minutes, 28 seconds, in 2001 the average was 59 minutes, 34 seconds and in 2002 it was 1 hour, 5 minutes and 4 seconds.

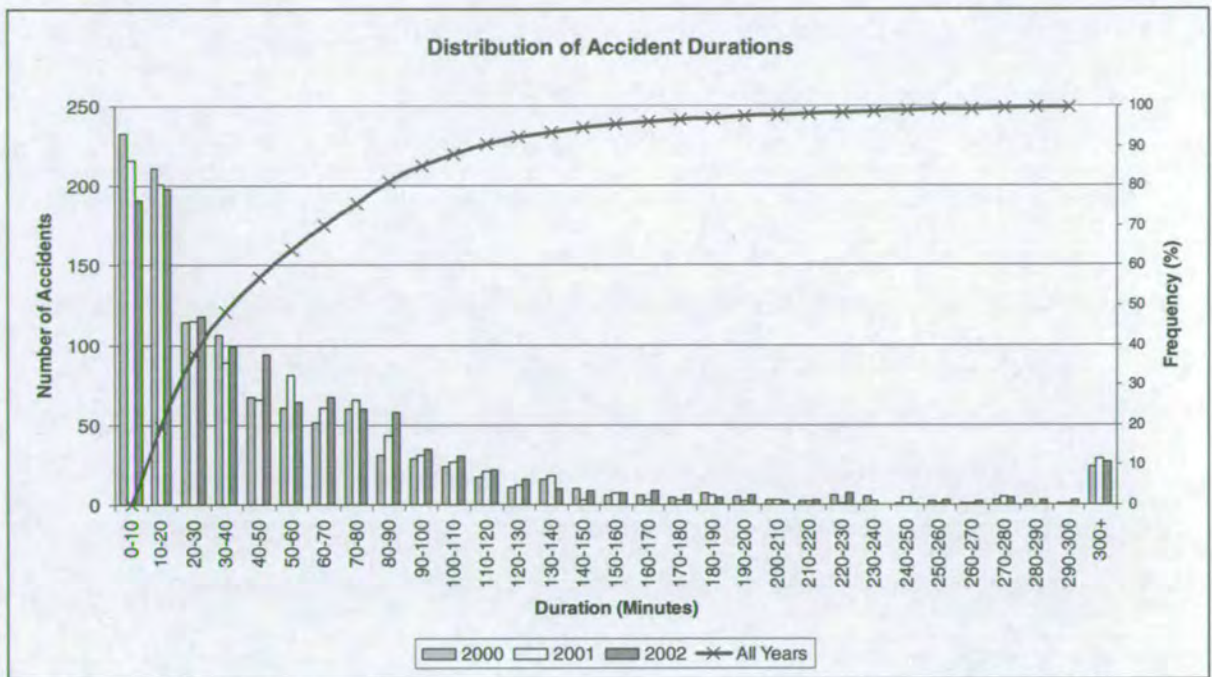


Figure 4.12 Comparison of Accident Duration Distributions.

Figure 4.12 shows the distribution of durations for all accidents. The distribution shows that approximately 50% of all accidents last less than 40 minutes, 75% of all accidents last less than 80 minutes and 90% of all accidents last less than 120 minutes.

Table 4.5 Comparison of A-D test results for duration distributions.

A-D Test Value	Year		
	2000	2001	2002
Fitted Distribution			
lognorm	1.708	3.249	2.605
InvGauss	2.151	3.663	3.313
Pearson5	3.589	5.562	4.694
Expon	29.96	18.95	18.2
ExtValue	+Infinity	39.06	40.27
Logistic	+Infinity	+Infinity	57.92
Triang	1970	1800	1649
Uniform	2652	2483	2352
Student	7634	7686	8109
Pareto2	+Infinity	+Infinity	+Infinity
Rayleigh	+Infinity	+Infinity	+Infinity
Pareto	+Infinity	+Infinity	+Infinity
Normal	+Infinity	+Infinity	+Infinity
Erf	+Infinity	+Infinity	+Infinity

Theoretical statistical distributions were fitted against the recorded accident durations. A selection of fourteen distributions were examined and the Anderson-Darling (A-D) test used to measure the goodness of fit between the data and the theoretical distributions. In the A-D test, the lower the number indicates a better fit.

A review of the A-D test results for the trialled distributions is shown in Table 4.5. It can be seen that the lognormal distribution provides the best fit to the recorded accident durations. This agrees with previous American studies (Giuliano (1989), Jones et al (1991), Golob et al (1987), Skabardonis (1999)) of incident analysis.

A review of average accident durations by day of the week and month showed that on average the longest accidents are on Sundays in August at 2 hours 6 minutes 18 seconds in length and the shortest are Saturdays in December at 29 minutes 54 seconds. On average Wednesdays have the shortest accidents and Sundays have the longest durations. During a day the average duration of accidents varies by as much as 1 hour 56 minutes 57 seconds as shown in figure 9. The average duration is reasonably constant between 8am and 10pm but between 10pm and 8am the durations are greatly increased with the maximum average duration between 1am and 2am of 2 hours 43 minutes 33 seconds. Extended durations through the night time period could be due to the extra time additional equipment can take to reach an accident scene, but is more likely to be because accidents may be more severe at night. Unfortunately severity data was not available.

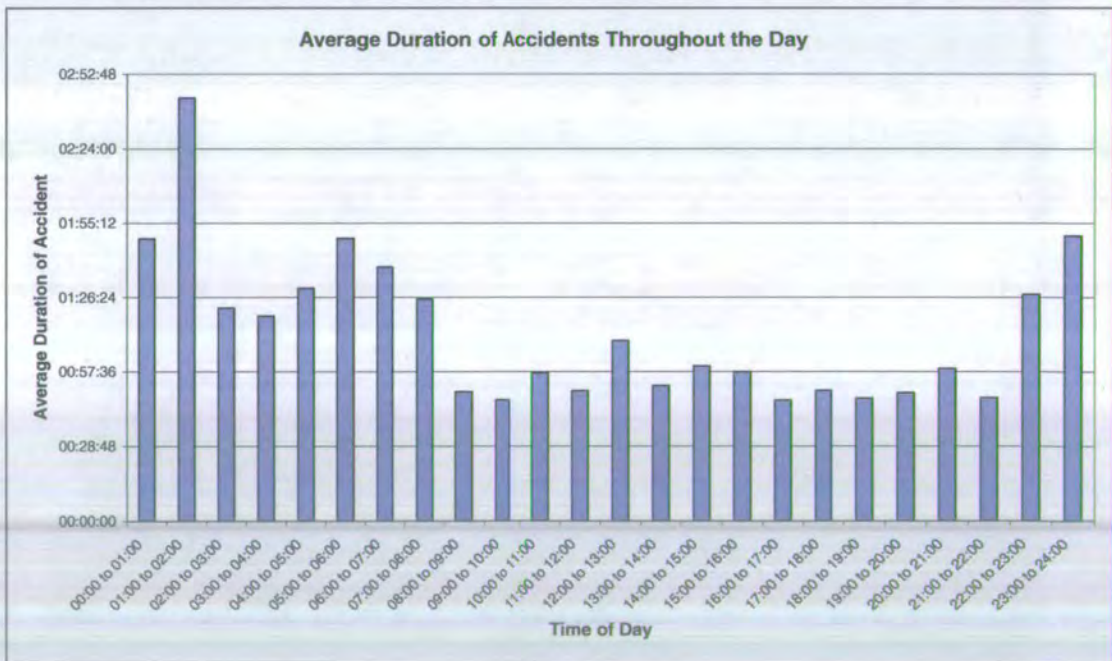


Figure 4.13 Graph of Average Duration Throughout the Day for all Years.

Accident Locations

The matrix signal databases included the marker post location of the activated signal. The location of the first activated signal was extracted and then manually sorted into junction-by-junction groups. The number of accidents by junction locations is shown in figure 4.14. Also shown is the line of the normalised accidents or accidents per mile - the number of accidents in each section have been divided by the mileage of the section. It can be seen that for a straight count of accidents then the section between junctions 5 and 6 has the highest occurrences of accidents. However, this section is one of the longest in the sample, which when normalised falls below the average accident rate. The highest rate of accidents per mile is for the section between junctions 7 and 8, which is 85.31 accidents per mile for the study period.

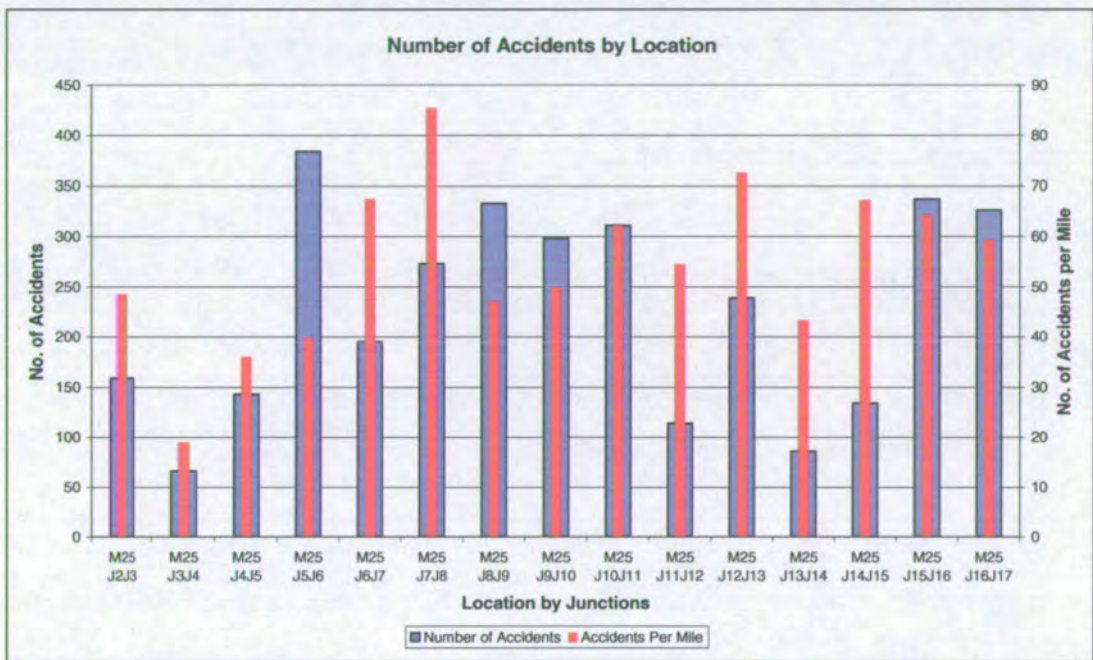


Figure 4.14 Graph of Accident Locations by Junctions.

4.4.4 Section Summary

This section has shown an overview of the characteristics of motorway matrix signal accident activations on the southern part of the M25 London orbital motorway for the period between January 2000 and December 2002. Accident frequency, durations and locations were examined.

It was found that:

- The average frequency of accidents was 3.1 accidents per day or 0.05 accidents per mile per day for the study area.
- The majority of recorded accidents occurred on a Friday.
- The spring months were found to have the lowest number of occurrences and the winter months were found to be the highest.
- Between 5pm and 6pm was found to have the highest occurrence of accidents.
- The average accident duration for the study period was 1 hour 1 minute 22 minutes.
- A lognormal distribution was shown to fit recorded durations.
- Sundays in August were shown to have the longest durations.
- Accident durations through the day were examined with the longest accident durations between 10pm and 8am.
- The majority of accidents have occurred between junctions 5 and 6 but between junctions 7 and 8 had the highest accident rate of 85.31 accidents per mile for the study period.

It was shown that it is possible to analyse data collected from motorway matrix signal accident activation records. The analysis of this data was however very labour intensive, requiring manual identification and summary of each incident. This could lead to operator errors when identifying the characteristics of incidents contained within the records.

The analysis is also reliant on the accuracy of the original matrix signal activation reason. If controllers accidentally selected an incorrect reason for example, “obstruction” instead of “accident” this would not have been identified in this study. It is believed however that by using a large data set, such as the one used here, these errors will be negligible.

4.5 Chapter Conclusions

This chapter involved the collection and examination of motorway incident data in order to fully understand the influence and role of ISUs on the M25 Sphere.

The activities of Incident Support Units on the M25 Sphere were examined in chapter 3. As the proportion of ISU attended incidents to all incidents was not known motorway incident data was collected by the author through observing motorway operations at a police control room. This analysis was shown in section 4.3. Historical data was also obtained to provide a larger data set for analysis, which is detailed section 4. Conclusions for each section are detailed below.

Section Three

The collection and analysis of motorway incident data on the south western part of the M25, from Surrey Police's Godstone motorway control room, was examined to establish an accurate representation of incidents on motorways. One month of daily incident data was collected, through observation, by the author. The data was examined and incident frequency, durations, locations and ISU involvement were established. The following are the key points that can be concluded from the analysis undertaken:

- An average frequency of 16.1 incidents per day was observed, the majority of which (64.7%) were breakdowns. It should be noted that ISUs are not contractually obliged to assist with general broken down vehicles. This sheds further light on the differing benefit-cost ratios discussed in chapter 3 where US programmes assisted broken down motorists.
- 31% of incidents occurred in-lane. The majority of these incidents would have involved a request for an ISU to attend.
- ISUs were requested to attend 21.33% of all incidents, including 40% of all accidents, and had an average response time of 12 minutes.

This section has shown that ISUs play a large role in the incident management of the M25 motorway. They were requested to attend more than 90 incidents to provide

traffic management, debris clearance and spill containment. Therefore the estimated benefit found in chapter 3 has been demonstrated to be a significant one.

Section Four

To provide a larger, three year, data set for the analysis of incidents, historic matrix signal activations were examined and an analysis was presented. It was chosen to only examine “accident” signal activations. Accident frequency, durations and locations were examined.

It was shown that it is possible to analyse data collected from motorway matrix signal accident activation records. The analysis of this data was however very labour intensive, requiring manual identification and summary of each incident. This could lead to operator errors when identifying the characteristics of incidents contained within the records.

The analysis is also reliant on the accuracy of the original matrix signal activation reason. If controllers accidentally selected an incorrect reason for example, “obstruction” instead of “accident” this would not have been identified in this study. It is believed however that by using a large data set, such as the one used here, these errors will be negligible.

Data Set Comparison

A comparison between the two data sets is detailed below.

- Accuracy – Personally collected data can always be guaranteed to be more accurate than any other obtained source.
- Data set size – Historical records provide much larger sample sizes than those obtained manually.
- Time – Data collection is very time consuming.
- Cost – Data collection can prove to be very expensive over long periods.
- Accessibility – Historical records are easily obtained for analysis

- **Data Availability** – Historical data is generally available for all times and days and not dependent on data collection periods, which can sometimes miss incidents.
- **Analysis** – The ease of analysis of data can be important as errors can be introduced if the analysis is very complicated and laborious.

5 The Influence of Motorway Incidents on Traffic Flow

5.1 Introduction

Incidents are defined as any non-recurrent events that create a temporary reduction in roadway capacity, which in turn, impedes the normal flow of traffic. Incidents may physically block part or all of a motorway or may be clear of the carriageway and only providing a distraction to passing motorists. In order to effectively manage an incident on a motorway and reduce its impact, it is essential to accurately estimate the incident's impact on the flow of traffic. Once the influence is known and understood, appropriate mitigation strategies can be implemented to reduce the incident's impact.

This chapter examines the influence of motorway incidents on traffic flow. Their impact on the capacity of the roadway is examined and the impact of rubbernecking is investigated. Investigations and analysis are undertaken to evaluate the impact of incidents on motorways including the total delay experienced.

This chapter is structured as follows:

- **Section Two.** The loss of capacity due to traffic incidents on motorways is characterised. A review of incident capacity reduction estimations from US freeways and other studies is presented. The roadway capacity under normal and incident conditions was estimated for a sample of incidents, with the resulting reduction due to incidents summarised.
- **Section Three.** In addition to the impact of physically blocking travel lanes, “rubbernecking” by motorists can reduce the capacity of a facility. An investigation into the effect of rubbernecking on roadway capacity, capacity speed and safety is detailed.
- **Section Four.** An assessment of the resulting delays due to incidents was presented.
- **Section Five.** Chapter summary and conclusions.

5.2 Characterisation of Capacity Reduction Resulting from Traffic Incidents

5.2.1 Introduction

When an incident occurs on a motorway, it temporarily reduces the capacity of the road which in turn causes congestion. It has been estimated that incidents account for approximately 25% of all congestion on the trunk road network which is thought to cost the British economy approximately £750 million per year (National Audit Office, 2005).

In order to effectively manage an incident on a motorway and reduce its impact, it is essential to accurately estimate the incident's impact on the flow of traffic. If the loss of capacity due to an incident can be estimated, then using current demand flow, from loop detectors and simple analysis, such information as queue length, average delay and number of vehicles delayed can be estimated. With this information proper traffic management and diversion plans can be implemented and accurate information can be disseminated to the public.

This section will categorise the average capacity reduction on a motorway, due to an incident, by estimating the roadway capacity under normal and incident conditions for a sample of incidents.

5.2.2 Background

The capacity of a roadway section is defined as “the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions” (TRB, 2000)

Usually when an incident occurs a bottleneck rapidly forms due to the fact that the demand for travel is greater than the remaining capacity. Therefore, the bottleneck traffic flow can be taken as the remaining capacity at an incident scene, assuming that the roadway section is operating at its (remaining) capacity.

The Highway Capacity Manual (TRB, 2000) states that the loss of capacity is likely to be greater than simply the proportion of original capacity which is physically blocked. The added loss of capacity arises because drivers increase their headways and slow to look at the incident while they are abreast of it and are slow to react to the possibility of speeding up to move through the incident area. This is known as “rubbernecking”.

The most commonly cited source of capacity reduction figures is the Highway Capacity Manual (TRB, 2000). In Chapter 22, “Freeway Facilities Methodology”, of the manual, Table 22-6 details the proportion of capacity available under incident conditions, based on the number of lanes at the incident location and the number and location of lanes blocked. The figures presented in Table 22-6 of the manual are shown in table 5.1 below.

Table 5.1 Portion of Freeway Capacity Available Under Incident Conditions (TRB, 2000)

Number of Freeway Lanes by Direction	Shoulder Disablement	Shoulder Accident	One Lane Blocked	Two Lanes Blocked	Three Lanes Blocked
2	0.95	0.81	0.35	0	N/A
3	0.99	0.83	0.49	0.17	0
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.26
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

It was not possible to determine the original source research for the information presented in the table but the most often referenced original research on incident capacity reduction was conducted in 1971 by Goolsby (Goolsby, 1971). Goolsby analysed 27 accidents and breakdowns that occurred between 1968 and 1969 on a 6.5 mile section of the Gulf Freeway in Houston. A summary of the effect on traffic flow that Goolsby observed is shown in table 5.2. It was estimated that a broken down vehicle blocking one lane, out of three, would reduce capacity by 48% and an accident blocking one lane would reduce capacity by 51%. These figures are consistent with the Highway Capacity Manual figure of 49% remaining capacity. He also noted a 79% loss of capacity with the closure of two of the three available lanes.

The study only used 312 counted 1-minute volumes under normal conditions downstream of the study site, not the capacity under prevailing conditions, therefore possibly over-estimating the capacity reduction. Also, only 517 1-minute volume counts were made of the incident capacity, and the measurement was not well described. The inherently unstable nature of using 1-minute flows may also contribute to over-estimation or under-estimation (Qin and Smith, 2001).

Table 5.2 Effect of Differing Incident Conditions on Traffic Flow on a Three-Lane (One Direction) Freeway (Goolsby, 1971)

Condition	No. Of Blocked Lanes	Average Flow Rate (vph)	Volume Reduction (%)
Normal	-	5,560	-
Stall	1	2,880	48
Non-Injury Accident	1	2,750	51
Accident	2	1,150	79
Accident on Shoulder	-	4,030	28

Sullivan (1997) presented as part of an incident impact model, called IMPACT, estimates of capacity reduction based on several previous studies. This information is presented in table 5.3 and is separated into two categories: Accidents and debris and all other incident types. These figures are in general agreement with other previous studies.

Table 5.3 Percent of Original Capacity Remaining for Different Incident Types (Sullivan, 1997)

Lateral Location of Incident	Original Width of Roadway			
	4+	3	2	1
Accident and Debris				
Median Shoulder	74.0	69.0	64.0	59.0
Right Shoulder	85.0	83.0	81.0	79.0
1 Lane Blocked	62.0	53.0	39.0	0
2 Lane Blocked	26.7	18.4	0	N/A
3 Lane Blocked	13.9	0	N/A	N/A
4 Lane Blocked	0	N/A	N/A	N/A
All Other Incident Types				
Median Shoulder	80.0	76.0	71.0	67.0
Right Shoulder	96.0	90.0	84.0	78.0
1 Lane Blocked	66.7	57.0	42.0	0
2 Lane Blocked	28.7	19.8	0	N/A
3 Lane Blocked	14.9	0	N/A	N/A
4 Lane Blocked	0	N/A	N/A	N/A

A more recent study by Smith et al (2003) examined over 200 accidents that occurred on freeways in the Hampton Roads region of Virginia, USA. They found that an accident blocking one of three lanes resulted in an average capacity reduction of 63% and an accident blocking two of three lanes resulted in an average capacity reduction of 77% (table 5.4). These figures vary quite significantly from the ones stated in the Highway Capacity Manual, with 12% less capacity for a single lane accident and 6% more capacity for a two lane closure.

**Table 5.4 Portion of Freeway Capacity Available Under Accident Conditions
(Smith et al, 2003)**

Number of Freeway Lanes by Direction	One Lane Blocked	Two Lanes Blocked
3	0.37	0.23

Information relating to the UK is the rather more conservative. The default value which is given as a remaining lane capacity of 0.78 for each of the remaining three lanes in a four lane motorway (DETR, 1999) meaning only a 42% reduction.

A study by Roberts et al (1994) conducted in 1992 and 1993 on several stretches of British motorways estimated a 24.2% reduction in capacity across all incidents and lane blockages observed. Unfortunately a breakdown of incident type, lane location or number of lanes blocked was not given so can not be compared.

**Table 5.5 Capacity reduction According to the Number of Blocked Lanes
(Huddart & Thompson, 2001)**

% Reduction	Number of blocked lanes				
	1	2	3	4	5
No. of Lanes					
2	75	95	N/A	N/A	N/A
3	60	85	95	N/A	N/A
4	50	75	90	95	N/A
5	40	65	75	85	95

A more recent British report however contained information on capacity reduction relating specifically to accidents on the M25 and is detailed in table 5.5.

In comparison with the US results the UK results in table 5.5 are relatively similar. The major differences are that table 5.5 states a remaining capacity of 5% when all lanes are closed. This is a result of vehicles moving into the hard shoulder and thus moving through the incident site. A case study in Surrey showed that for the past 2 years there were no incidents that brought traffic to a complete stand still for more than 2 hours (Huddart & Thompson, 2001). Thus motorists have been able to escape from the motorway and the 5% rate would account for this.

5.2.3 Method

A selection of data, recorded at Surrey Police's Godstone motorway control room, was collated to provide a representative sample to estimate the residual capacity at incidents on motorways. Once the selected incidents were examined and locations established, the four lane road capacities under prevailing conditions were estimated by calibrating speed-flow curves for the relative motorway sections using MIDAS traffic flow information. An example of loop detector location in relation to the incident is shown in figure 5.1. The remaining capacity at the incident was then measured as the minimum ten minute flow rate during incident conditions. A ten minute flow rate interval was used as it was found that it enabled stable flow rates to be calculated and also allowed smaller variations to be identified during an active incident. This is less than the fifteen minutes recommended in the Highway Capacity Manual (TRB, 2000). A ten minute period was confirmed by Smith and Ulmer (2003). It should be noted that the capacity reduction results are from the theoretical maximums.

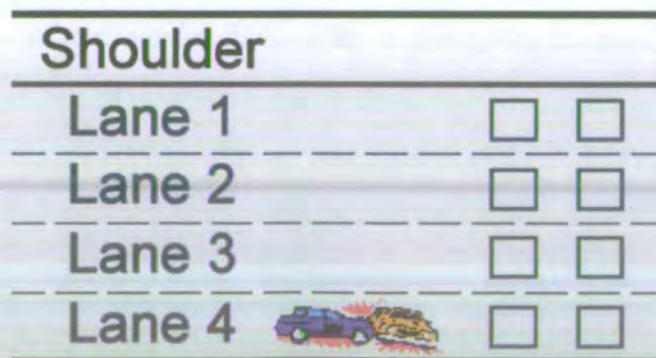


Figure 5.1 Example of MIDAS Loop Detectors Location in Relation to an Incident.

5.2.4 Data Description

Two data sets were used to estimate the impact of incidents on the M25.

Godstone Incident Data

This data is detailed in 4.3.2.

MIDAS Traffic Data

The Motorway Incident Detection and Signalling (MIDAS) system records traffic data 24 hours a day in 1-minute averages on:

- flow
- speed
- headway
- occupancy
- vehicle length category

The data is stored in binary form and a program called TDAS (Traffic Data Analysis System) version 1.0 is used, within Microsoft Access, to extract relevant information. Both the TDAS program and MIDAS data was also obtained from Mott MacDonald, Glasgow.

5.2.5 Estimation of capacity

The capacity of the four lane motorway section of interest was estimated by using calibrated speed-flow curves. These use matched speed and flow data to graphically show flow breakdown, with the peak of the curve signifying the capacity of the section. Traffic flow data for an arbitrary one week period was examined for each section which resulted in 40,320 data points. For all incidents examined the section capacity ranged from 2725 vehicles per hour per lane (vphpl) to as low as 1750 vphpl. Two examples are shown below in figures 5.2 and 5.3.

Figure 5.2 shows the speed-flow curve for incident number 85 which was an accident on the M25 between junctions 9 and 10 and MIDAS flow data was obtained from loops at 4637A. The numerous data points within the parabola are due to the various

traffic conditions experienced over the period. The capacity under prevailing conditions was taken as 2,350 vehicles per hour per lane (vphpl) for this incident.

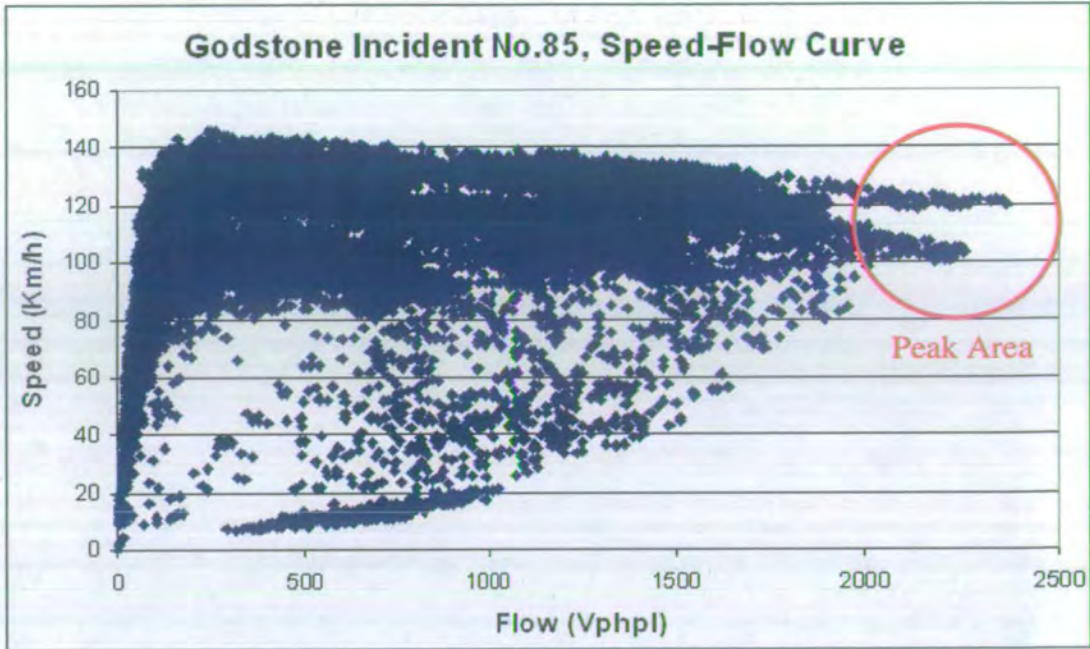


Figure 5.2 Incident No.85 Speed Flow Curve

Figure 5.3 shows the speed-flow curve for incident number 93, a suicide, on the M25 also between junctions 9 and 10. MIDAS flow data was obtained from loops at 4697A. The capacity under prevailing conditions was taken as 2,215 vphpl for this incident.

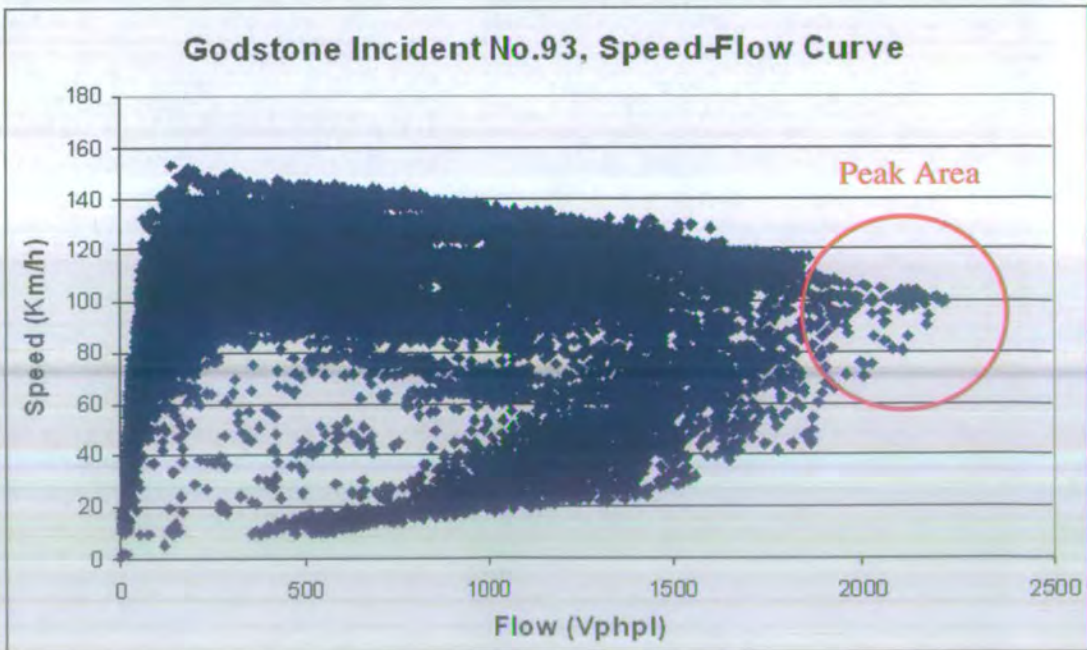


Figure 5.3 Incident No.93 Speed Flow Curve

Once capacities had been calculated for all incident sections it was decided to reduce the capacity by 90% as the majority of speed-flow curves did not have a well defined peak. This would improve the accuracy of the capacity estimation by moving the value into the more stable peak area rather than a single point at the peak.

5.2.6 Estimation of incident capacity

When an incident occurs on a motorway and the demand is larger than the available capacity, a bottleneck quickly forms. Therefore, the remaining capacity following an incident can be taken as the bottleneck traffic flow. Examples of the two incidents detailed above are shown in figure 5.4 and 5.5. The two figures demonstrate the significant variations of the short one minute measurement intervals. A moving average was used to smooth the flow and reduce the variation in incident capacity. Generally the minimum value of the moving average was taken as the bottleneck, or incident, capacity of the section.

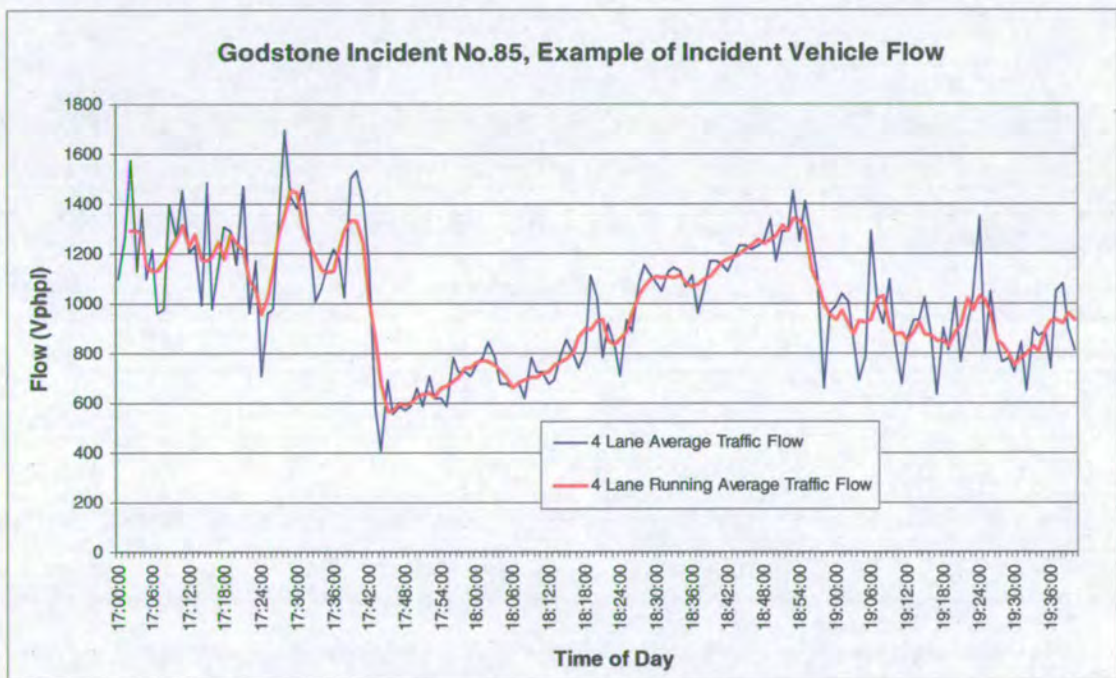


Figure 5.4 Incident No.85 Vehicle Flow

Figure 5.4 illustrates the initial drop in traffic flow when incident 85 occurred at 17:43. Due to this artificially lowering the moving average it was decided to not take

the lowest value, but to take the second lowest, once flow had stabilised at 18:06 with a value of 700 vphpl.

Figure 5.5 also illustrates the initial drop in traffic flow when incident 93 occurred at 10:01. Again due to this artificially lowering the moving average it was decided to not take the lowest value, but to take the second lowest. For this two lane closure incident it was decided to select 700 vphpl as the incident capacity.

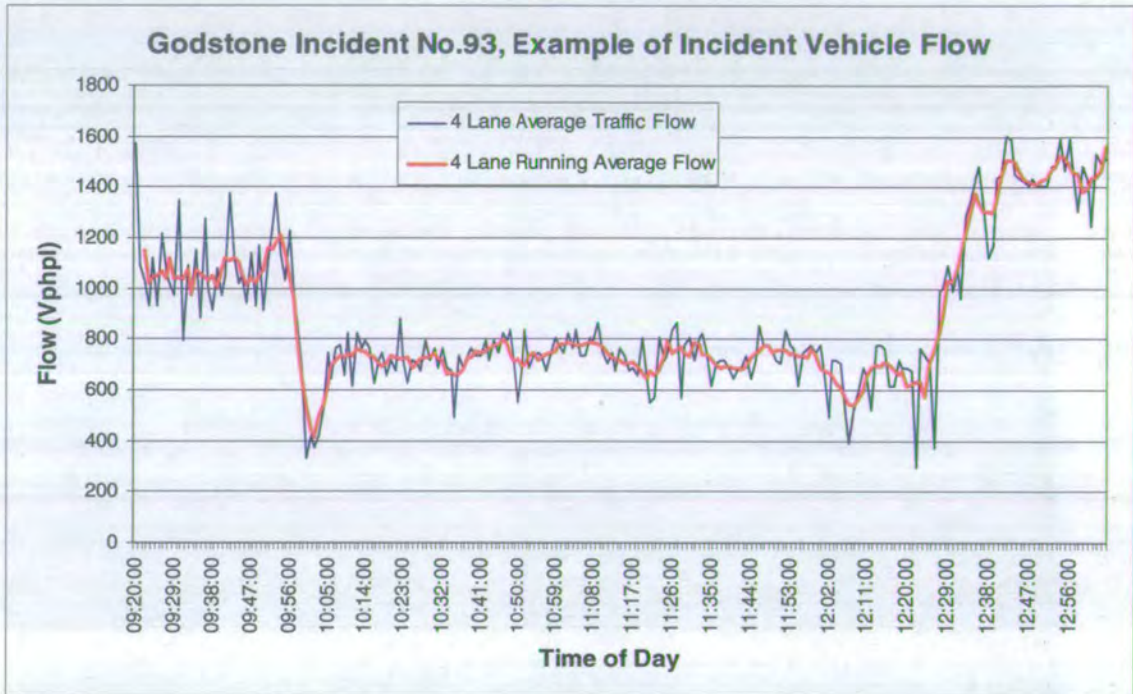


Figure 5.5 Incident No.93 Vehicle Flow

5.2.7 Calculation of capacity reduction

When both values of capacity are known the estimation of reduction can be calculated. The capacity reduction is the difference between the prevailing conditions capacity, section capacity, and the estimated incident capacity.

$$\text{Capacity Reduction} = \text{Section Capacity} - \text{Incident Capacity}$$

The percentage reduction value is then calculated as the incident capacity over the capacity under prevailing conditions.

$$\text{Percentage Capacity Reduction} = \text{Incident Capacity} / \text{Section Capacity}$$

5.2.8 Summary of results

The capacity remaining results for all examined incidents are shown in detail in table 5.6 and a summary of average capacity by lane is shown in table 5.7.

Table 5.6 shows the great variability of both section and incident capacities. The maximum section capacity was 2,725 vphpl between junctions 8 and 9 and the minimum was 1,750 vphpl between junction 7 and 6. The minimum incident capacity was 420 vphpl for a three lane blocking accident between junctions 11 and 12.

Table 5.6 Capacity Remaining Results.

Incident	No. of Lanes	No. Blocked	Lane Blocked	Absolute Capacity	90% Capacity	Reduced Capacity	Remaining %	Reduced%
20	4	1	4	2500	2250	825	36.67%	63.33%
26	4	1	1	2550	2295	1060	46.19%	53.81%
48	4	1	4	2450	2205	888	40.27%	59.73%
48	4	2	3+4	2450	2205	741	33.61%	66.39%
85	4	2	1+2	2350	2115	595.5	28.16%	71.84%
85	4	1	1	2350	2115	700	33.10%	66.90%
93	4	2	3+4	2215	1993.5	700	35.11%	64.89%
93	4	0	H/S	2215	1993.5	927	46.50%	53.50%
123	4	1	1	2150	1935	804	41.55%	58.45%
123	4	1	1	2150	1935	1009.5	52.17%	47.83%
123	4	0	H/S	2150	1935	1380	71.32%	28.68%
161	4	1	1	2640	2376	960	40.40%	59.60%
161	4	2	1+2	2640	2376	780	32.83%	67.17%
161	4	1	1	2640	2376	1069.5	45.01%	54.99%
203	4	2	3+4	2525	2272.5	843	37.10%	62.90%
203	4	0	H/S	2525	2272.5	1330.5	58.55%	41.45%
208	4	1	1	2525	2272.5	1025	45.10%	54.90%
208	4	0	H/S	2525	2272.5	1293	56.90%	43.10%
269	4	2	3+4	2025	1822.5	729	40.00%	60.00%
269	4	1	4	2025	1822.5	1030	56.52%	43.48%
283	4	1	4	2725	2452.5	913.5	37.25%	62.75%
283	4	0	H/S	2725	2452.5	1072	43.71%	56.29%
289	4	3	2+3+4	1850	1665	430	25.83%	74.17%
289	4	2	3+4	1850	1665	700	42.04%	57.96%
289	4	1	4	1850	1665	1093.5	65.68%	34.32%
401	4	1	4	2350	2115	840	39.72%	60.28%
405	4	2	1+2	2200	1980	721	36.41%	63.59%
428	4	3	2+3+4	2375	2137.5	420	19.65%	80.35%
428	4	2	3+4	2375	2137.5	630	29.47%	70.53%
556	4	1	1	2600	2340	1260	53.85%	46.15%
574	4	2	3+4	2000	1800	590	32.78%	67.22%
579	4	2	2+3	1750	1575	640	40.63%	59.37%
579	4	0	H/S	1750	1575	1000	63.49%	36.51%
594	4	1	4	2125	1912.5	840	43.92%	56.08%
682	4	2	3+4	2175	1957.5	880	44.96%	55.04%
682	4	0	H/S	2175	1957.5	1380	70.50%	29.50%
706	4	2	1+2	2150	1935	1120	57.88%	42.12%

Table 5.7 shows both the average percentage capacity remaining and reduction for all incidents. These incidents are all for four lane sections of motorway.

Table 5.7 Average Capacity Reduction Results Summary.

Lanes Blocked	Remaining %	Reduced%
0	58.71%	41.29%
1	45.16%	54.84%
2	37.38%	62.62%
3	22.74%	77.26%

5.2.9 Discussion

A total of 21 incidents were examined and 37 readings taken. The chosen data provided a cross-section of incidents blocking just the hard shoulder to blocking 3 of 4 lanes. All incidents occurred on the 4 lane sections of the M25.

It can be seen that incidents greatly reduce the available capacity of the road, beyond that of the physical blockage. This shows that incidents with minimal physical impacts can have a considerable impact on traffic flow. A graphical comparison with other studies is shown in figure 5.6.

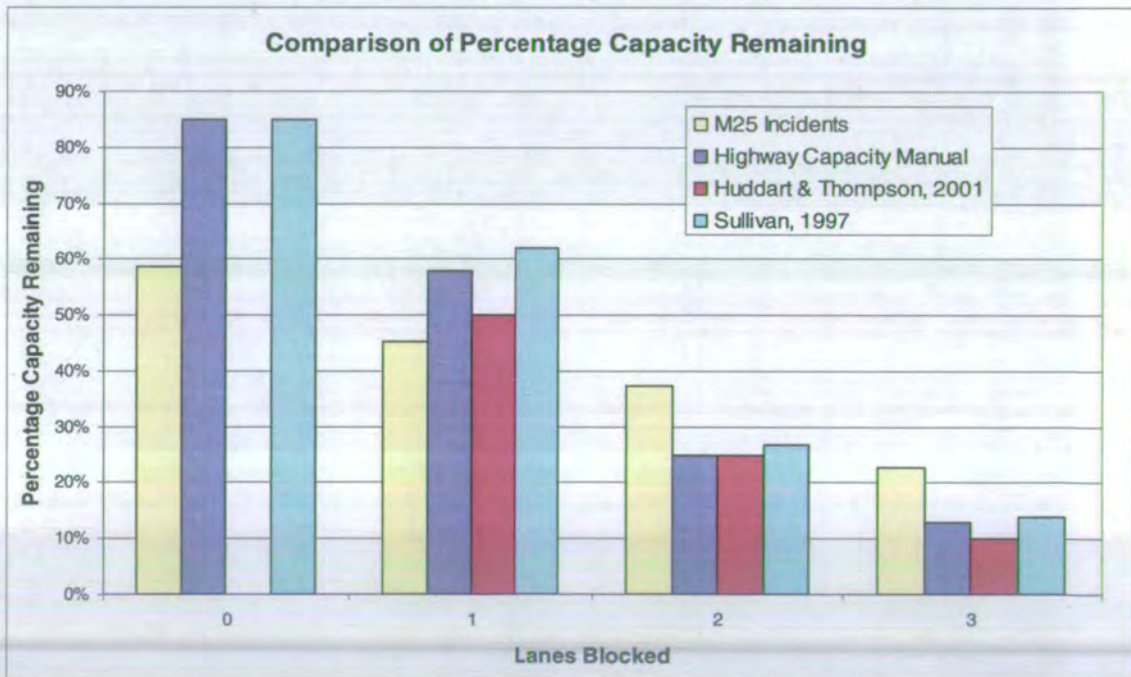


Figure 5.6 Comparison of Percentage Capacity Remaining Between Studies.

In comparison to the Highway Capacity Manual and the majority of other studies the calculated reductions are quite different. Virtually all other studies follow the same trend but this study's results cross it, with a greater impact of lesser incidents and a

lesser impact on more major incidents. The Highway Capacity Manual suggests 85% capacity remaining at an accident on the shoulder but this study suggests 59% remaining. For a single lane out of four blocked, this study found the remaining capacity to be 45% while the Highway Capacity Manual states 58%. Another study on the M25 by Huddart and Thompson is closer to this study at 50% remaining capacity for a single lane closure out of four lanes. Two lanes blocked reduced the capacity of the motorway to 37% and three lanes blocked suggested that 23% of roadway capacity was available. In comparison to the Highway Capacity Manual these values are much higher than 25% and 13% respectively. It should be noted that the sample size for the three lane blockages was very small at 2 incidents, which may be the cause of the discrepancies.

Differences in vehicle characteristics and capabilities, as well as driver behaviour, may account for some of the considerable differences between studies.

The presented information demonstrates that incidents should be cleared as quickly as possible to reduce their impact. There are numerous actions that can be taken to reduce the impact of an incident on motorway traffic. These include:

- faster detection of incidents
- reduction in response times
- improved incident handling and clearance
- faster vehicle recovery

Another example may be to request recovery vehicles immediately, on notification of an incident, and either requested to respond directly to the incident scene or wait at the previous junction until required. This would reduce the total incident timeline as incidents could be cleared quicker. Responding recovery vehicles would also not be delayed by congestion as a result of the incident.

With the high capacity penalty from rubbernecking motorists, due to an emergency vehicles just being on the hard shoulder, any incident where there are no injuries should be relocated to the next junction, clear of the roadway. This would not only increase safety but would also reduce delay from the capacity reduction.

5.2.10 Section Summary

It has been shown that incidents on motorways significantly reduce the available capacity of the road, greater than just the proportion of original capacity physically blocked.

It was shown that:

- an incident blocking three lanes out of four reduced the roadway capacity by 77.26%
- an incident blocking two lanes out of four reduced the roadway capacity by 62.62%
- an incident blocking one lanes out of four reduced the roadway capacity by 54.84%
- an incident only blocking the hard shoulder of four lane motorway reduced the roadway capacity by 41.29%
- the results varied from those of previous studies

5.3 The Impact of Rubbernecking on Motorways

5.3.1 Introduction

When an incident on a motorway occurs, the capacity of the carriageway and the opposite carriageway is often also affected by passing motorists “rubbernecking”, trying to see what is happening. This “rubbernecking” not only causes delay to many motorists but also decreases the safety of the network, as motorists attention is no longer where it should be- on the road ahead.

A CCTV image showing an example of rubbernecking is shown in figure 5.7. It can be seen on the opposite carriageway than the incident, at the top of the picture headways are very small, whereas headways are much increased as the traffic is leaving the picture to the right. The queue resulting from rubbernecking at this incident was observed to extend some 2.5 kilometres.



Figure 5.7 CCTV Image Showing an Example of Rubbernecking.

This section will examine the impact of rubbernecking on motorways.

5.3.2 Background

“Rubbernecking” is defined in the Chambers English dictionary as “someone who stares or gapes inquisitively or stupidly”. Motorists driving past incidents on motorways and in the opposite direction are often easily distracted and are curious to see what is happening. As they do this they reduce their speeds and increase their headways, which leads to congestion. It has already been shown in section 5.2 that rubbernecking causes a reduction in capacity with 41.3% less capacity on a 4 lane road when an incident is on the hard shoulder and not blocking any lanes.

There has been very little work on the impact of rubbernecking on roadway capacity in the opposite carriageway from the incident. Two studies in the UK, Roberts et al (1994) and Huddart and Thompson (2001), both identified that rubbernecking was an issue. Huddart and Thompson (2001) stated that traffic capacity in the reverse direction than the original incident is also reduced, perhaps by 30%, as a result of drivers increasing their safety spacing while trying to see details of the incident. Roberts et al (1994) measured a reduction of 13% while another incident involved a reduction of 38%.

In the US the Highway Capacity Manual (TRB, 2000) suggests that rubbernecking could be responsible for a reduction in capacity in the direction of travel opposite to that in which the incident occurred. The reduction can range from 5% for a single car accident and one emergency vehicle to 25% for multiple-vehicle accident with several emergency vehicles. Masinick and Teng (2004) conducted a thorough examination of the impact of rubbernecking due to accidents on the Hampton Roads freeway system, in Virginia, USA. They found that approximately 10% of accidents caused rubbernecking on the opposite carriageway, which on average caused an average delay of 107 vehicle/hours and reduced the capacity of the roadway by 12.7%.

Incidents caused by drivers being distracted while rubbernecking have been estimated to account for as many as 35% of accidents (Masinick and Teng, 2004).

5.3.3 Method

Godstone motorway incident data was examined for records of rubbernecking. Once the selected incidents were examined and locations established, the four lane road capacities under prevailing conditions were estimated by calibrating speed-flow curves for the relative motorway sections using MIDAS traffic flow information. This data was then filtered for consistency and accuracy, resulting in a total of eight incidents involving rubbernecking to be examined. The capacity reduction due to rubbernecking at the incident was then measured as the minimum ten minute flow rate during incident conditions. The influence of incidents on speed will also be examined.

5.3.4 Results

A summary of results found is shown in table 5.8.

It can be seen that on average over all eight incidents the average speed of traffic, on the opposite carriageway to the incident, fell by approximately 45.29% compared with just prior to the incident. The average speed at one incident even fell to as low as 15.5 km/h. The greatest reduction in speed was at incident number 579 where speeds fell by 80.65%. A plot of vehicle speed against time is shown in figure 5.8

and clearly demonstrates the impact of the incident. It should be noted that incident number 579 was a major incident which involved a complete carriageway closure and the response of many emergency vehicles, all of which motorists do not regularly see on a motorway.

At three incidents there was no visible reduction in flow as a result of an incident. For the remaining incidents however there was an average theoretical maximum capacity reduction of 39.9%, with a maximum reduction in flow at incident number 428, of 48%. Another indicator of rubbernecking may be the reduction of flow compared to that just prior to an incident. In comparison to pre-incident flows, rubbernecking reduced the flow by 15.63%.

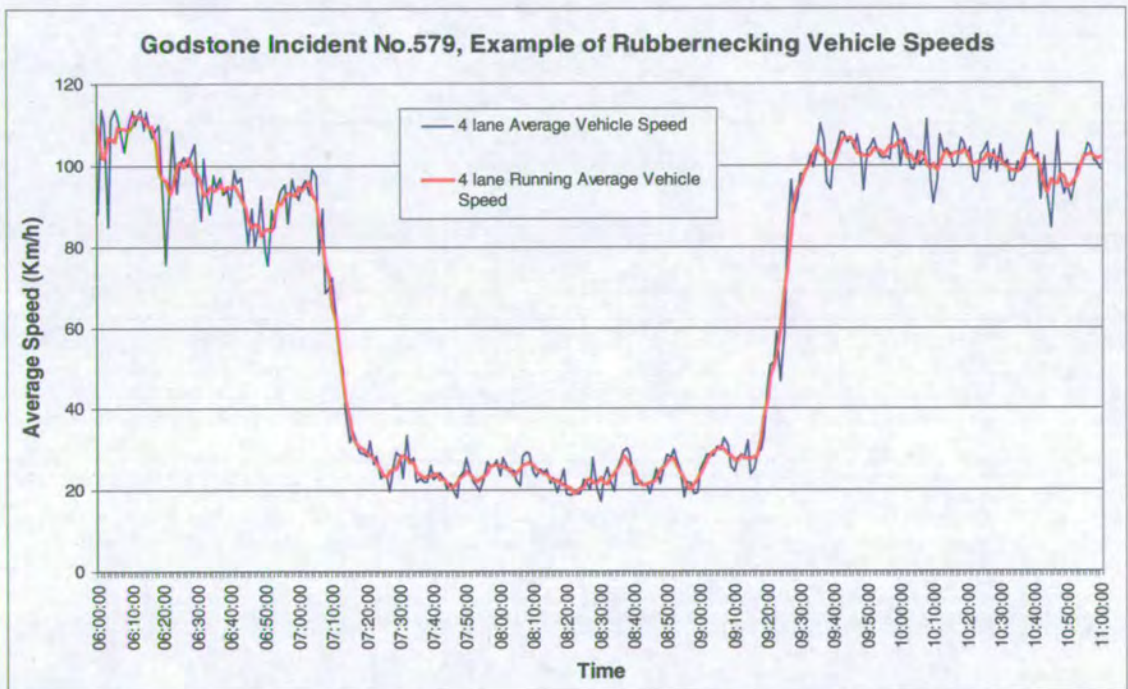


Figure 5.8 Incident No.579 Rubbernecking Vehicle Speeds.

Table 5.8 Rubbernecking Results.

Incident No.	Pre Speed (Km/h)	During Speed (Km/h)	% Reduced	Absolute Capacity	90% Capacity	Pre-Flow	Reduced Capacity	Remaining %	Reduced%	Pre-Remaining %	Pre-Reduced%
123	107	69	35.51%	2028	1825.2		No visible reduction	N/A	N/A	N/A	N/A
161	100.5	67	33.33%	2160	1944	1416	1336.5	68.75%	31.25%	94.39%	5.61%
269	108.25	61.825	42.89%	2256	2030.4	1158	1096.5	54.00%	46.00%	94.69%	5.31%
290	92	52	43.48%	2448	2203.2	1338	1242	56.37%	43.63%	92.83%	7.17%
428	50.5	15.55	69.21%	2166	1949.4	1645	1014	52.02%	47.98%	61.64%	38.36%
458	108	97	10.19%	2106	1895.4		No visible reduction	N/A	N/A	N/A	N/A
498	85	45	47.06%	2520	2268		No visible reduction	N/A	N/A	N/A	N/A
579	107	20.7	80.65%	1740	1566	1389	1087.5	69.44%	30.56%	78.29%	21.71%

Results Summary

The overall results from eight incidents involving rubbernecking indicated the following:

- (1) Incidents on the opposite carriageway affected speeds greater than flows.
- (2) Several incidents showed no visible signs of change in speed or flow.
- (3) The average speed at one incident was reduced by 80.65% during emergency operations on the opposite carriageway.
- (4) On average the "average speed" dropped by 45.29% from pre-incident conditions.
- (5) The theoretical absolute capacity of the carriageway was reduced by a maximum of 47.98%.
- (6) The average maximum capacity reduction was 39.88%
- (7) Comparing pre-flows to incident flows, the flow was reduced by 15.63%

5.3.5 Discussion

The above data shows that rubbernecking on the M25 causes a greater reduction in capacity than is shown in the Highway Capacity Manual.

When trying to establish the effect of rubbernecking, traffic flow on the opposing carriageway must be running at capacity so that any reduction in flow is a function of decreased vehicle speed and not variable vehicle demand upstream of the incident. Alternatively flows could be below capacity, but it would be necessary to ensure that flows prior to, during and after the incident were constant to avoid measuring speed/flow effects associated with variable demand.

The effect on the opposite carriageway to an incident can be affected by many factors: roadway characteristics, number and type of emergency vehicles, vehicle lighting on scene (number of blue lights), severity of incident, whether motorists can actually see the incident, location of incident within carriageway and the general light levels. It was observed that incidents had a greater influence if it was dark, there were numerous emergency vehicles, especially fire engines, with their blue lights flashing and they were located in lanes nearer the central reservation. At the

majority of locations on the M25, carriageways are only separated by a centre reservation barrier, therefore there is nothing blocking motorists' view of an incident, but at locations where carriageways are grade separated or there is vegetation between them, the impact is lessened.



Figure 5.9 Example of Incident Visibility From Opposite Carriageway.

An example of the visibility of an incident from the opposite carriageway is shown in figure 5.9. This demonstrates how easily incident management operations can be seen from the opposite carriageway on some sections of motorway. It can also be seen how high visibility markings and clothing, used to improve responder safety can actually prove to be a distraction to drivers.

During the data gathering at Godstone motorway control room, two incidents were observed that occurred due to rubbernecking, both involving injuries: one on the opposite carriageway and the other in the next lane to an existing incident. This demonstrates the impact of rubbernecking on the safety of other motorists and incident responders.

The impact of rubbernecking on traffic and safety further demonstrates the need to clear incidents as quickly as possible.

In an attempt to reduce rubbernecking on the M25 a new portable incident screen system is soon to be trialled. The system will be used at major incidents to block passing motorists' view from the opposite carriageway. The system is mounted to the central reservation crash barrier and a demonstration is shown in figure 5.10. The system is currently used in the Netherlands where it has had a major impact on rubbernecking congestion and similar results are expected on the M25. The use of increased height concrete safety barrier would also limit the view of motorists into the opposing carriageway.



Figure 5.10 Photographs of a new portable incident screen system (Source: Mr. Bob Wadsworth).

5.3.6 Section Summary

It was shown that:

- Rubbernecking can significantly reduce the capacity of the carriageway- on average traffic flow dropped by 15.63% during an incident.

- Rubbernecking can also reduce the speed of vehicles on the opposite carriageway- average speed dropped by 45% during an incident.
- The safety of operatives and other motorists can be compromised by rubbernecking- two incidents were witnessed as a result of rubbernecking on the opposite carriageway during this study.
- Possible mitigation strategies have been discussed.

5.4 Calculation of Incident Delays on Motorways

5.4.1 Introduction

It has been shown, in section 5.2, that incidents reduce the available capacity of motorways. Therefore if traffic flows are greater than that of the available capacity of the roadway, motorists will experience delay.

This section will detail the calculation of estimated delays due to incidents on motorways.

5.4.2 Background

Incident induced delays have been calculated using a variety of methods. There are two basic ways to determine delays on motorways: either to measure directly or simulate it. To measure it directly requires an extensive network of accurate loop detectors, accurate incident information and extensive computation. Simulation of the delay due to incidents is far more popular.

The most commonly used simulation approach is to use the deterministic queuing method which involves performing simple calculations incorporating roadway capacity, duration of the incident and the reduced incident capacity. Another way to simulate delay is to use a micro-simulation or macro-simulation package. These commercial packages require extensive input data and calibrating to produce accurate incident delay estimation. Other methods using shock wave analysis and traffic simulation have also been used to determine incident delay.

The most frequently used method was developed by Morales (1987) and used a cumulative volume approach to calculate delays on US freeways due to incidents. Morales' approach was to use two cumulative volume curves (one for arrivals and the other for departures at the incident location) which are plotted on the same time axis. The area between the two curves represents the delay experienced by motorists due to the incident. His model enabled delay, time-to-normal-flow and the maximum queue length to be quickly and easily established.

Al-Deek et al (1995) developed a new method and made improvements to Morales' approach by looking at delays in time slices. Traffic volumes were used in conjunction with traffic speeds in the new delay formula with incident delay being calculated using a reference average speed which reflects the normal traffic conditions.

5.4.3 Method

Delays caused by incidents will be estimated by using a cumulative arrival-departure curve. The magnitude of delay varies with the traffic volume, number of lanes blocked and the duration of the incident. This information was obtained from Godstone incident records and MIDAS traffic flow data.

The cumulative demand and capacity method is one of the most commonly used in traffic engineering. It is based on a static model which implies constant traffic demand D_0 upstream of the incident location. The advantage of this method is its simple analytical formulation. The total delay D is expressed through the formula:

$$D = \left[(t_2 - t_1)^2 \times (C - C_r) \times (Q - C_r) \right] + 2 \times (C - Q) \quad [\text{Eq. 5.1}]$$

Where C is the roadway capacity under normal conditions, C_r is the reduced capacity, Q is the volume of the demand upstream of the incident and $(t_2 - t_1)$ the duration of the incident. This formula shows that the total delay due to an incident is proportional to the square of the incident duration, demonstrating the importance of quick incident clearance.

The delay due to an incident can also be graphically represented, as shown in figure 5.11 below. The horizontal axis is a time line indicating the occurrence of the incident related event and the overall duration of their impact on traffic flow. The vertical axis is the cumulative traffic volume – the sum of vehicles passing any given point on the motorway in a defined time period. Time to normal flow (TNF) and maximum queue (Q_{max}) can also be calculated.

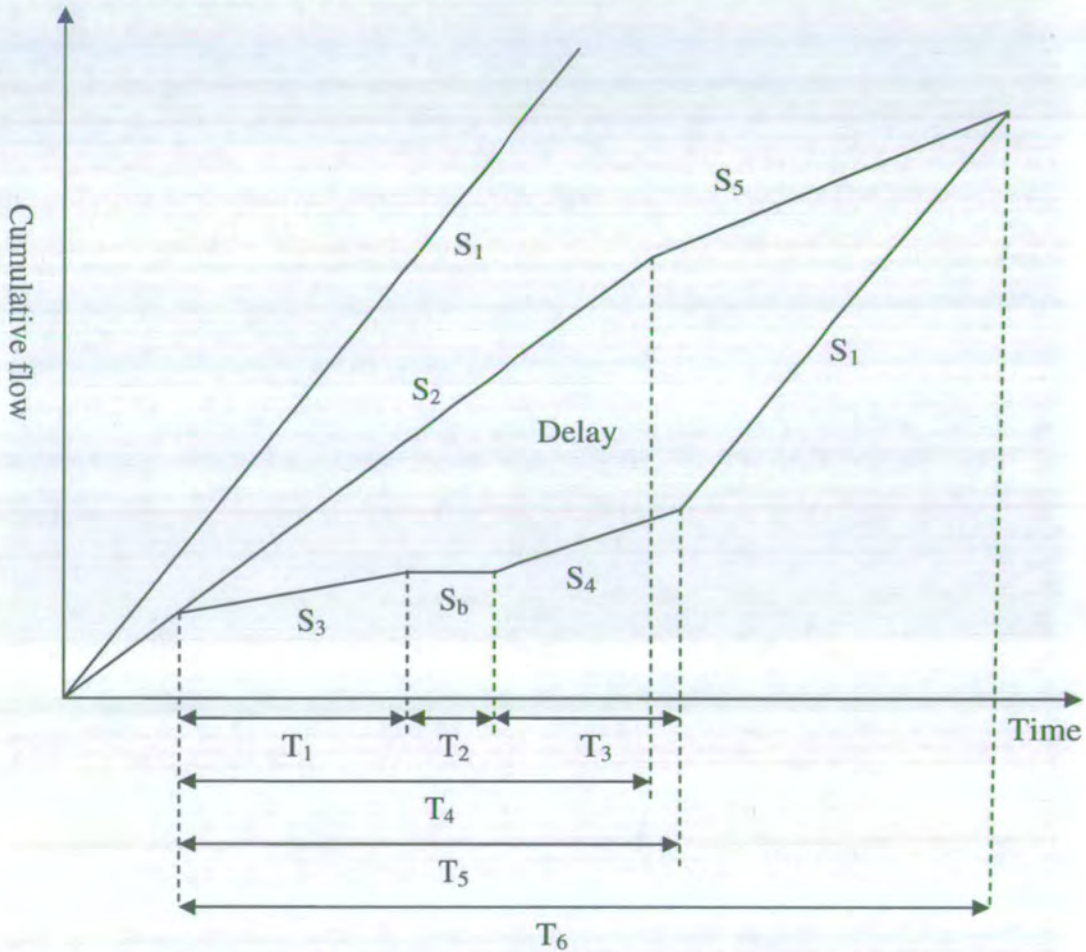


Figure 5.11 Graphical Representation of Incident Delay.

The demand flow or volume – the total number of vehicles using the motorway at a given time is represented by line S_2 . When an incident occurs, the reduced roadway capacity (S_3) is less than the demand flow because of a lane blockage. This reduced capacity remains in effect until something is done. In the example shown in figure 5.11 there is a short total closure, at T_2 where $S_b=0$, when the police would stop the traffic to clear all vehicles to the hard shoulder. Once lanes are no longer blocked,

the capacity would be increased, but still not fully, shown as S_4 . When the incident is fully cleared, the queued traffic can begin to flow at getaway capacity, which is the same as the roadway capacity (S_1). When the last vehicle in the queue reaches the normal flow speed and the traffic resumes flowing at the demand volume, the effects of the incident are over. The total delay is the area within the flow lines.

The total delay, time to normal flow and queue length is then calculated using the below equations:

TotalDelay =

$$\left[\begin{aligned} &T_1^2(S_1 - S_3)(S_5 - S_3) + T_2^2 S_1 S_5 + T_4^2(S_1 - S_2)(S_2 - S_5) + 2T_1 T_2 S_1(S_5 - S_3) \\ &+ 2T_1 T_3(S_1 - S_4)(S_5 - S_3) + 2T_1 T_4(S_1 - S_3)(S_2 - S_5) + 2T_2 S_5(S_1 - S_4) \\ &+ 2T_2 T_4 S_1(S_2 - S_5) + 2T_3 T_4(S_1 - S_4)(S_2 - S_5) \end{aligned} \right] \quad [\text{Eq. 5.2}]$$

$$/ [2(S_1 - S_5)]$$

$$TNF = [T_1(S_1 - S_3) + T_2 S_1 + T_3(S_1 - S_4) + T_4(S_2 - S_5)] / (S_1 - S_5) \quad [\text{Eq. 5.3}]$$

$$Q_{\max} = T_a S_2 + T_b S_5 - T_c S_3 - T_d S_4 - T_e S_1 \quad [\text{Eq. 5.4}]$$

S_1 – Capacity flow rate of road (veh/hour)

S_2 – Demand flow rate

S_3 – Capacity due to incident, initial bottleneck

S_b – Road closed, zero capacity = 0

S_4 – New capacity, adjusted bottleneck capacity

S_5 – Revised demand flow rate.

T_1 – Incident duration until first change (Detection and response time)

T_2 – Road blocked for removal of vehicles to hard shoulder, time of total closure

T_3 – Time of incident clearance

T_4 – Time under initial demand

T_5 – Incident duration

T_6 – Time until normal flow resumed = *TNF*

T_a , T_b , T_c , T_d and T_e are functions of the conditions being considered.

5.4.4 Results

A worked example for Godstone incident number 405 using a cumulative arrival-departure curve will now be performed.

Incident 405 involved an accident blocking lanes one and two of the anti-clockwise M25 between junctions 13 and 12 at marker post 4857B. The incident was first observed by a police patrol on the opposite carriageway at 08:40 and lane control signals and VMS were immediately activated. An Incident Support Unit was on scene at 08:45 and the police arrived at 08:51. The incident involved two HGV's with one stuck in lane two due to its brakes seizing on. All travel lanes were cleared by 09:34 with all vehicles moved to the hard shoulder. The scene was completely cleared by 10:34.

The flow diagram for this incident is shown in figure 5.12 and demonstrates the three clear phases of the incident: (1) the initial capacity reduction prior to the travel lanes being cleared, (2) the improved flow of opening all travel lanes and (3) the traffic recovery period.

Using the above incident information the following data for the delay calculation can be established:

T_1 – 54 minutes

T_4 – 0 minutes

T_2 – 0 minutes

T_5 – 114 minutes

T_3 – 60 minutes

As demand was assumed to be constant T_4 is assumed to be zero.

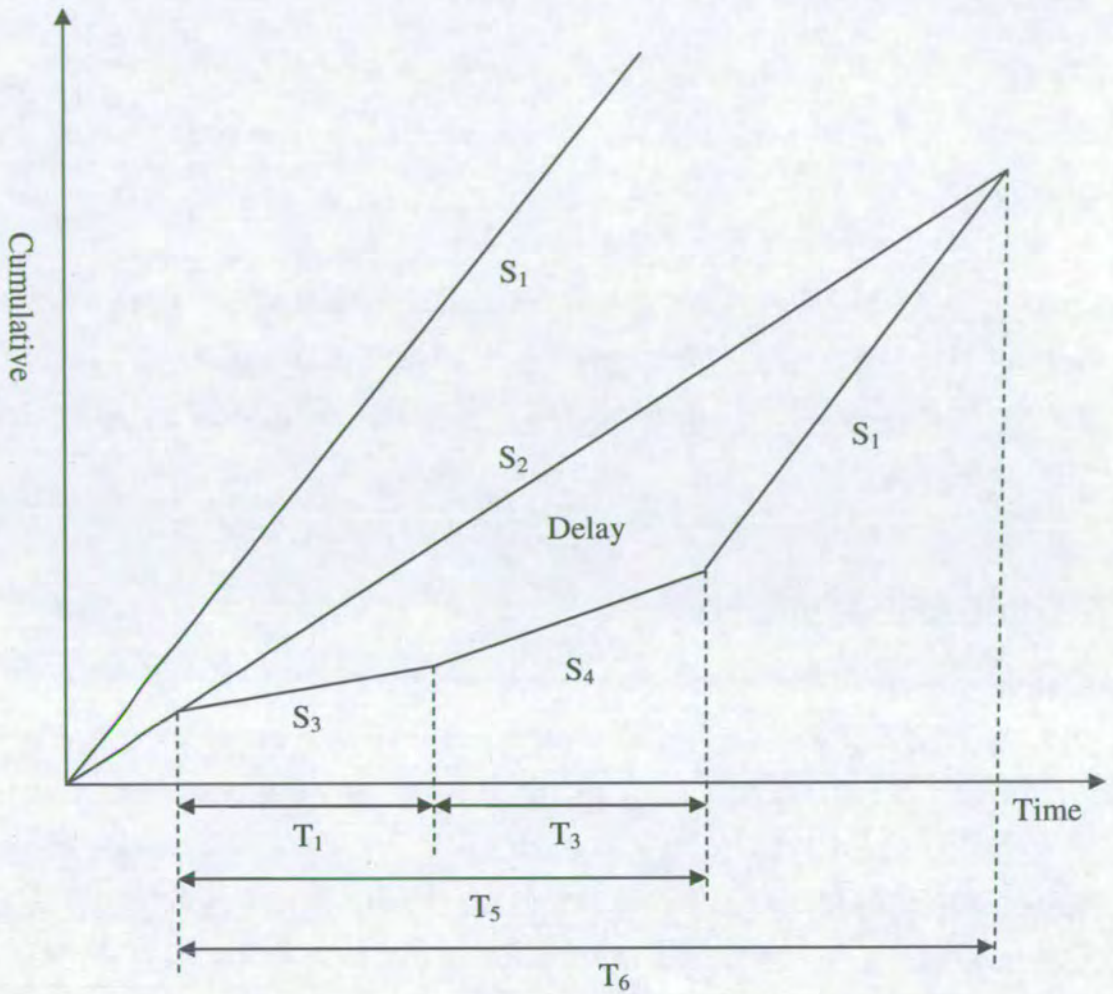


Figure 5.12 Graphical representation of Godstone incident No. 405 delay.

Using the MIDAS traffic flow data for the roadway section, all required flow data can be established. A selection of data was examined to establish a historical demand flow for the time of the incident. The section capacity was calculated using the same method detailed in section 5.2.5 above, which was then modified using the capacity reduction figures detailed in section 5.2. As the traffic was not stopped to remove vehicles to the hard shoulder S_b is zero. Also, it is assumed that there is no reduction in the demand flow therefore $S_5 = S_2$. Therefore the following flows will be used for the delay calculation:

- | | |
|---------------------------|---------------------------|
| $S_1 - 7920$ veh/hour | $S_4 - 4649.832$ veh/hour |
| $S_2 - 5800$ veh/hour | $S_5 - 5800$ veh/hour |
| $S_3 - 2960.496$ veh/hour | $S_b - 0$ veh/hour |

As all necessary required information to perform the delay calculation is now known, equations 5.2, 5.3 and 5.4 will be used to calculate the estimated total incident, time to normal flow and the maximum queue length:

Therefore, the Total Delay is approximately 7519 Vehicle Hours. The Time to Normal Flow (TNF) is 218.9 Minutes and the maximum queue length (Q_{max}) is 2555 Vehicles, approximately 5.8 kilometres (3.57 miles) (assuming 9 metres per vehicle over 4 lanes).

5.4.5 Section Summary

It has been shown that it is possible to calculate the delay associated with motorway incidents. By estimating the delay experienced by motorists it will enable new incident management techniques to be trialled and the benefits quantified. For example if supplying ISUs and HATOs with flashing headlights would reduce their response time to incidents by 2 minutes then the corresponding delay reduction could be estimated.

The accuracy of this method is dependent upon the input values and quality of input parameters. A real time system installed in control rooms could assist in setting of emergency diversion routes and support decision making regarding motorist welfare.

5.5 Chapter Conclusions

This chapter has examined the influence of motorway incidents on traffic flow. Their impact on the roadway capacity and the influence of rubbernecking were also examined. Finally, the total delay experienced by motorists due to incidents was calculated.

Conclusions for each section are detailed below:

Section Two

It was shown that incidents on motorways significantly reduce the available capacity of the road, by an amount greater than just the proportion of original capacity

physically blocked. This result agrees with previous research however the extent to which the capacity is reduced varies depending on the number of lanes blocked- this study found that minor incidents, blocking only the shoulder or one lane, had a greater impact and that more severe incidents had a lesser effect than that found in other studies. These differences may be accounted for by differences in traffic makeup, vehicle characteristics and capabilities, as well as driver behaviour.

This information with traffic flow data can be used to accurately estimate delays associated with incidents on motorways.

Section Three

The influence of rubbernecking on traffic flow was examined. It was shown that it can significantly reduce the flow and speed of traffic on the opposite carriageway to an incident. The safety of operatives and other motorists can also be compromised by rubbernecking- two incidents were witnessed as a result of rubbernecking on the opposite carriageway during this study.

Several factors were identified to have an influence on rubbernecking:

- roadway characteristics,
- number and type of emergency vehicles,
- vehicle lighting on scene (number of flashing blue lights),
- severity of incident,
- whether motorists can actually see the incident,
- location of incident within carriageway
- general light levels.

Additionally, it was observed that incidents had a greater influence if it was dark, there were numerous emergency vehicles, especially fire engines, with their blue lights flashing and they were located in lanes nearer the central reservation

Several mitigation strategies were also discussed including incident screening and higher central reservation barriers.

These results further enforce the need for quick clearance of incidents.

Section Four

It has been shown that it is possible to calculate the delay associated with motorway incidents. By estimating the delay experienced by motorists it is possible to quantify the benefits of any new incident management techniques that are trialled.

As with any model or calculation, the output is only as good as the input data and parameters. The data used within this study was used with confidence as the author personally collected it but for larger impact studies less reliable sources may have to be used.

The use of a real time system delay estimation system, using the presented method, in motorway control rooms could be used as a decision support system to support choices in setting of emergency diversion routes and motorist welfare assessment.

Understanding the breakdown of incident delays enables a better understanding of methods to mitigate their impact. This will be valuable in subsequent chapters, where the effectiveness of motorway signals in reducing delay is assessed, and the role of ISUs in reducing delay is also investigated.

6 Effectiveness of Matrix Signals and Signs

6.1 Introduction

Matrix signals and variable message signs are a very common sight on British motorways and trunk roads. Basic matrix signals have been in use since 1967 providing motorists with valuable safety information, and warning of hazards ahead. They were designed to influence traffic flow to prevent collisions or control traffic by displaying advisory speed limits and indications of available lanes during incidents. Originally signals were controlled by the local Police control office but this activity is currently being transferred to the Highways Agency.

Today matrix signals are installed over the majority of the majority of the motorway road network and on busier stretches of trunk roads. These signals are now often automatically controlled to provide protection to queuing motorists following automatic detection of incidents. New more advanced signals are now used to display mandatory speed limits to automatically control the flow of traffic.

This chapter will present a review of motorway matrix signals and signs in use on the motorway and trunk road network in Britain. Applications of the discussed signals and signs will also be detailed. The effectiveness of matrix signals and signs will then be assessed including compliance rates with mandatory signals and the impact of variable messages on driver route choice.

This chapter is structured as follows:

- **Section Two.** A background and review of matrix signals and their uses, both as a method of imparting general information to the motorist (e.g. of adverse weather ahead) and as a tool used to reduce delay and congestion caused by an incident is presented.
- **Section Three.** An assessment of motorists' compliance with motorway matrix signals is presented. To date there has been no study into driver compliance with matrix signals on a wide motorway, and this is required in

order to determine the likely effectiveness of the use of matrix signals in any incident management strategy.

- **Section Four.** This section assesses the impact of variable messaging signs on delay experienced by motorists, and consequently the level of reliance that should be put on the use of variable messaging signs in the management of traffic to reduce delay.
- **Section Five.** Chapter summary and conclusions.

6.2 Background

Matrix signals, often known as aspects, are electronic signs which are used to inform motorists about speed restrictions, lane closures, or even adverse weather conditions. These motorway traffic control signals are usually set for safety reasons. They are a simple method of incident management and allow motorists to be warned of an incident ahead, prior to any responding vehicles arriving at the incident scene. This also offers protection to responders at incident scenes. Variable Message Signs (VMS) are also used, often in conjunction with matrix signals, to provide information to motorists. All signal types use the same basic equipment and are designed to provide legible displays from 200 metres, with their flashing amber lanterns designed to attract motorists' attention to the signal visible from 500 metres (Harbord, 1991 and Russam, 1984).

6.2.1 Matrix Signals and Signs

On the M25 there are four similar examples of motorway matrix signs. Firstly, there are central reservation post-mounted signals that can be used for up to 3-lane motorways and trunk roads. The signs are also known as MS1's as they were the first generation matrix signs, first installed on the M4 motorway in 1967 (May, 1971) and still serve some 70% of the motorway network (National Audit Office, 2005). These are on all 3-lane sections of the M25 and are spaced at approximately 3 km intervals. They are however limited to displaying advisory fog warnings, speed restrictions and lane restrictions (using "wicket" symbols) with amber flashing warning lamps that apply to all carriageway lanes.

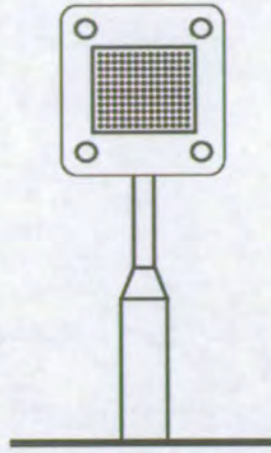


Figure 6.1 Example of Central Reservation Post Mounted Matrix Signal.

A further example of the post-mounted signal are those mounted in pairs- one either side of the lanes at the entry slip roads. These signals are identical to the standard central reservation ones but have the additional feature to display red lamps. This allows for the mandatory closure of an entry slip road. Entry slip signals are usually only installed on the busier road sections.

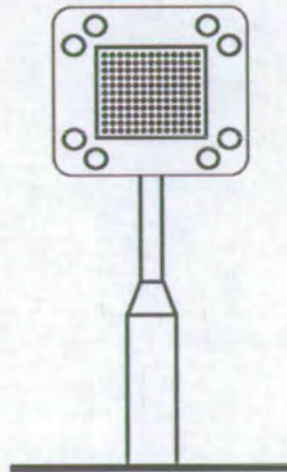


Figure 6.2 Example of Slip Road Post Mounted Matrix Signal.

The next example is a gantry based system, used on busier road sections or at interchanges, provides control for each lane of traffic and is more flexible as a different matrix signal for each lane on the road are used. In addition to the standard features of the post mounted signal these signals can display lane diversions and red "X" with red flashing lamps which allows for mandatory lane closures. These gantries are nominally spaced at 1 km intervals but this varies by location.

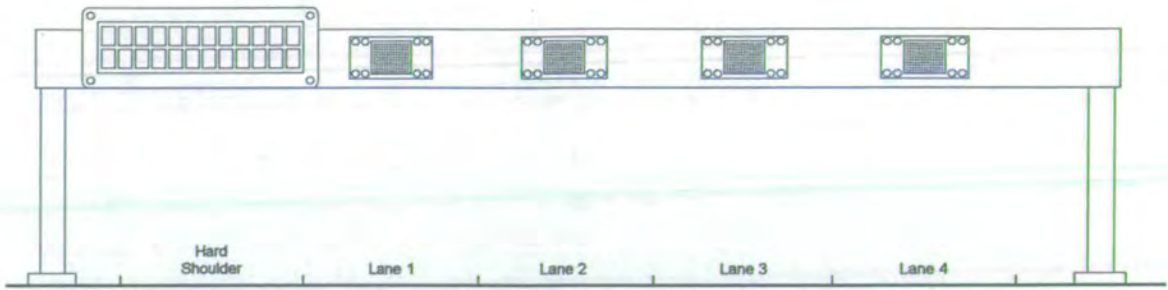


Figure 6.3 Example of Gantry Matrix Signals and Enhanced Message Sign.

The final example of standard matrix signals, on the M25, is a variation of a gantry mounted signal. These are used within the “Controlled Motorway” section, between junctions 10 and 16, with Controlled Motorway Indicators (CMIs) replacing standard matrix signals. The CMIs can display all of the previously described functions but when displaying mandatory speeds the figures are surrounded by red rings. This differentiates between the advisory speed limit of standard matrix signals and the mandatory ones shown on the Controlled Motorway section.

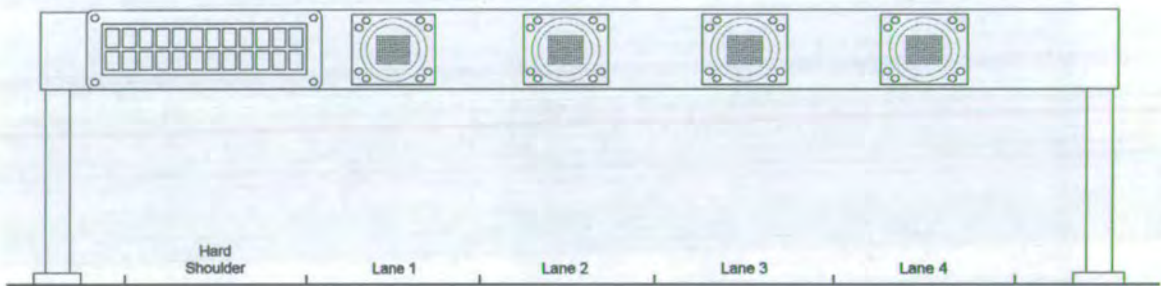


Figure 6.4 Example of Controlled Motorway Gantry Matrix Signals and Enhanced Message Sign

In addition to the standard matrix signals, Variable Message Signs (VMS) have also been used on the road network since the 1970s. A VMS or Enhanced Message Sign (EMS) is an electronic sign which can display text information concerning incident or hazards. EMSs can be mounted either on cantilever posts or alongside gantry mounted matrix signals. They can display 2 lines of 12 or 16 characters, with each cell displaying one character. These signs often provide motorists with explanations for the signal settings, in an attempt to improve compliance rates.

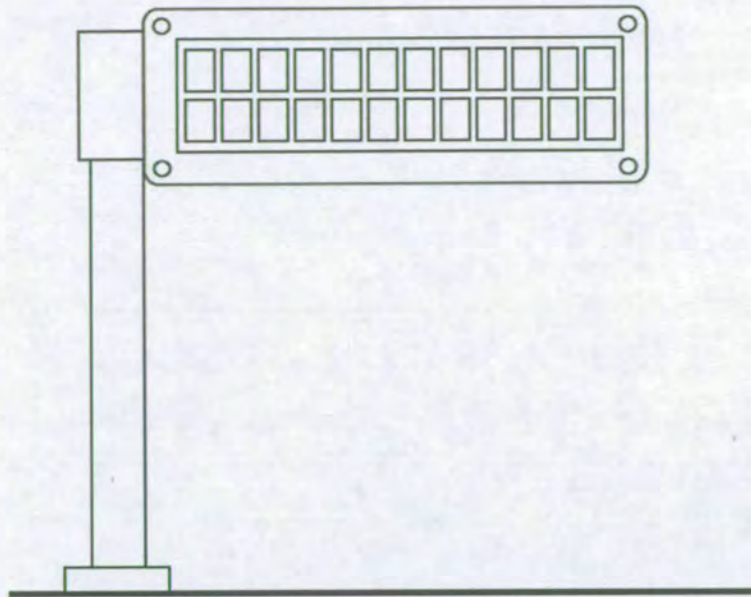


Figure 6.5 Example of a Cantilever Post Mounted Enhanced Message Sign

In 1991 a new signal called Motorway Signal Mark 2 (MS2) was installed on the M25 as part of a trial (Harbord, 1991). This new signal comprised of two elements—an Enhanced Matrix Indicator (EMI) and an EMS. The EMI's were larger than the standard matrix signal and capable of displaying information for 4 lanes of traffic, with a 20x14 matrix of cells rather than the 13x11 of standard matrix indicators. MS2s were only cantilever post mounted next to the carriageway. These signs are now obsolete and have been replaced by Motorway Signal Mark 3 (MS3) for new installations.

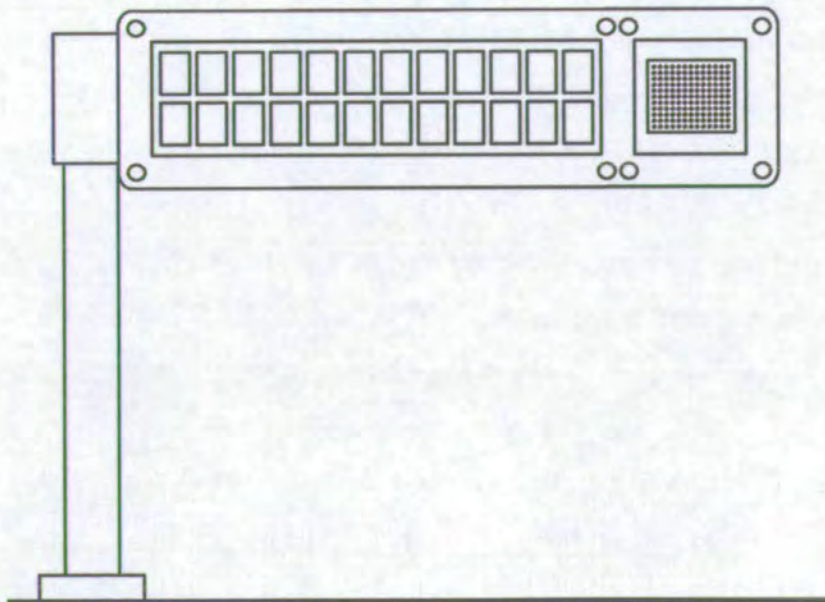


Figure 6.6 Example of a Cantilever Post Mounted Motorway Signal Mark 2

MS3s are larger and more advanced versions of MS2s with 2 lines of 16 characters or 3 lines of 18 characters and an EMI. As with MS2s, these signs are also only cantilever post mounted next to the carriageway. Standard VMS, without the matrix signal, are also used just to provide just text information to motorists, dependent on location requirements.

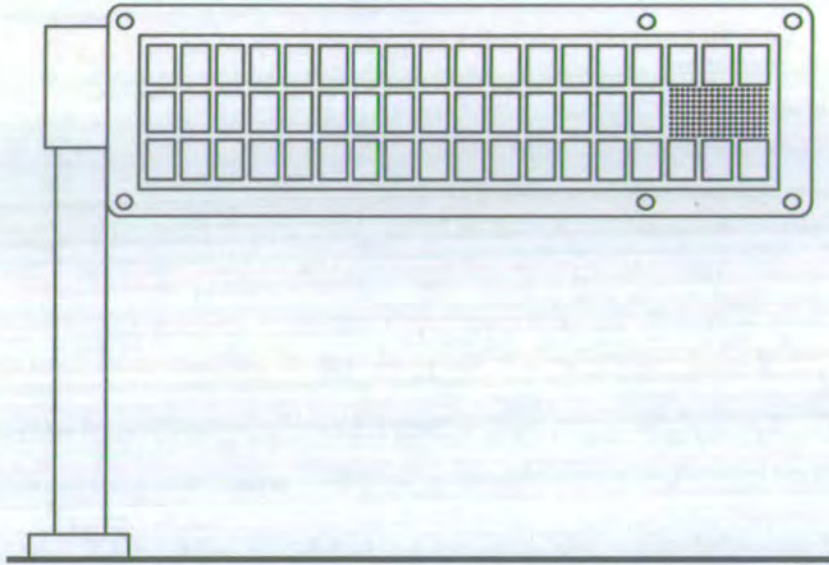


Figure 6.7 Example of a Cantilever Post Mounted Motorway Signal Mark 3.

The latest generation of signs, Motorway Signal Mark 4 (MS4), were initially installed as a trial on a section of the M4 motorway, between junctions 12 and 14 in late 2003, where thirty-six signs were spaced at nominally 1.5 kilometres. These signs use the latest, state of the art, LED technology which has increased flexibility and visibility of the display. As motorists now expect more information from road signs, these signs are capable of displaying standard text but also use graphics to convey their message. Drivers can process and understand picture based messages up to a second faster than a pure text message, allowing more time to react (Highways Agency, 2005b). These new signs are also more aesthetically pleasing than previous signs, with approximately 33% smaller surface area than MS3s. The use of LED technology also allows the signs to be lighter and more easily mounted, thus reducing costs. The trial was concluded at the end of 2004 and as a consequence MS4 signs are at present being installed on the M42 Automatic Traffic Management (ATM) pilot, replacing small EMS on gantries.

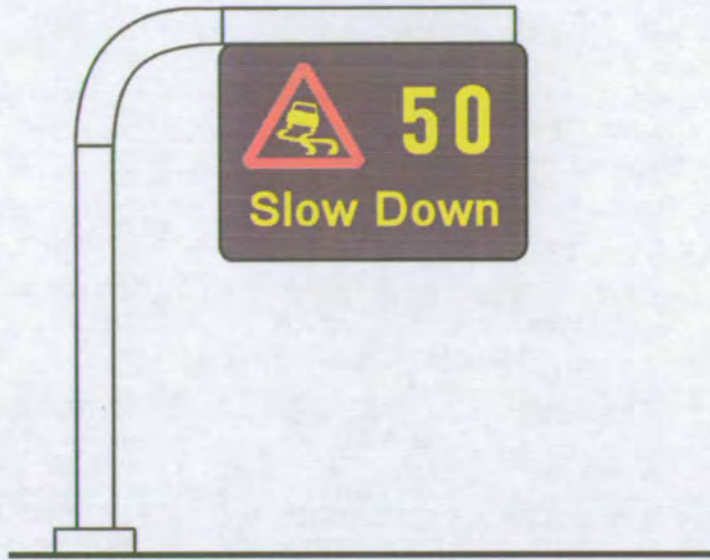


Figure 6.8 Example of a Cantilever Post Mounted Motorway Signal Mark 4.

Signal Settings

As already stated a wide variety of information can be displayed on the matrix signals. The signs can be used to display temporary reduced speed restrictions, to control speeds near incident scenes. Emergency lane closures can also be achieved using the signals before responders and any proper traffic management (cones and warning signs) arrives at an incident scene. This is helpful in order to protect stranded motorists and warn of debris blocking lanes of the carriageway. A graphic showing most of the available directions is shown in figure 6.9. Full details of displayable information is given in the Traffic Signs Regulations and General Directions 2002 (HMSO, 2002). The information displayed on the signals is enforceable; motorists disobeying these messages can be prosecuted.

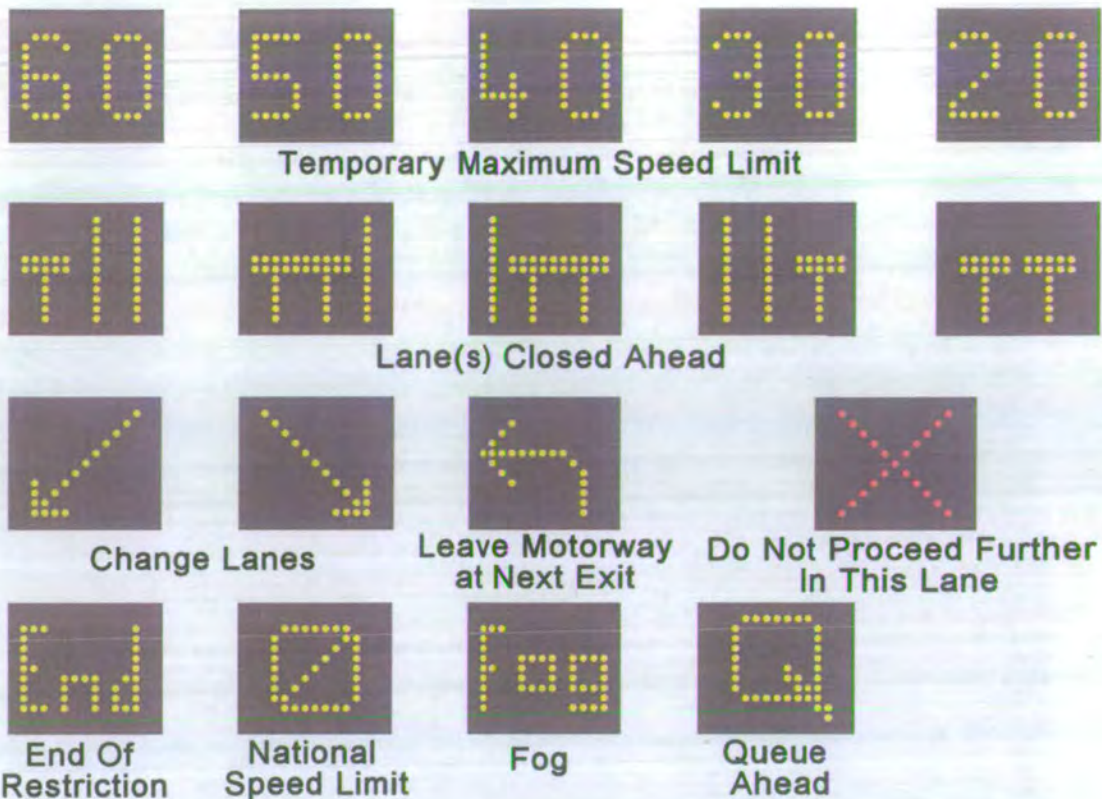


Figure 6.9 Examples of Matrix Signal Messages.

Full available display information, or legends, for Variable Message Signs is also given in the Traffic Signs Regulations and General Directions 2002 (HMSO, 2002). These legends include “Tactical”, “Driver Information” and “Strategic” messages. Only approved messages are allowed to be set, with operators having to choose which legend is required from a menu system. An example of a tactical message would be “Accident Ahead” or “Lane Closure Slow Down” where immediate action is required to manage a safety hazard locally. Tactical legends are restricted to a two lines by 12 character format for consistency and to reinforce their impact. Driver information messages such as “M25 Closed At Next Junction” or “M1 North Congestion” are used to inform motorists of incidents, either on the road that they are travelling or on one which they may soon be travelling on. Strategic messages are typically set by the HA’s National Traffic Control Centre (NTCC) to inform motorists of significant delays on a route and advise strategic diversions. An example strategic message could be “M40 Closed J10, For London, Use M6 (S), M1 (S)”. Strategic messages are often set a great distance away from an incident in an attempt to influence motorist’s journey choices.

Example Incident Signal Settings

Figure 6.10 shows a CCTV image of an example emergency lane closure using motorway matrix signals and VMS. This incident involved tyre debris in lane one approximately 200 metres past the red “X” signal in the image. It can also be seen that a tactical message has been set on the VMS to convey to motorists the reason for the lane closure.



Figure 6.10 CCTV Image of an Example Lane Closure

Figure 6.11 shows a schematic of example incident signal settings for an accident in lane three of a three lane carriageway, with centre reservation post mounted signals installed. It can be seen that the signal nearest the incident is showing a “wicket” symbol representing the right hand lane being closed and that the proceeding signal has been set to an advisory speed limit of 50 mph.

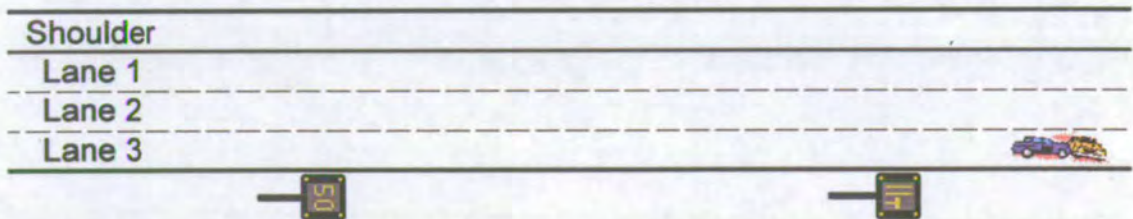


Figure 6.11 Example Incident Signal Layout and Settings for Post Mounted Signals

Figure 6.12 shows a schematic of example incident signal settings for an accident in lane four of a four lane carriageway, with overhead gantry mounted signals installed. This example would be similar to an incident on the M25 controlled motorway section, where mandatory speed limits can be displayed. On another stretch of motorway, the only difference would be that the speed limits would not have red rings around them and would only be advisory. With this incident it can be seen how much more flexible the gantry mounted system is and how motorists receive improved information. The signal nearest the incident, in the appropriate lane is displaying a red "X" with flashing red lanterns and the preceding signal is automatically showing a left divert arrow. It can also be seen that VMS can be used to provide motorists with information of the situation ahead, in this case warning of "Accident Ahead", "Lane Closure Slow Down" and "Accident Slow Down".



Figure 6.12 Example Incident Signal Layout and Settings for Gantry Signals

Method of setting

All matrix signals and VMS on the English motorway and trunk road network are controlled by the police, but this function is gradually being transferred to the HA following the Roles and Responsibility review (Highways Agency, 2005a). They are managed by the appropriate HA Regional Control Centre (RCC) or Police Control Office (PCO). Control room staff activate signs and signals using the Highways Agency Traffic Management System (HATMS) or the Control Office Base System (COBS) respectively, which through the National Motorway Communication System Mark 2 (NMCS2) activates the required settings. The control system (COBS or HATMS) is an interactive graphical picture of the road network with signals, signs, CCTV, MIDAS system and emergency roadside telephones. This allows the operators to choose quickly the exact signs and signals which should be set for the individual incident. When the controller selects the desired signal and chooses from the system menus the reason and aspect required, associated settings are

automatically set. For example with an emergency lane closure- the signal nearest the incident is selected, the reason for setting chosen and the aspect to be displayed selected, the system would automatically set the proceeding signals either to lane diverts or advisory speed limits. This ensures that signals are set safely and efficiently. In the near future, message signs will also be automatically coordinated with signals settings.

Public Attitudes

In recent years the British press have publicly criticised the setting of motorway signals on roads all over Britain as being inaccurate and inappropriate. They are often held in low regard by many drivers. On some stretches of road, without CCTV, controllers must rely on the accuracy of incident locations and severity reports from the general public. As this information is often erroneous it can consequently lead to situations where signals are set with the wrong meaning and in completely wrong location or over very large areas. It is normal practice for the location and symptom to be updated once responders reach the incident scene and the situation has been assessed. The police have acknowledged however that signals sometimes get left on after an incident. After ensuring that casualties are attended to, the carriageway is cleared, traffic is moving safely and witnesses' statements are collected, signals become relatively low priority and are sometimes forgotten (Rutley, 1992).

In a survey of public attitudes carried out in 1986 (Rutley, 1987) drivers were asked whether they thought the signals were switched on and off when they should be. Although most motorists were satisfied that they were switched on when needed there was considerable criticism that the signals were not switched off when they were no longer needed.

Similarly, in a survey carried out in 1978 (Cross and Parker, 1980) many drivers reported dissatisfaction with motorway signals. Approximately 15% of drivers felt that the signals served no useful purpose and 54% said they only "sometimes" complied with the signal settings displayed. The majority of drivers interviewed,

83%, did however clearly regard the matrix signals as an integral safety feature of the motorway network.

6.2.2 MIDAS System

The Motorway Incident Detection and Signalling (MIDAS) system is used to detect incidents, and automatically set upstream signals and message signs, to provide motorists with advanced warning of queuing traffic and incidents. The system was designed to minimise the impact of motorway incidents and improve driver safety.

The main components of the system were first trialled, by the HA, on the M1 motorway (Automated Incident Detection (AID) system) and the M4 motorway (Autowarn system). The M1 motorway AID system was trialled between 1985 and 1990 between junctions 10 and 19 (Cooper et al, 1992). The M4 Autowarn system was installed to protect motorists queuing on approach to toll booths at the Severn Bridge (Hobbs and Clifford, 1989). The M25 controlled motorway scheme used the basic infrastructure of the MIDAS system and was modified to provide a more advanced system. More detailed information on the development of the MIDAS system on the M25 is available from Morris and Negus (1997).

The MIDAS system consists of a pair of 3 turn inductive loops, buried in the surface of the road in each lane, spaced at approximately 500 metres along the length of each MIDAS section (figure 6.13). The magnetic field of passing vehicles induces a current in each loop. The system is wired so that the carriageway and lane number of the vehicle can be identified. The system controller uses this information to give each vehicle a timestamp, this can then be compared to the timestamp of the previous vehicle and the front to front time headway can be obtained. The difference in activation times and longitudinal separation of each half of the loop pair may be used to estimate the speed of each vehicle. The activation and deactivation times may also be used to calculate the time over loop, which combined with the speed estimate, can be used to calculate the vehicle length. All of this information is recorded in one minute intervals.

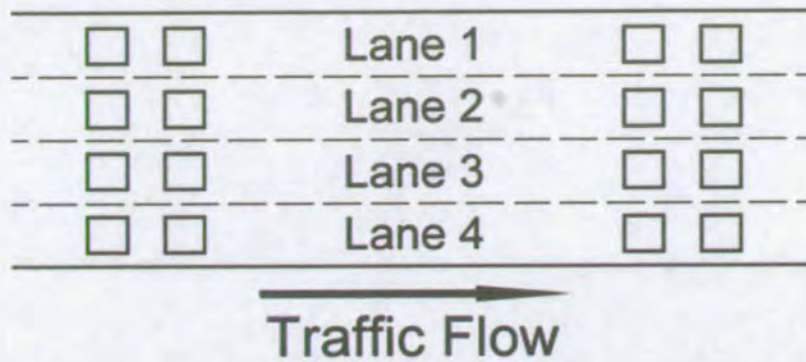


Figure 6.13 Example of MIDAS Loop Arrangement.

Each group of loops is connected to an outstation and all outstations are then linked to an instation, usually at the controlling office, via the transmission network. Each outstation examines the data using the HIGH OCCUPANCY (HIOCC) incident detection algorithm and transmits “high occupancy” alerts to the instation. The system then automatically sets lower speed limits (40 mph, 50 mph and 60 mph) on proceeding signals, to protect the back of the queue and give advanced warning to approaching motorists. The system also monitors the queue as it moves upstream, setting signals as necessary to continue to provide motorists with protection. Each outstation produces flow and speed alerts, using a flow and speed threshold algorithm (congestion alerts), warning of areas of high flows or low speed. The thresholds at which the alerts are generated are configurable for each site in order to make allowances for local road configurations. Both high flows and low speeds alerts are used to set a sequence of speed signals (60 mph and 50 mph) depending on whether the levels continue beyond the second threshold.

The signal setting output for the system also has two additional algorithms. Firstly a time smoothing algorithm is used to prevent the signals being changed too frequently. Once a series of signals have been implemented following an alert, the signals will remain on for a set period of time, even if the alert is clear. Any new alerts will however be immediately implemented. Secondly an algorithm monitors which signals are set along the motorway and will “fill the gaps” between any sites that are displaying reduced speeds. For example, two MIDAS sites may be showing a speed of 60, due to flow alerts, but the site in-between may be showing a blank

symbol. If this situation occurs the algorithm would automatically set the dividing signals also to a speed of 60. These algorithms reduce the number of speed limit changes experienced by motorists as they drive along the motorway.

The MIDAS system has been installed and is now operational on more than 800 kilometres of the HA's motorway network. Before permanent installation a candidate road sections must meet the following criteria (Highways Agency, 1997):

- **Traffic Flow:** The flow of traffic should exceed 15,000 vehicles per lane AADT on an existing motorway. On a new motorway, MIDAS should be installed if the traffic forecast will exceed the above limit within 5 years.
- **Length:** The section length should not be less than 20 kilometres, based upon 3 kilometre signal spacing. However, when there is greater density of signals a minimum of 10 signal sites should be covered.
- **Other Considerations:** MIDAS should be considered if areas have at least 20% higher than the national annual average accident rate for motorways, if sections of motorway have abnormal design standards for example tunnels, crawler lanes, steep gradients etc, closer than normal interchanges with a high density of joining and leaving traffic and if a junction queues back onto the motorway on a daily basis.

A recent study by the Transportation Research Laboratory, for the HA, examined accident rates on 600 kilometres of motorways where MIDAS had been operational for more than six months. They compared accidents rates before the introduction of MIDAS and after, over a ten-year period to September 2003. It was found that on motorway stretches where MIDAS was operated the number of injury accidents had fallen by 13%, which equates to an estimated annual saving of £40 million or £50,000 per kilometre of motorway.

6.2.3 M25 Controlled Motorway

Since August 1995, on the south-western part of the M25, the London Orbital Motorway, a "Controlled Motorway" pilot scheme has been operated. Initially the pilot operated between junction 11 (M3) and junction 15 (M4) but was extended in

November 1995 down to junction 10 (A3) following the completion of widening works. The scheme was again extended in March 2002 up to junction 16 (M40) giving a total of approximately 32km (20 miles). At present all roads within the Controlled Motorway are dual 4-lane. By the end of 2005 however junction 16 to 15 will be dual 6-lane and junction 15 to 12 will be dual 5-lane.

Traffic control is accomplished by using Controlled Motorway Indicators (CMIs) which are advanced motorway matrix lane control signals, and are capable of displaying “red rings” around the displayed variable speed limit, thus making it mandatory. These CMIs are installed above each lane on standard motorway gantries which are installed at nominal 1 kilometre intervals, depending on junction layouts. CMIs are also installed at entry slip roads to provide merging traffic with warning of the speed limit. Enhanced Message Signs are also installed on every gantry to provide additional driver information.



Figure 6.14 M25 Controlled Motorway

The philosophy behind Controlled Motorways is to manage congestion using mandatory variable speed limits that are correct for the traffic conditions. This uniform traffic speeds and reduces the seriousness of shockwaves (thus reducing stop-start driving). Smoothing traffic flow in this way helps to delay the onset of flow breakdown and advances the recovery of traffic flow from congested conditions (Highways Agency, 2004b). Using technology developed for the MIDAS system the Controlled Motorway system monitors traffic conditions and attempts to predict flow breakdowns and will reduce the speed limit to reduce their impact.

Initially when the Controlled Motorway scheme was first installed a fixed time plan (setting mandatory speed limits at certain times of day, regardless of traffic conditions) was used to control speeds. The plan was developed by examining historical traffic flow data and establishing when flow thresholds were expected to be exceeded. The fixed plan system was intended only to operate for a 3-month period to allow motorists to become accustomed to the system, after which a live traffic flow driven system would be introduced. During monitoring of the fixed time plan system it was noted that the speed limits were not always suitable for the traffic conditions, which was confirmed by the number of complaints received by the HA from motorists using this section of road. In response, an automatic live flow based operation was introduced earlier than planned, in September 1995.

The control system has been continually evaluated and enhanced to allow optimum operation. Parameters such as the flow trigger levels and the signal change timings were modified and their impact examined. To stop the speed limits changing too often, the traffic flow data input to the signal system was smoothed using a continuous moving average. An optimal set of control parameters for the whole scheme was established in April 1996. The parameters are continually reassessed as traffic conditions change over the years and each control site is assessed individually as traffic behaviour varies between locations.

In February 1997 the HA adapted the signal control algorithm to operate on both flow and speed data following complaints from motorists that the speed control signals were increasing or switching off while they were in heavy congestion. These complaints were caused by flow levels in queues falling below the specified thresholds as the system was unable distinguish between low flows during congestion and free flowing periods.

The High OCCupancy (HIOCC) incident detection algorithm was introduced in October 1997 to detect queuing or slow moving traffic and protect it by

automatically setting lower speed limits upstream (40mph, 50mph and 60mph). The HIOCC algorithm works in parallel with the controlled motorway system.

Between junction 10 and 13 in October 1998, the setting of Enhanced Message Signs (EMS) was coordinated with the signal settings. This feature provided motorists with appropriate and relevant information regarding the signal settings and warnings of congestion or queues ahead. This was expanded to the other areas of the controlled motorway in July 1999.

In order to realise the anticipated benefits of the Controlled Motorway scheme a high level of compliance with the mandatory speed limits was needed. To ensure this an automated enforcement system was developed to detect and record vehicles exceeding the speed limit. The enforcement equipment is capable of covering all lanes and is securely mounted in weatherproof enclosures on the rear of the motorway gantries. The enforcement system uses similar technology to that found in normal speeding and red-light cameras installed on many roads in Britain and around the world. The system consists of radar speed measuring equipment, flash, a 35mm camera, a "Rugby" clock receiver and a Controlled Motorway Indicator interface. A radar based speed detection system and conventional film technology is used as they provided the only proven method to meet the requirements of the Home Office Speedmeter Handbook. All of the speed enforcement systems are always live however there are only a few cameras, due to costs, which are moved between gantries to provide area wide coverage. As with standard roadside speed enforcement systems there is no way for the motorist to know if there is a camera or film in the unit as the system will still flash if an offence is detected. The Controlled Motorway Indicator interface is used to inform the enforcement system what speed limit is currently set by a primary (electrical) and secondary (optical) system. The trigger level of the unit can be varied by the Police and is set in accordance with agreed Association of Chief Police Officers (ACPO) guidelines. There is also an adjustable delay between the change of speed limit and the start of enforcement to allow drivers to safely change their speed. Once the system detects an offence two photos are taken, separated by 0.5 seconds, allowing the distance travelled between

the two photos to be measured, providing a secondary method of speed measurement as required by the Home Office's Speedmeter Handbook. Each photograph includes information regarding date, time, location, speed of the offending vehicle and what speed was displayed on the CMI, confirmed by both electrical and optical systems. The enforcement system was extensively tested both off road and on road, and was given Home Office Type Approval in May 1995. (Harbord and Jones, 1996)

There has been continual monitoring of the controlled motorway pilot since its implementation in 1995 (Highways Agency, 2004b and Harbord, 1998) with several benefits identified:

- Journey times improved,
- Journey time reliability improved,
- Increased throughput,
- Speed compliance increased,
- Lane utilisation improved,
- Headways more uniform,
- Less lane changing,
- Reduction in accidents,
- Reduction in emissions,
- Reduction in traffic noise.

The Active Traffic Management (ATM) Pilot, currently underway, on the M42 motorway in the West Midlands is using enhanced features developed for the M25 Controlled Motorway pilot. ATM involves the use of existing, enhanced and new technology with tried and tested traffic management techniques (Aston, 2005). Using loop technology similar to the MIDAS system on the M25, but spaced at 100 metre intervals, variable mandatory speed limits will be used to manage traffic and actively manage the hard shoulder as a running lane. An enhanced enforcement system, Highways Agency Digital Enforcement Camera System (HADECS), has been developed for this pilot. It will be digital camera based and capable of enforcing speed limits, hard shoulder usage and red "X" signals (Narroway and Jones, 2005, Cowling and Dewhurst, 2003).

6.3 Compliance with Matrix Signals

6.3.1 Introduction

This section will examine compliance rates with motorways matrix signals on the M25 motorway, particularly with mandatory red “X” lane control signals.

Matrix signals are used by the Highways Agency (HA) and the police to provide emergency traffic management for incidents on motorways and trunk roads throughout England. If a lane has to be closed, a red “X” (TSRGD, 6031.1), accompanied by red flashing beacons, will be displayed above the required lane. Examples of two motorway gantry signals found on the M25 are shown in figure 6.15.

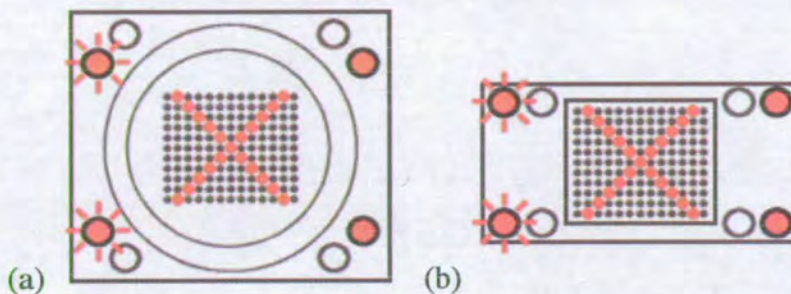


Figure 6.15 Examples of Motorway Matrix Signals Displaying a Red “X” STOP signal. (a) Controlled Motorway Indicator, (b) Standard Gantry Signal

6.3.2 Background

If an emergency lane closure, using motorway matrix signals, has to be made, either a centre reservation post mounted signal will display a lane closed “wicket” or on busier sections of road where gantries are installed, a lane control signal will display a red “X” STOP (Traffic Signs Regulations and General Directions 2002 (HMSO, 2002), Section 38), accompanied by red flashing beacons, above the required lane. Centre reservation post mounted signals can only display advisories to motorists, but overhead gantry red “X” signals are mandatory and it is an offence under the Road Traffic Act 1988 (HMSO, 1988a) not to comply with their instructions. A detailed summary of the appropriate sections of the Traffic Signs Regulations and General Directions 2002 and Road Traffic Act 1988 are provided in appendix B.

There is anecdotal evidence, from the police and other emergency responders, that compliance with red "X" signals is poor, however there has been no any investigations into this.

Two CCTV images in figure 6.16 show examples of emergency lane closures using red "X" signals on the M25. The first image shows lanes three and four closed, with 2 red "X" above the lanes, but there are several vehicles still using the lanes. The second image shows a lane four closure with an incident support unit already on scene and numerous vehicles still using the lane, placing the ISU operative at increased danger.

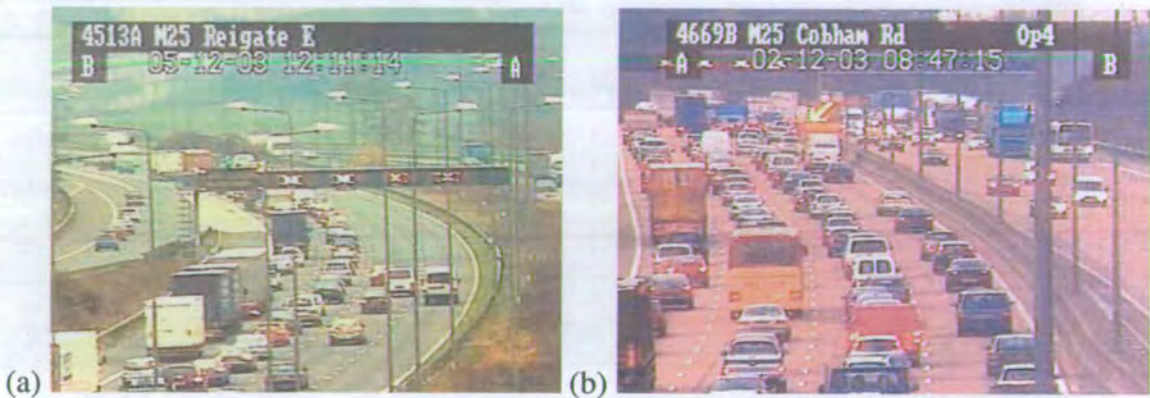


Figure 6.16 CCTV Image Examples of Red "X" Violations

6.3.3 Study Area

The study area is shown in figure 6.17 and includes some of the busiest sections of the M25, with the AADT regularly passing 200,000 vehicles per day. CCTV cameras, emergency roadside telephones (ERT), gantry matrix signals for speed and lane controls and MIDAS are installed over the complete study area, between junctions 6 (marker post 4416) and junction 14 (marker post 4919), 50.3 kilometres (31.3 miles).

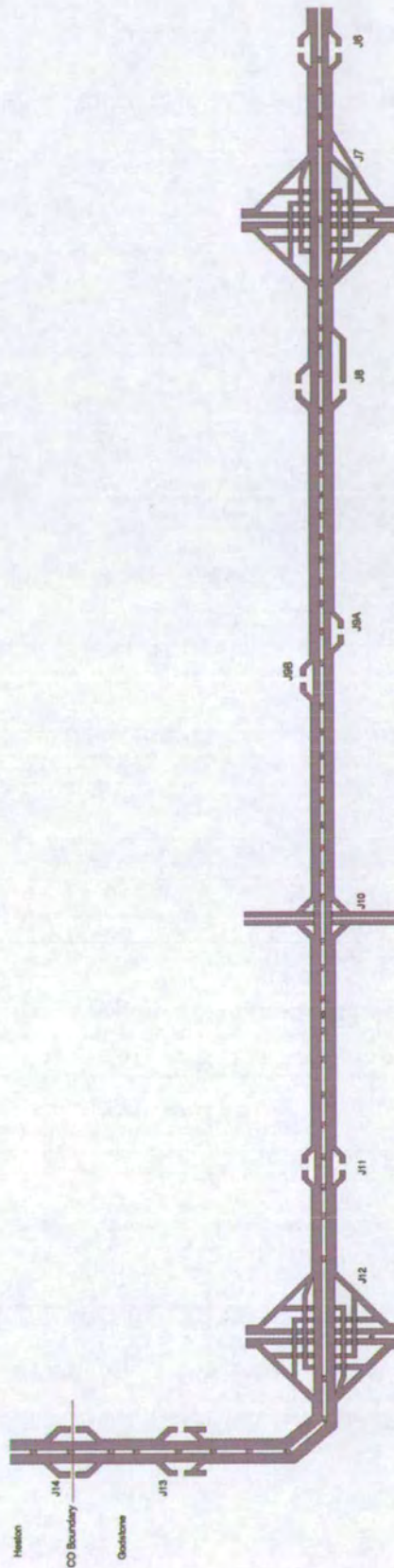


Figure 6.17 Map of Surrey Police's Section of the M25. (Picture source: Mott MacDonald)

6.3.4 Data Description

Three sets of data were used to assess the level of compliance with motorway signals on the M25.

Godstone Incident Data

Detailed in section 4.3.2.

Matrix Sign Databases

Whenever a signal is set on the road network the following information is recorded:

- Date and time of signal activation
- Who set the sign (Either automatic through fog sensors and MIDAS or manually by a controller)
- The type of signal
- The location of the signal (Including motorway, marker post and lane)
- The aspect required
- The reason for setting
- Date and time of de-activation
- Any faults are also recorded

This information is recorded at the relevant police control office from where the signals were set and provides a legal record of all signal and sign settings. The relevant information for this study was obtained in database form from Mott MacDonald, Glasgow, who maintain the records for the Highways Agency.

Within the signal logs, a lane closure, or red cross (“X”), is identified by “STOP” in the ‘aspect code’ field and lane diverts are “LDL” or “LDR” depending on whether the divert is to the left or the right. Speed limits are identified just by the number that was displayed (for example, 50 = 50mph) with mandatory speed limits including an “R” following the number.

MIDAS Traffic Data

The Motorway Incident Detection and Signalling (MIDAS) system records traffic data 24 hours a day in 1-minute averages on:

- flow
- speed
- headway
- occupancy
- vehicle length category

The data is stored in binary form and a program called TDAS (Traffic Data Analysis System) version 1.0 is used, within Microsoft Access, to extract relevant information. Both the TDAS program and MIDAS data was also obtained from MacDonald, Glasgow.

6.3.5 Method

The recorded incident data, from Surrey Police's Godstone motorway control room, was examined and all lane blocking incidents extracted. The 132 incidents, approximately 29.3% of all incidents, were then matched against the signal activity logs. All STOP signals and other relevant signal settings were extracted for each incident. MIDAS traffic data was then also matched against the recorded incident data. All of the information was then filtered for consistency and accuracy giving a total number of incidents of 60 and a total number of signal lane closures of 105. There are a higher number of signal lane closures in comparison to the number of incidents due to the fact that several incidents blocked multiple lanes, which caused the closure of those lanes and lead-in lanes. Control room staff may also have set the second preceding gantry when motorist compliance with the lane closure signals was poor. The filtered data has a much lower number of incidents than the total number recorded because not all in-lane incidents involved signalled lane closures and also due to several loop faults within the MIDAS data. Additionally in some cases there was not an appropriate downstream loop site close enough to the signal gantry, but prior to the incident, to give confident results. Ideally the loop site should be positioned adjacent to the signal site to give positive results. An example of an ideal loop location in relation to a signal gantry and incident are shown in figure 6.18.

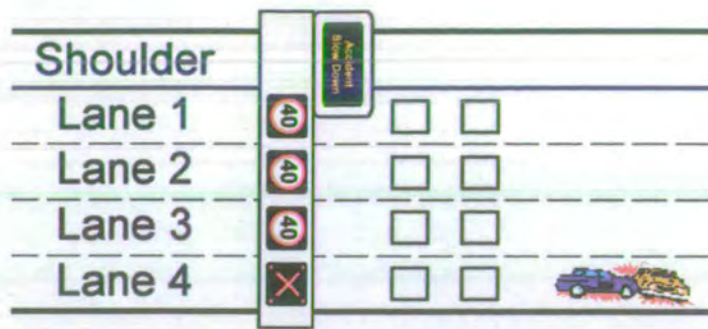


Figure 6.18 Example of Ideal MIDAS Loop Detectors Location in Relation to a Signal Gantry and Incident.

MIDAS flow data were converted into vehicle counts and were summed for each lane closure. Matrix signal activity is recorded to the second but the MIDAS data is recorded for 1-minute averages, therefore counts were only taken for the next whole minute through the last whole minute of activation. For example if a signal was recorded as being activated at 13:04:45, the count would be taken from 13:05:00 in the MIDAS data. If the signal was deactivated at 14:11:19 the count would be stopped at 14:10 to ensure confidence. Vehicle speed data was also treated in the same way. Four offence counts within incidents were not available, due to data inconsistency. Because of this a conservative approach has been taken whereby these totals have been zeroed.

6.3.6 Results

Example 1

On the 14th November 2003 at marker post 4737A, between junctions 10 and 11 on the M25, there was an incident involving a collision between three cars and one Large Goods Vehicle (LGV), Godstone study incident number 203. The motorway control room at Godstone was first notified of the incident by a 999 call received at 09:49. The incident was verified on CCTV with two cars blocking lanes three and four and the other vehicles on the hard shoulder a little distance further downstream. Once verified, signals were activated closing lanes three and four, to protect the incident scene, at the nearest upstream signal gantry. From the settings archive, shown in table 6.1, it can be seen that the controller activated STOP red “X” signals at 4734A in lanes three and four, approximately 400 metres upstream from the incident, with the automatic lane diverts activated at MP 4721A and 4717A. It can

also be seen that the MIDAS system had detected the incident using the HIOCC algorithm and had automatically set 40 mph speed signals several minutes before the police had been notified of the incident. Once all vehicles had been moved to the hard shoulder by the police at 09:58 all lane closure signals were deactivated.

Table 6.1 Signal Compliance Matrix Signal Logs – Example 1

Settings Archive							
Log Counter	OnDateTime	By	Type	Device	Aspect Code	Reason	OffDateTime
72284	14/11/2003 09:44:02	AUTO MID	SIG	SIG M25/4721A1	60	INCIDENT	14/11/2003 09:46:59
72285	14/11/2003 09:44:02	AUTO MID	SIG	SIG M25/4721A2	60	INCIDENT	14/11/2003 09:46:59
72286	14/11/2003 09:44:02	AUTO MID	SIG	SIG M25/4721A3	60	INCIDENT	14/11/2003 09:46:59
72287	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4725K1	60	INCIDENT	14/11/2003 09:46:57
72288	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4725K2	60	INCIDENT	14/11/2003 09:46:57
72289	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4734A1	40R	INCIDENT	14/11/2003 10:01:27
72290	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4734A2	40R	INCIDENT	14/11/2003 10:01:27
72291	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4734A3	40R	INCIDENT	14/11/2003 09:49:57
72292	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4734A4	40R	INCIDENT	14/11/2003 09:49:57
72293	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4741A1	40R	INCIDENT	14/11/2003 10:01:02
72294	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4741A2	40R	INCIDENT	14/11/2003 10:01:02
72295	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4741A3	40R	INCIDENT	14/11/2003 10:01:02
72296	14/11/2003 09:44:07	AUTO MID	SIG	SIG M25/4741A4	40R	INCIDENT	14/11/2003 10:01:02
72297	14/11/2003 09:46:57	AUTO MID	SIG	SIG M25/4725K1	40	INCIDENT	14/11/2003 10:10:29
72298	14/11/2003 09:46:57	AUTO MID	SIG	SIG M25/4725K2	40	INCIDENT	14/11/2003 10:10:29
72299	14/11/2003 09:46:59	AUTO MID	SIG	SIG M25/4714A1	50	INCIDENT	14/11/2003 09:52:24
72300	14/11/2003 09:46:59	AUTO MID	SIG	SIG M25/4714A2	50	INCIDENT	14/11/2003 09:52:24
72301	14/11/2003 09:46:59	AUTO MID	SIG	SIG M25/4714A3	50	INCIDENT	14/11/2003 09:49:52
72302	14/11/2003 09:46:59	AUTO MID	SIG	SIG M25/4714J1	50	INCIDENT	14/11/2003 09:52:24
72303	14/11/2003 09:46:59	AUTO MID	SIG	SIG M25/4721A1	40	INCIDENT	14/11/2003 10:10:31
72304	14/11/2003 09:46:59	AUTO MID	SIG	SIG M25/4721A2	40	INCIDENT	14/11/2003 09:49:52
72305	14/11/2003 09:46:59	AUTO MID	SIG	SIG M25/4721A3	40	INCIDENT	14/11/2003 09:49:52
72310	14/11/2003 09:49:52	OIF 6	SIG	SIG M25/4706A1	50	ACCIDENT	14/11/2003 09:58:40
72316	14/11/2003 09:49:52	OIF 6	SIG	SIG M25/4721A3	LDL	ACCIDENT	14/11/2003 09:58:48
72315	14/11/2003 09:49:52	OIF 6	SIG	SIG M25/4721A2	LDL	ACCIDENT	14/11/2003 09:58:48
72314	14/11/2003 09:49:52	OIF 6	SIG	SIG M25/4714A3	LDL	ACCIDENT	14/11/2003 09:58:48
72313	14/11/2003 09:49:52	OIF 6	SIG	SIG M25/4706A4	50	ACCIDENT	14/11/2003 09:58:40
72311	14/11/2003 09:49:52	OIF 6	SIG	SIG M25/4706A2	50	ACCIDENT	14/11/2003 09:58:40
72312	14/11/2003 09:49:52	OIF 6	SIG	SIG M25/4706A3	50	ACCIDENT	14/11/2003 09:58:40
72317	14/11/2003 09:49:57	OIF 6	SIG	SIG M25/4734A3	20R	ACCIDENT	14/11/2003 09:50:01
72318	14/11/2003 09:49:57	OIF 6	SIG	SIG M25/4734A4	20R	ACCIDENT	14/11/2003 09:50:01
72323	14/11/2003 09:50:01	OIF 6	SIG	SIG M25/4734A3	STOP	ACCIDENT	14/11/2003 09:58:52
72324	14/11/2003 09:50:01	OIF 6	SIG	SIG M25/4734A4	STOP	ACCIDENT	14/11/2003 09:58:52
72411	14/11/2003 09:58:48	OIF 5	SIG	SIG M25/4714A3	40	CLEAR	14/11/2003 10:10:31
72412	14/11/2003 09:58:48	OIF 5	SIG	SIG M25/4721A2	40	CLEAR	14/11/2003 10:10:31
72413	14/11/2003 09:58:48	OIF 5	SIG	SIG M25/4721A3	40	CLEAR	14/11/2003 10:10:31
72414	14/11/2003 09:58:52	OIF 5	SIG	SIG M25/4734A3	40R	CLEAR	14/11/2003 10:01:27
72415	14/11/2003 09:58:52	OIF 5	SIG	SIG M25/4734A4	40R	CLEAR	14/11/2003 10:01:27

The nearest appropriate loop data was found to be at 4737A, which is not an ideal loop location as it is a reasonable distance away from the signal gantry. Any vehicle recorded in the closed lanes can however be confirmed as committing an offence due to the distance from the gantry, as the motorists will have had sufficient time to change lanes. MIDAS flow data from the location was examined in lanes three and four for the time period between 09:50 and 09:57, due to the limitations of 1-minute averages of the MIDAS data. It was found that for the 7 minutes of the closure 156 vehicles were observed to use the closed lanes, 113 in lane three and 43 in lane four.

These 156 vehicles account for nearly 36% of all traffic on this section of road. A graph showing the traffic flow over the time period of interest is shown in figure 6.19. It can be seen that as the lanes are re-opened more people used lane 4 prior to the signals being deactivated.

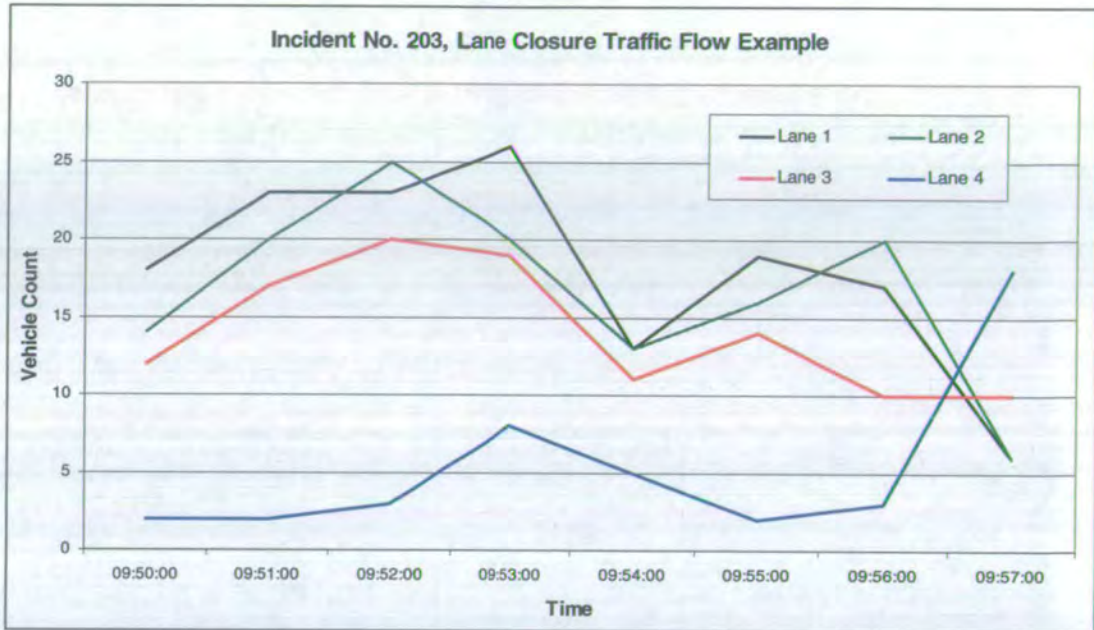


Figure 6.19 Graph of Example Lane Closure Traffic Flow.

Speed compliance was very good at the incident scene. The signal gantry with the lane closures, 4734A, was displaying a mandatory speed limit of 40 mph across lanes one and two with other advisory speed limits further upstream as gantry 4734A was just inside the controlled motorway section, allowing mandatory speeds to be set and enforced. Across all four lanes, at 4734A, the average speed was less than 12 mph, well below the speed limit. This speed may have been artificially lowered due to motorists “rubbernecking” and by the police stopping traffic to tow the incident vehicles to the hard shoulder. It can be seen from table 6.2 that the highest speed was in lane one. This is most likely due to less weaving and lane changing, slowing the traffic, than in lane two where more vehicles will be trying to merge out of the incident affected lanes.

Table 6.2 Incident No. 203, Average Speed by Lane (MPH).

Lane 1	Lane 2	Lane 3	Lane 4
14.52	10.87	8.77	11.57

For the ten minutes prior to the incident the average speed was 67 mph across all four lanes and 76 mph in lane four, with no mandatory or advisor speed limits being displayed at that time. This shows the major impact that motorway incidents have on the speed of traffic.

Example 2

On the 6th December 2003 at marker post 4780B, between junctions 11 and 10 on the anti-clockwise M25, there was an incident involving one car, Godstone study incident number 594. The vehicle had a major mechanical failure leading to it being stranded in lane 4. The control room staff were notified by a passing motorist using an emergency roadside telephone at 09:28 and once verified activated signals closing lane four at 4785B, some 500 metres upstream of the incident. As can be seen from settings archive in table 6.3 a 40 mph mandatory speed limit was initially instated across all lanes, prior to the positive identification of the stranded vehicle's location. The police were on scene at 09:33 and promptly cleared the disabled vehicle to the hard shoulder but it had left a large pool of oil in the carriageway that required clearing. An ISU was then requested and arrived at 09:41, promptly dealing with the spill, allowing lane four to be cleared at 09:57 and the lane closure signals to be deactivated.

The nearest appropriate loop site was found to be at 4783B, 200 metres downstream of the signal gantry and approximately 300 metres from the incident. MIDAS flow data, from the location, was examined in lane four for the time period between 09:32 and 09:56. For the duration of the 24 minute closure, a total of 1,487 vehicles passed over all four lanes at loop site 4738B, 95 vehicles passed lane four, equating to nearly 6.5% of the total traffic passing under the red "X" signal. The traffic flow over the time period of interest is shown in figure 6.20, clearly showing again that as the lanes are physically cleared of the obstruction, more people move back over to lane 4 prior to the signals actually being deactivated.

Table 6.3 Signal Compliance Matrix Signal Logs – Example 2

Settings Archive							
Log Counter	OnDateTime	By	Type	Device	Aspect Code	Reason	OffDateTime
32935	06/12/2003 09:29:13	OIF 8	SIG	SIG M25/4785B1	40R	OBSTRUCTION	06/12/2003 10:00:23
32936	06/12/2003 09:29:13	OIF 8	SIG	SIG M25/4785B2	40R	OBSTRUCTION	06/12/2003 10:00:23
32937	06/12/2003 09:29:13	OIF 8	SIG	SIG M25/4785B3	40R	OBSTRUCTION	06/12/2003 10:00:23
32938	06/12/2003 09:29:13	OIF 8	SIG	SIG M25/4785B4	40R	OBSTRUCTION	06/12/2003 09:31:46
32939	06/12/2003 09:29:13	OIF 8	SIG	SIG M25/4794B1	60R	OBSTRUCTION	06/12/2003 09:31:46
32940	06/12/2003 09:29:13	OIF 8	SIG	SIG M25/4794B2	60R	OBSTRUCTION	06/12/2003 09:31:46
32941	06/12/2003 09:29:13	OIF 8	SIG	SIG M25/4794B3	60R	OBSTRUCTION	06/12/2003 09:31:46
32942	06/12/2003 09:29:13	OIF 8	SIG	SIG M25/4794B4	60R	OBSTRUCTION	06/12/2003 09:31:46
32943	06/12/2003 09:29:33	OIF 8	SIG	SIG M25/4776B1	40R	OBSTRUCTION	06/12/2003 09:57:20
32944	06/12/2003 09:29:33	OIF 8	SIG	SIG M25/4776B2	40R	OBSTRUCTION	06/12/2003 09:57:20
32945	06/12/2003 09:29:33	OIF 8	SIG	SIG M25/4776B3	40R	OBSTRUCTION	06/12/2003 09:57:20
32946	06/12/2003 09:29:33	OIF 8	SIG	SIG M25/4776B4	40R	OBSTRUCTION	06/12/2003 09:57:20
32947	06/12/2003 09:31:46	OIF 1	SIG	SIG M25/4785B4	20R	OBSTRUCTION	06/12/2003 09:31:49
32948	06/12/2003 09:31:46	OIF 1	SIG	SIG M25/4794B1	50R	OBSTRUCTION	06/12/2003 09:34:03
32949	06/12/2003 09:31:46	OIF 1	SIG	SIG M25/4794B2	50R	OBSTRUCTION	06/12/2003 09:34:03
32950	06/12/2003 09:31:46	OIF 1	SIG	SIG M25/4794B3	50R	OBSTRUCTION	06/12/2003 09:34:03
32951	06/12/2003 09:31:46	OIF 1	SIG	SIG M25/4794B4	LDL	OBSTRUCTION	06/12/2003 09:57:17
32952	06/12/2003 09:31:46	OIF 1	SIG	SIG M25/4806B1	50R	OBSTRUCTION	06/12/2003 09:39:24
32953	06/12/2003 09:31:46	OIF 1	SIG	SIG M25/4806B2	50R	OBSTRUCTION	06/12/2003 09:39:24
32954	06/12/2003 09:31:46	OIF 1	SIG	SIG M25/4806B3	50R	OBSTRUCTION	06/12/2003 09:39:24
32955	06/12/2003 09:31:49	OIF 1	SIG	SIG M25/4785B4	STOP	OBSTRUCTION	06/12/2003 09:57:17

Speed compliance was very good at the incident scene. The signal gantry with the lane closures, 4785B, was displaying a mandatory speed limit of 40 mph across lanes one, two and three. Across all four lanes, at 4783B, the average speed was less than 20 mph, well below the speed limit, but as before the speed may have been artificially lowered due to motorists “rubbernecking” and by the police stopping traffic to tow the incident vehicle to the hard shoulder.

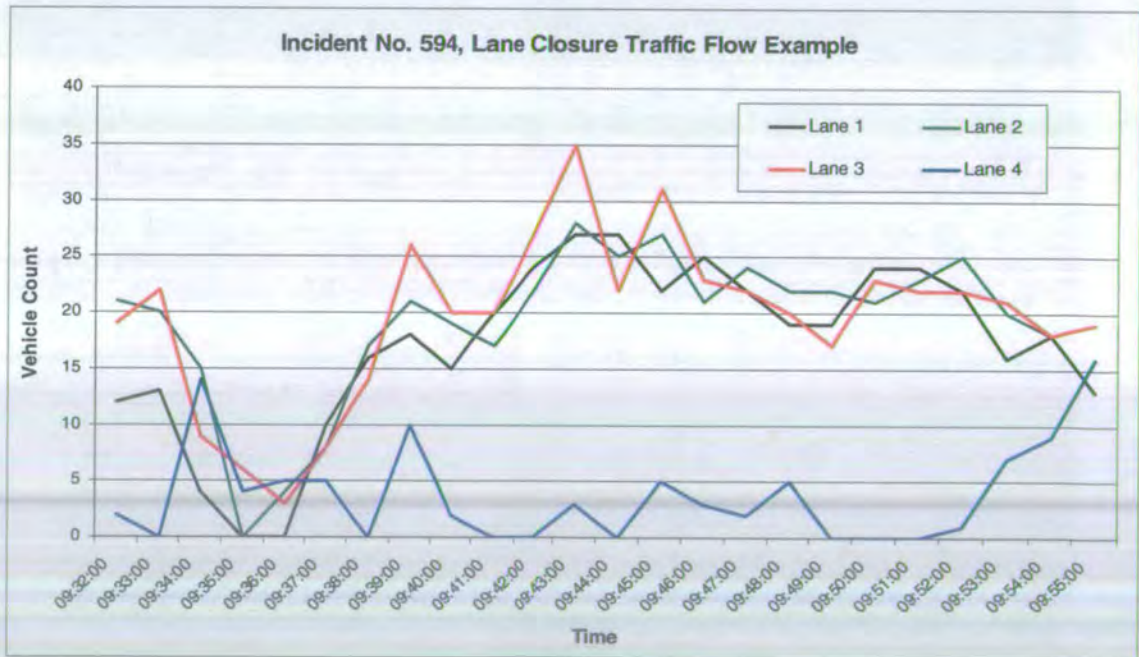


Figure 6.20 Graph of example lane closure traffic flow

It can be seen from table 6.4 that the highest speed, in a legal lane, was in lane one which, as before, is most likely due to less weaving and lane changing, slowing the traffic than in lane three where more vehicles will be trying to merge out of the incident affected lanes. The recorded speed is highest in lane four, mainly due to the fact that there were very few vehicles in it and free flow was available. Figure 6.21 shows two CCTV images of the incident, showing numerous vehicles illegally using lane four approaching the incident scene and demonstrates the differences in flow between the four lanes.

Table 6.4 Incident No. 594, Average Speed by Lane (MPH).

Lane 1	Lane 2	Lane 3	Lane 4
19.20	18.92	14.81	23.72

For the ten minutes prior to the incident the average speed was 56 mph across all four lanes and 60 mph in lane 4, with no mandatory or advisor speed limits being displayed at that time. This again shows the major impact that motorway incidents have on the speed of traffic.



Figure 6.21 CCTV images of lane closure at incident 594.

Example 3

A lane closure was requested by one of Carillion’s ISUs to undertake an emergency repair on two potholes in lane one on the clockwise M25 between junctions 9 and 10, MP 4697A, at 08:47 on 16th November 2003, Godstone study incident number 255. The control room staff duly set signals and signs at 08:48 to support the operatives while they were in the carriageway, the signal and sign logs are shown in tables 6.5

and 5.16. It can be seen that lane one was closed using a STOP red “X” at gantry 4697A and an advisory speed limit of 50 mph was set both at the lane closure gantry and the preceding gantries upstream, 4677A and 4685A.

Table 6.5 Signal Compliance Matrix Signal Logs – Example 3

Settings Archive							
Log Counter	OnDateTime	By	Type	Device	Aspect Code	Reason	OffDateTime
76410	16/11/2003 08:48:49	OIF 4	SIG	SIG M25/4677A1	50	OBSTRUCTION	16/11/2003 09:34:11
76411	16/11/2003 08:48:49	OIF 4	SIG	SIG M25/4677A2	50	OBSTRUCTION	16/11/2003 09:34:11
76412	16/11/2003 08:48:49	OIF 4	SIG	SIG M25/4677A3	50	OBSTRUCTION	16/11/2003 09:34:11
76413	16/11/2003 08:48:49	OIF 4	SIG	SIG M25/4677A4	50	OBSTRUCTION	16/11/2003 09:34:11
76414	16/11/2003 08:48:59	OIF 4	SIG	SIG M25/4685A1	LDR	OBSTRUCTION	16/11/2003 09:34:11
76415	16/11/2003 08:48:59	OIF 4	SIG	SIG M25/4685A2	50	OBSTRUCTION	16/11/2003 09:34:11
76416	16/11/2003 08:48:59	OIF 4	SIG	SIG M25/4685A3	50	OBSTRUCTION	16/11/2003 09:34:11
76417	16/11/2003 08:48:59	OIF 4	SIG	SIG M25/4685A4	50	OBSTRUCTION	16/11/2003 09:34:11
76418	16/11/2003 08:48:59	OIF 4	SIG	SIG M25/4697A1	20	OBSTRUCTION	16/11/2003 08:49:03
76419	16/11/2003 08:48:59	OIF 4	SIG	SIG M25/4697A2	50	OBSTRUCTION	16/11/2003 09:34:11
76420	16/11/2003 08:48:59	OIF 4	SIG	SIG M25/4697A3	50	OBSTRUCTION	16/11/2003 09:34:11
76421	16/11/2003 08:48:59	OIF 4	SIG	SIG M25/4697A4	50	OBSTRUCTION	16/11/2003 09:34:11
76422	16/11/2003 08:49:03	OIF 4	SIG	SIG M25/4697A1	STOP	OBSTRUCTION	16/11/2003 09:34:11

Once the signals had been visually confirmed active, at 08:51, the ISU operatives started to lay traffic management cones and signs out into lane one from their vehicle to give themselves an emergency buffer area while they filled the potholes.

Table 6.6 Signal Compliance VMS Logs – Example 3

Settings Archive							
Log Counter	OnDateTime	By	Type	Device	Aspect Code	Reason	OffDateTime
15196	16/11/2003 08:49:54	OIF 4	MSS	MSS M25/4697A	WORKFORCE IN ROAD-SLOW	OBSTRUCTION	16/11/2003 09:34:40
15197	16/11/2003 08:50:19	OIF 4	MSS	MSS M25/4685A	WORKFORCE IN ROAD-SLOW	OBSTRUCTION	16/11/2003 09:34:40

At 09:19, the ISU operatives had finished patching the holes and started to back track towards the hard shoulder, collecting their traffic management as they went. They were clear of lane 1 at 09:31 and contacted the control room. The signals and signs were then deactivated at 09:34.

The nearest appropriate loop site was found to be at 4697A, adjacent to the signal gantry. MIDAS flow data, from the location, was examined in lane one for the time period between 08:49 and 09:33. For the duration of the 43 minute closure, a total of 2,034 vehicles passed over all four lanes at loop site 4697A, 72 vehicles passed lane one, equating to nearly 3.54% of the total traffic passing under the red “X” signal. The traffic flow over the time period of interest is shown in figure 6.22, showing the understandable low flow levels of a Sunday morning and relatively good compliance rate. The relatively good compliance rates may be due to several factors including the low flow conditions where finding space to change lanes is not an issue, there

was no delay in changing lanes early, poor driving habits such as lane discipline where drivers do not return to the near side after overtaking thus the lower count in lane one, the ISU operatives placed a large TM taper and signs encouraging motorists to change lanes and also the fact that the ISU was a large crash cushion and light arrow vehicle which can be seen from several miles.

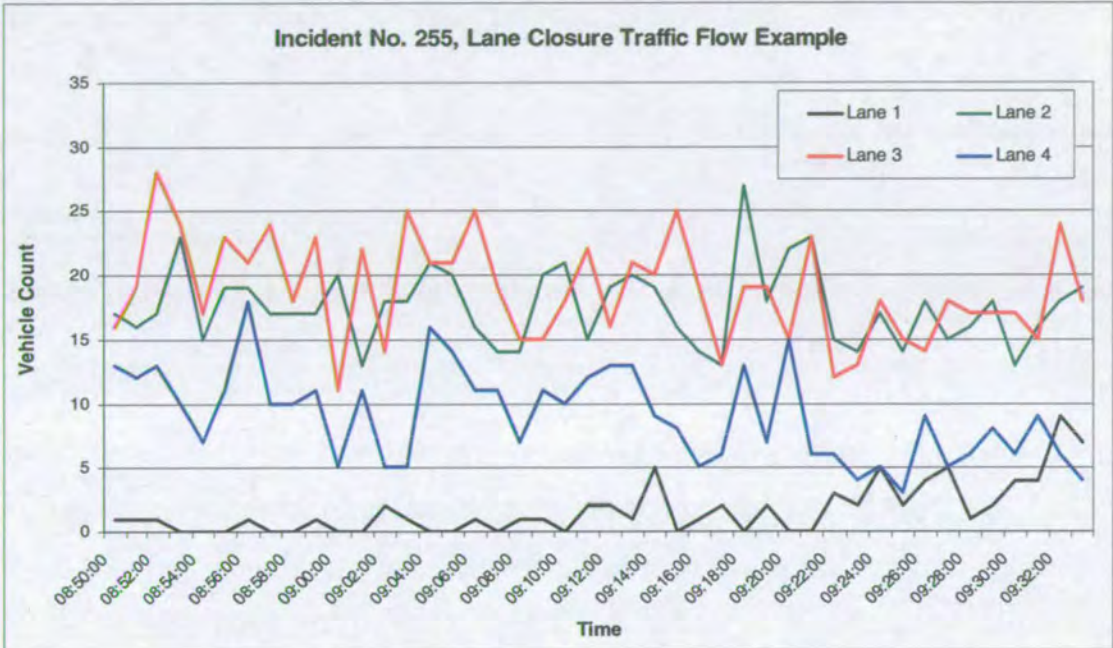


Figure 6.22 Graph of example lane closure traffic flow

Speed compliance was very poor for this incident with traffic in all lanes exceeding the displayed advisory speed limit. The average speeds by lane for the duration of the lane closure are shown in table 5.17. On average across all four lanes vehicles were travelling at 63.4 mph and vehicles in lane four alone were exceeding the advisory speed limit by more than 25 mph and the national speed limit by almost 6 mph.

Table 6.7 Incident No. 255, Average Speed by Lane (MPH).

Lane 1	Lane 2	Lane 3	Lane 4
53.17	57.79	66.76	75.75

For the ten minutes prior to the lane closure the average speed across all four lanes was 78 mph with the average in lane four alone greater than 91 mph. This shows that there was an approximate 14.5 mph reduction in speed following the activation

of the advisory speed limit signs but speeds were still excessive. The speeds observed at gantries further upstream also showed very poor compliance, with lane four at gantry 4677A recording an average speed of 93 mph.

Results Summary

A summary of all 60 incidents and 105 signal activations are shown in tables 6.8 through 6.12 with the results showing a great variability in the number of vehicles passing under a red “X”.

General Results

The number of vehicles observed to be committing an offence of driving under a red “X” per incident varied from 0, or complete compliance, to 3,450 vehicles over a 2 hour 46 minute closure. In total for all red “X” signal activations there were 23,788 offences recorded which equates to an average of 396.47 offences per incident or 226.55 offences per signal activation. A red “X” was displayed for an average of 36 minutes per incident and while activated there was an average rate of 8.73 offences per minute.

Table 6.8 Summary of offences by lane.

	Lane 1	Lane 2	Lane 3	Lane 4	All Lanes
No. of Recordings	40	10	16	39	105
No. of Offences	5416	1681	6309	10382	23788
Average	135.4	168.1	394.3125	266.2051	226.5524
Percentage	22.8%	7.1%	26.5%	43.6%	100.0%

A summary is shown in table 6.8 detailing the number of offences by lane. It can be seen that lane three has the highest average number of offences.

Lane Utilisation

Percentage lane utilisation varied considerably from 0%, complete compliance, to as high as 49.2% for a one lane closure on a two lane slip road and 43% for a two lane closure on a four lane carriageway. Table 6.10 presents results for all incidents and shows that on average 15.26% of traffic passed under a red “X” per incident.

No.	Incident No.	Time Of Day	Incident Location	Signal Location	Count Location	Lane1		Lane2		Lane3		Lane4		Total	
						Duration	Offences Recorded	Duration	Offences Recorded	Duration	Offences Recorded	Duration	Offences Recorded	Duration	Vehicle Count
1	19	15:21	4630B	4638B	4638B	00:32:00	101							00:32:00	101
2	20	16:54	4859A	4851A	4853A							00:10:00	149	00:10:00	149
3	26	06:48	4527A	4522A	4522A	01:10:00	675							01:10:00	675
4	29	08:49	4791A	4785A	4787A							00:17:00	279	00:17:00	279
5	30	09:04	4731B	4734B	4732B	00:05:00	151							00:05:00	151
6	48	15:32	4773B	4776B	4772B					00:03:00	44	00:13:00	85	00:16:00	129
7	49	17:13	4830A	4826A	4826A	00:22:00	596							00:22:00	596
8	63	11:06	4551B	4556B	4556B	00:24:00	30							00:24:00	30
9	85	17:48	4638A	4616A	4617A	01:19:00	369	00:36:00	284					01:55:00	653
		17:51		4629A	4633A	01:15:00	429	00:33:00	361					01:48:00	810
10	93	10:05	4697A	4685A	4697A					02:33:00	1963	02:33:00	523	05:06:00	2486
		10:10		4677A	4677A					02:28:00	2102	02:28:00	1289	04:56:00	3391
11	123	15:20	4708A	4706A	4706A	00:36:00	201							00:36:00	201
		15:20		4697A	4697A	00:36:00	265							00:36:00	265
		16:31		4706A	4706A	00:12:00	114							00:12:00	114
12	145	11:47	4494J	4490J	4490J	00:39:00	204							00:39:00	204
13	161	14:07	4860A	4860A	4858A	00:45:00	77	00:08:00	83					00:53:00	160
14	179	10:57	4856A	4851A	4853A	00:01:00	46							00:01:00	46
15	180	10:55	4667B	4677B	4677B	00:10:00	14							00:10:00	14
16	198	08:46	4790B	4785B	4783B							00:01:00	10	00:01:00	10
		08:46		4794B	4792B							00:07:00	73	00:07:00	73
		08:51		4806B	4806B							00:02:00	42	00:02:00	42
17	199	08:57	4668A	4667A	4666A	00:21:00	59							00:21:00	59
18	203	09:50	4737A	4734A	4737A					00:07:00	113	00:07:00	43	00:14:00	156
19	214	13:06	4446B	4447B	4447B							00:11:00	125	00:11:00	125
20	217	14:26	4430A	4435A	4435A	00:06:00	24							00:06:00	24
21	241	13:50	4675B	4677B	4677B	00:02:00	0							00:02:00	0
				4685B	4684B	00:03:00	3							00:03:00	3
22	255	08:50	4697A	4697A	4697A	00:43:00	72							00:43:00	72
23	269	15:36	4491B	4508B	4508B					00:04:00	39	02:42:00	3411	02:46:00	3450
		15:47		4496B	N/A									00:00:00	0
		15:44		4490B	4490B					00:17:00	140	00:33:00	123	00:50:00	263
24	283	09:19	4582A	4577A	4577A							00:12:00	154	00:12:00	154
25	289	13:07	4510B	4508B	4508B									00:00:00	0
				4517B	4512B			00:14:00	60	02:53:00	280	06:38:00	46	09:45:00	386
26	307	10:58	4890A	4883A	4883A					00:03:00	52	00:03:00	11	00:06:00	63
27	313	14:56	4860A	4860A	4863A	00:11:00	12							00:11:00	12
28	314	15:29	4803L	4806L	4806L			00:19:00	78					00:19:00	78
29	317	17:21	4593B	4596B	4592B							00:02:00	26	00:02:00	26
30	345	18:59	4651B	4658B	4658B	00:30:00	240	00:11:00	64					00:41:00	304
31	395	16:35	4479B	4483B	4483B							00:25:00	377	00:25:00	377
				4490B	4490B							00:26:00	575	00:26:00	575
32	401	07:20	4500B	4508B	4508B							01:28:00	936	01:28:00	936
														Sub-Total	17642

Table 6.9 Summary of results

No.	Incident No.	Time Of Day	Incident Location	Signal Location	Count Location	Lane1		Lane2		Lane3		Lane4		Total	
						Duration	Offences Recorded	Duration	Offences Recorded	Duration	Offences Recorded	Duration	Offences Recorded	Duration	Vehicle Count
33	405	08:55	4857B	4870B	4868B	00:38:00	428	00:38:00	445					01:16:00	873
				4860B	4858B	00:39:00	82	00:39:00	162					01:18:00	244
34	428	16:51	4820A	4813A	4817A			00:06:00	61	00:31:00	136	00:31:00	169	01:08:00	366
35	446	10:33	4636B	4638B	4638B							00:06:00	28	00:06:00	28
36	454	14:28	4916J	4915J	4917J	00:23:00	7							00:23:00	7
37	458	16:32	4627A	4616A	4617A	00:37:00	133							00:37:00	133
		16:33		4629A	4633A	00:38:00	99							00:38:00	99
38	464	07:50	4743A	4741A	4742A	00:10:00	5							00:10:00	5
39	469	12:22	4504A	4490A	4490A							00:11:00	64	00:11:00	64
				4501A	4501A							00:11:00	23	00:11:00	23
		12:37		4490A	4490A							00:01:00	0	00:01:00	0
				4501A	4501A							00:01:00	9	00:01:00	9
40	481	08:01	4490B	4490B	4490B							00:09:00	38	00:09:00	38
		08:01		4496B	N/A									00:00:00	0
41	486	10:37	4869B	4870B	4868B	00:03:00	10							00:03:00	10
42	490	11:44	4673B	4677B	4677B	00:13:00	6							00:13:00	6
				4685B	4684B	00:13:00	17							00:13:00	17
43	494, 495	12:25	4509B	4517B	4512B	02:28:00	61							02:28:00	61
		13:43	4509A	4501A	4501A	00:04:00	5							00:04:00	5
		13:44	4509A	4509A	N/A									00:00:00	0
44	497	14:00	4774A	4764A	4767A	00:17:00	30							00:17:00	30
		14:01		4776A	N/A									00:00:00	0
45	505	08:09	4800J	4798J	4800J			01:19:00	63					01:19:00	63
46	506	08:30	4675A	4667A	4672A							00:33:00	360	00:33:00	360
47	520	16:32	4819B	4819B	4817B							00:04:00	104	00:04:00	104
		16:38		4825B	4822B							00:01:00	48	00:01:00	48
48	556	16:24	4649A	4649A	4649A	02:13:00	19							02:13:00	19
				4637A	4637A	01:47:00	401							01:47:00	401
49	557	17:01	4452B	4458B	4455B					00:21:00	321			00:21:00	321
50	562	18:42	4641A	4637A	4637A	00:03:00	14							00:03:00	14
51	574	11:51	4506B	4517B	4517B					01:11:00	405	01:12:00	45	02:23:00	450
				4508B	4508B					01:11:00	210	01:11:00	12	02:22:00	222
52	575	12:01	4525A	4522A	4522A	00:04:00	9							00:04:00	9
53	579	13:35	4430B	4440B	4440B					00:12:00	135	00:12:00	33	00:24:00	168
54	594	09:32	4780B	4785B	4783B							00:24:00	95	00:24:00	95
55	598	10:18	4890A	4883A	4883A	00:09:00	28							00:09:00	28
56	666	09:26	4776A	4667A	4672A							00:22:00	289	00:22:00	289
		09:27		4677A	4677A							00:21:00	348	00:21:00	348
57	667	09:40	4645A	4637A	4637A					00:02:00	53	00:02:00	24	00:04:00	77
58	682	07:50	4823A	4813A	4817A					00:12:00	153	00:12:00	118	00:24:00	271
				4821A	4822A					00:11:00	163	00:11:00	83	00:22:00	246
59	701	16:46	4894B	4900B	4897B							00:21:00	215	00:21:00	215
60	706	18:04	4870B	4870B	4868B	00:16:00	193							00:16:00	193
				4876B	4873B	00:16:00	187							00:16:00	187
														Total	23788

Table 6.9 (Cont) Summary of results

No.	Incident No.	Lane1			Lane2			Lane3			Lane4			All Lanes		
		Duration	Offences Recorded	Other Traffic	Duration	Offences Recorded	Other Traffic	Duration	Offences Recorded	Other Traffic	Duration	Offences Recorded	Other Traffic	Offences	Other Traffic	Percentage
1	19	00:32:00	101				500			697		0	101	1197	7.78%	
2	20			186			177			190	00:10:00	149	149	553	21.23%	
3	26	01:10:00	675				1293			1622		1768	675	4683	12.60%	
4	29			N/A			459			N/A	00:17:00	279	279	459	N/A	
5	30	00:05:00	151				38			176		198	151	412	26.82%	
6	48			217			225	00:03:00	44	175	00:13:00	85	0	129	617	17.29%
7	49	00:22:00	596				209			367		461	596	1037	36.50%	
8	63	00:24:00	30				481			668		42	30	1191	2.46%	
9	85	01:19:00	369		00:36:00	284	738			1368		1417	653	3523	15.64%	
		01:15:00	429		00:33:00	381	703			1576		1929	810	4208	16.14%	
10	93			2529			2703	02:33:00	1963		02:33:00	523	2486	5232	32.21%	
				1749			1735	02:28:00	2102		02:28:00	1289	3391	3484	49.32%	
11	123	00:36:00	201				219			273		307	201	799	20.10%	
		00:36:00	265				641			759		778	265	2178	10.85%	
		00:12:00	114				219			273		307	114	799	12.49%	
12	145	00:39:00	204				229						204	229	47.11%	
13	161	00:45:00	77		00:08:00	83	756			938		1222	160	2916	5.20%	
14	179			50			43			48	00:01:00	46	46	141	24.60%	
15	180	00:10:00	14				254			283		209	14	746	1.84%	
16	198			10			19			20	00:01:00	10	10	49	16.95%	
				82			162			248	00:07:00	73	73	492	12.92%	
							63			113	00:02:00	42	42	176	19.27%	
17	199	00:21:00	59				465			575		490	59	1530	3.71%	
18	203			145			134	00:07:00	113		00:07:00	43	156	279	35.86%	
19	214			235			276			389	00:11:00	125	125	900	12.20%	
20	217	00:06:00	24				71			111		114	24	296	7.50%	
21	241	00:02:00	0				17			23		13	0	53	0.00%	
		00:03:00	3				83			112		81	3	276	1.08%	
22	255	00:43:00	72				757			816		389	72	1962	3.54%	
23	269			1583			2764	00:04:00	39	3154	02:42:00	3411	3450	7501	31.50%	
													0	0	N/A	
				533			556	00:17:00	140	275	00:33:00	123	263	1364	16.16%	
24	263			209			N/A			193	00:12:00	154	154	402	N/A	
25	269												0	0	N/A	
				6621	00:14:00	60	8440	02:53:00	280	6421	06:38:00	46	386	21482	1.77%	
26	307						103	00:03:00	52		00:03:00	11	63	103	37.95%	
27	313	00:11:00	12				172			230		276	12	678	1.74%	
28	314			257	00:19:00	78							78	257	23.28%	
29	317			60			89			N/A	00:02:00	26	26	149	N/A	
30	345	00:30:00	240		00:11:00	64	192			473		595	304	1260	19.44%	
31	395			706			615			448	00:25:00	377	377	1789	17.57%	
				632			528			477	00:26:00	575	575	1637	25.99%	

Table 6.10 Summary of lane usage percentage

No.	Incident No.	Lane1			Lane2			Lane3			Lane4			All Lanes			
		Duration	Offences Recorded	Other Traffic	Duration	Offences Recorded	Other Traffic	Duration	Offences Recorded	Other Traffic	Duration	Offences Recorded	Other Traffic	Offences	Other Traffic	Percentage	
33	405	00:38:00	428		00:38:00	445				516			643	873	1159	42.96%	
		00:39:00	82		00:39:00	162				962			1095	244	2057	10.60%	
34	428			189	00:06:00	61		104	00:31:00	136		00:31:00	169	366	598	37.97%	
35	446			64				145				00:06:00	28	28	416	6.31%	
36	454	00:23:00	7					161						7	161	4.17%	
37	458	00:37:00	133					529					708	133	2079	6.01%	
		00:38:00	99					729					828	99	1557	N/A	
38	464	00:10:00	5					162					66	5	388	1.27%	
39	469			130				273				00:11:00	64	64	784	7.55%	
				138				237				00:11:00	23	23	705	3.16%	
				17				17				00:01:00	0	0	37	0.00%	
				N/A				N/A				00:01:00	9	9	7	N/A	
40	481			186				210				00:09:00	38	38	703	5.13%	
														0	0	N/A	
41	486	00:03:00	10					121					113	10	333	2.92%	
42	490	00:13:00	6					320					375	6	1046	0.57%	
		00:13:00	17					330					366	17	1042	1.61%	
43	494, 495	02:28:00	61					2781					3374	61	9635	0.63%	
		00:04:00	5					79					75	5	244	2.01%	
														0	0	N/A	
44	497	00:17:00	30					267					463	30	1120	2.61%	
														0	0	N/A	
45	505			1405	01:19:00	63								63	1405	4.29%	
46	506			569				N/A						360	1222	N/A	
47	520			90				118						104	361	22.37%	
				47				31						48	120	28.57%	
48	556	02:13:00	19					2921					4184	19	10813	0.18%	
		01:47:00	401					2499					2617	401	8159	4.68%	
49	557			290				299	00:21:00	321				321	589	35.27%	
50	562	00:03:00	14					71					62	14	225	5.86%	
51	574			N/A				472	01:11:00	405				45	450	487	N/A
				1516				1710	01:11:00	210				12	222	3226	6.44%
52	575	00:04:00	9					87					103	9	312	2.80%	
53	579			224				261	00:12:00	135				33	168	485	25.73%
54	594			425				477						95	95	1392	6.39%
55	598	00:09:00	28					320						335	28	655	4.10%
56	666			484				N/A						584	289	1068	N/A
				479				515						513	348	1507	18.76%
57	667			60				61	00:02:00	53				24	77	121	38.89%
58	682			254				156	00:12:00	153				118	271	410	39.79%
				209				166	00:11:00	163				83	246	375	39.61%
59	701			474				430						N/A	215	904	N/A
60	706	00:16:00	193					241						341	468	1050	15.53%
		00:16:00	187					213						460	187	1025	15.43%
															Average	15.26%	

Table 6.10 (Cont.) Summary of lane usage percentage.

Speed Compliance

For all examined incident speed compliance was good overall with an average traffic speed 9.55 mph less than the posted advisory or mandatory speed limit. Twenty-six signal activations however had greater average speeds than those displayed. The largest speed limit difference recorded was 13.4 mph over but the average was 7 mph. The impact of displaying speed limits is difficult to establish as speed may be artificially lowered near incident scenes. Traffic may be slow due to congestion caused by irregular merging and weaving as well as drivers increasing their headway and slowing down while passing incident scene, also known as rubbernecking.

Time of Day

Figure 6.23 shows the variability of offences rate against the time of day. It can be seen that in general there is a higher rate of offences during the peak periods of the day. This may be because the road section is at or very near capacity and there is nowhere for affected vehicles to go, or it could be that drivers are under more pressure to reach their destination during peak periods.

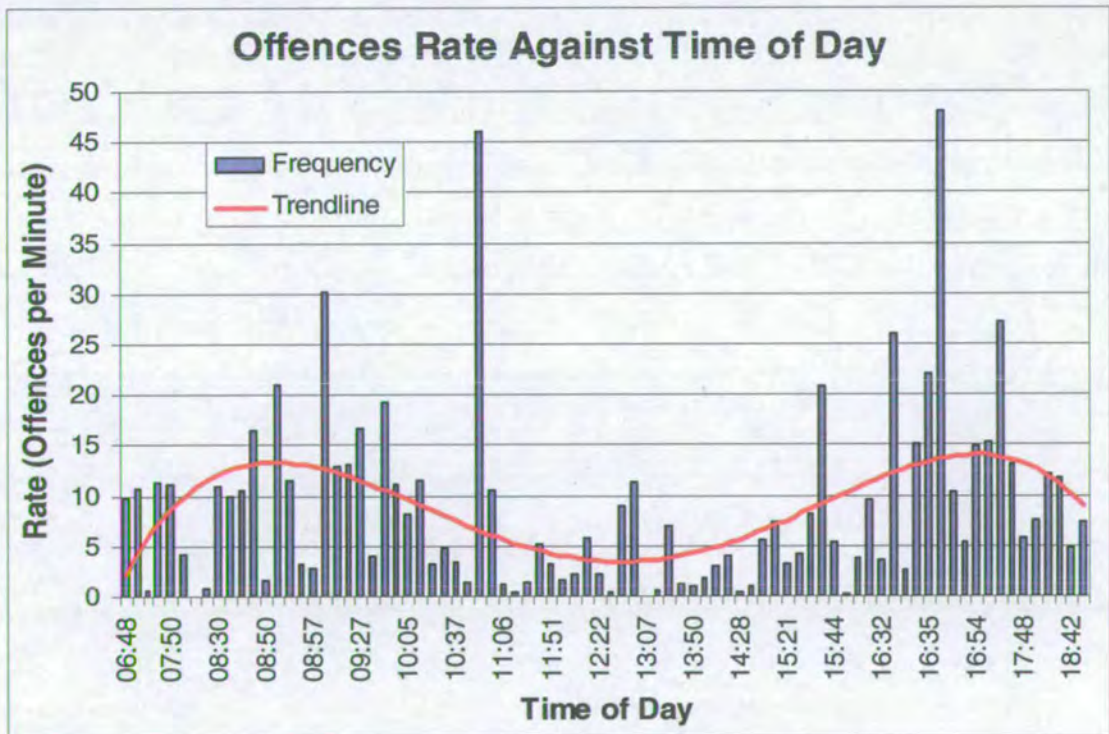


Figure 6.23 Graph of Offences Rate Against Time of Day

Incident-Signal Separation

It can be seen in figure 6.24 that there is generally a greater rate of offences with an increased distance from an incident. The trend line shows a steady increase with distance from the actual incident scene. This may be due to motorists not reacting to the signals and preferring to rely on their own judgement, continuing to travel along the closed lane until they have a physical reason for moving.

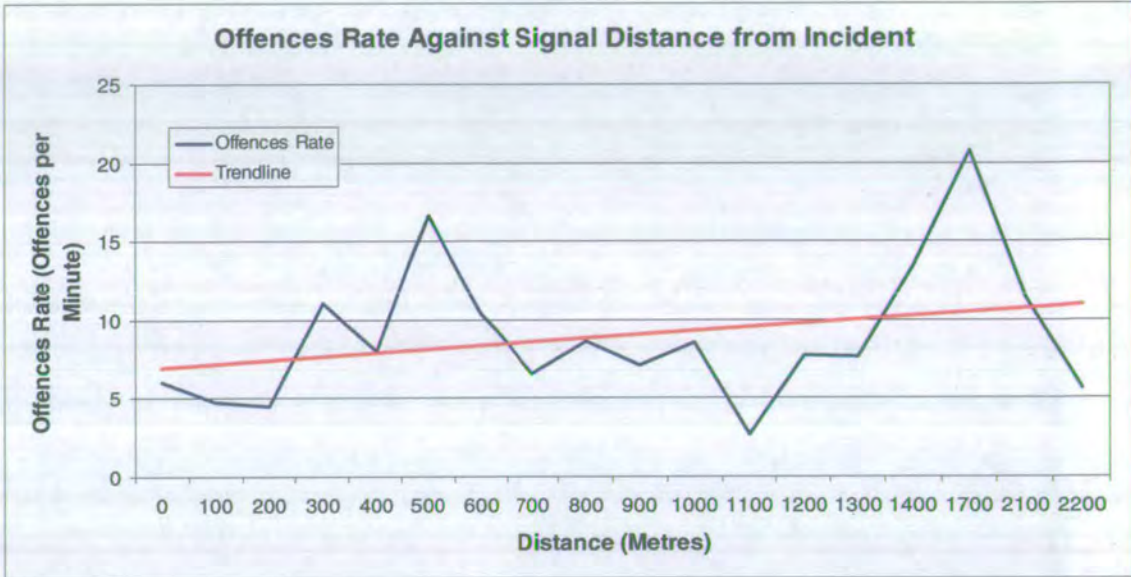


Figure 6.24 Graph of Offences Rate Against Distance from Incident

Multiple Signal Activation

It was noted that twenty incidents involved more than one red “X” activation in an attempt to increase motorist compliance and protect the incident scene. A summary is shown in table 6.11 and it can be seen from the offence rates that signal compliance is greater with the second (nearest to incident) stop signal. When multiple signals were used the average rate for the furthest gantry was 10.25 and the closer one was 7.54 offences per minute demonstrating how the gantry closest to the incident has a lower offences rate. As noted above however that compliance is less with a greater distance from the incident.

Table 6.11 Signal Compliance Rates (1st / 2nd Signals)

Incident No.	Time Of Day	Incident Location	Signal Location	Count Location	Total		Rate (Offences per Minute)
					Duration	Vehicle Count	
85	17:48	4638A	4616A	4617A	01:55:00	653	5.68
	17:51		4629A	4633A	01:48:00	810	7.50
93	10:05	4697A	4685A	4697A	05:06:00	2486	8.12
	10:10		4677A	4677A	04:56:00	3391	11.46
123	15:20	4708A	4706A	4706A	00:36:00	201	5.58
	15:20		4697A	4697A	00:36:00	265	7.36
198	08:46	4790B	4785B	4783B	00:01:00	10	10.00
	08:46		4794B	4792B	00:07:00	73	10.43
	08:51		4806B	4806B	00:02:00	42	21.00
241	13:50	4675B	4677B	4677B	00:02:00	0	0.00
			4685B	4684B	00:03:00	3	1.00
			4508B	4508B	02:46:00	3450	20.78
269	15:35	4491B	4496B	N/A	00:00:00	0	N/A
	15:44		4490B	4490B	00:50:00	263	5.26
	13:07		4510B	4508B	N/A	00:00:00	0
395	16:35	4479B	4517B	4512B	09:45:00	386	0.66
			4483B	4483B	00:25:00	377	15.08
			4490B	4490B	00:26:00	575	22.12
405	08:55	4857B	4870B	4868B	01:16:00	873	11.49
			4860B	4858B	01:18:00	244	3.13
			4616A	4617A	00:37:00	133	3.59
458	16:32	4627A	4629A	4633A	00:38:00	99	2.61
	16:33		4490A	4490A	00:11:00	64	5.82
	12:22		4504A	4501A	4501A	00:11:00	23
469	12:37		4490A	4490A	00:01:00	0	0.00
			4501A	4501A	00:01:00	9	9.00
			4490B	4490B	00:09:00	38	4.22
481	08:01	4490B	4496B	N/A	00:00:00	0	N/A
	08:01		4677B	4677B	00:13:00	6	0.46
	11:44		4673B	4685B	4684B	00:13:00	17
497	14:00	4774A	4764A	4767A	00:17:00	30	1.76
	14:01		4776A	N/A	00:00:00	0	N/A
	16:32		4819B	4819B	4817B	00:04:00	104
520	16:38	4819B	4825B	4822B	00:01:00	48	48.00
	16:24		4649A	4649A	02:13:00	19	0.14
	11:51		4506B	4637A	4637A	01:47:00	401
574	11:51	4506B	4517B	4517B	02:23:00	450	3.15
			4508B	4508B	02:22:00	222	1.56
			09:26	4676A	4667A	4672A	00:22:00
666	09:27	4823A	4677A	4677A	00:21:00	348	16.57
	07:50		4813A	4817A	00:24:00	271	11.29
	18:04		4870B	4821A	4822A	00:22:00	246
706	18:04	4870B	4870B	4868B	00:16:00	193	12.06
			4876B	4873B	00:16:00	187	11.69

Controlled Motorway Comparison

Table 6.12 demonstrates the comparison between the Controlled Motorway section and the MIDAS section of the M25 covered by this study. The controlled motorway section has fewer offences per incident than the MIDAS section, 197.16 compared to 538.83, but this is mainly due to the shorter signal duration, some 32 minutes less. There is also more than 6.5% greater percentage of traffic offending in the controlled section and the offence rate is nearly double that of the MIDAS section. Speed compliance was greater on average within the controlled section than just the MIDAS section by 3 mph, which is most likely to the enforcement system and mandatory speed limits in operation.

Table 6.12 Controlled Motorway Section Comparison.

	Controlled Motorway Section	MIDAS Section	Total
No. of Incidents	25	35	60
No. of Activations	41	64	105
Offences Recorded	4929	18859	23788
Offences per Incident	197.16	538.83	396.47
Offences per Activation	120.22	294.67	226.55
% Traffic Offending	19.25%	12.57%	15.26%
Ave. Signal Duration	00:16:28	00:48:39	00:36:05
Offences Rate	12.20	6.62	8.73
Speed Compliance (mph)	-11.44	-8.40	-9.55

Summary

The overall results from 60 incidents indicated the following:

1. 105 red "X" matrix signal activations
2. 23,788 offences of driving under a red "X" matrix signal were recorded
3. 396.47 average offences of driving under a red "X" matrix signal per incident
4. 226.55 average offences of driving under a red "X" matrix signal per signal activation
5. 15.26% of traffic passed under a red "X" signal
6. Average red "X" duration was 36 minutes
7. Average offence rate of 8.73 offences per minute.
8. The average traffic speed was 9.55 mph less than the posted advisory or mandatory speed limit
9. Offences rate varied with the time of day
10. Compliance fell with the distance from the incident scene
11. For multiple signal activation compliance was greater with the signals closest to the incident scene
12. Many differences were found between the MIDAS section and the Controlled Motorway sections of the M25.

6.3.7 Discussion

Compliance with overhead gantry motorway signals has been shown to be very variable. In some circumstances, it was found that there was complete compliance but in others it was very poor, with up to 43% of vehicles offending, and on average 15.26% traffic using the road was observed to be contravening the red "X" signals.

With some 23,788 vehicles illegally driving through emergency lane control signals there are major safety implications for both incident victims and responders.

There are numerous possible reasons for the poor compliance with red "X" signals. It may be that motorists just do not understand what the signal means, how they are supposed to react or what the penalties are for contravening its instruction. A 1987 report by the Transport and Road Research Laboratory (Rutley, 1987) detailed the response to a public attitude survey in which only 50% of interviewees correctly identified the meaning of a red "X" signal. As there is currently no re-testing of drivers, many older aged drivers may have never been introduced to motorways or motorway signals since their construction so may have no knowledge of the signals. If the understanding of the signal is the issue, drivers must be further educated to the reasons for setting emergency signals and the possible major safety implications if they do not comply with them. On the M25 specifically, lack of compliance may partly be due to the very frequent daily use of matrix signals either for queue protection using MIDAS or within the controlled motorway section. Drivers may have become complacent to the meaning of the signals, or sign blind, choosing to drive as they want not as requested. Ultimately it may be that many drivers within the study area are just very inconsiderate and aggressive in their driving habits. Matrix signals are effective for the majority of the time but are reliant on motorists to comply with their instructions to ensure the operational safety of the facility.

May (1971) found in 1969, on the elevated section of the M4 motorway in London, that between 8% and 13% of the total traffic stream violating red "X" signals. This is similar to the 15.26% stated above, but slightly lower, which may be due to the increased volume of traffic using the roads today.

Speed compliance was good overall for incidents but as previously stated these speeds may have been externally influenced. Webb (1980) found that the average car speed was reduced by approximately 4.9% when an advisory speed limit was displayed on a post mounted matrix signal. A study on the M4 motorway in London by May (1971) found that advisory speed limits attracted compliance from less than

15% of drivers. Several studies by the Transport and Road Research Laboratory have examined the effect of motorway signals on vehicle speeds including both post mounted and gantry mounted signals. Lines (1978) found that on an urban stretch of the M1 motorway with 3 lane gantry signals there was an average reduction in speed of 7%, or approximately 5mph, when a 50 mph advisory speed limit was displayed. A similar result was also found for the rural stretch of the M1, which used post mounted signals, in the same study. Another study by Lines (1981), also on the M1, found that there was an average 4 mph, or 6%, decrease in speed, again when a 50 mph advisory speed is displayed. Smaller reductions were recorded for 60 mph advisory speed limits and slightly larger reductions were observed for 50 mph limits and lane closures. In a survey of driver opinions reported by Cross and Parker (1980) only 45% of drivers said they always complied with the speed restrictions. The main reason given for not complying was that drivers were in too much of a hurry.

6.3.8 Section Summary

Compliance with overhead gantry signals has been shown to be very variable. A total of 60 incidents and 105 red "X" matrix signal activations were examined. The following was found:

1. 23,788 offences of driving under a red "X" matrix signal were recorded, this represents 15.26% of traffic.
2. 396.47 average offences of driving under a red "X" matrix signal per incident, with 226.55 average offences of driving under a red "X" matrix signal per signal activation
3. Average red "X" duration was 36 minutes
4. Average rate of 8.73 offences per minute
5. The average traffic speed was 9.55 mph less than the posted advisory or mandatory speed limit at the incident scene
6. Offence rate varied with the time of day
7. For multiple signal activation compliance was greater with the signals closest to the incident scene, but in general, compliance fell with the distance from the incident scene.

8. Many differences were found between the MIDAS section and the Controlled Motorway sections of the M25.

In summary it can be concluded that motorway matrix signals are effective for the majority of the time but are completely reliant on motorists to comply with their instructions. Subsequently, although motorway matrix signals can be an effective tool in traffic management and delay reduction, matrix signals should not be solely relied upon for responder and motorist protection, and traffic management at an incident scene.

6.4 The Effectiveness of Variable Message Signs

6.4.1 Introduction

Large strategic variable message signs (VMS) are now installed prior to every junction within the study area on the M25 and the majority of motorway gantries are also equipped with tactical VMS, spaced at nominal 1 kilometre intervals. These message signs are capable of displaying a variety of information, detailed in section 6.2.1. VMS are used to provide motorists with information to increase safety and to influence route choice. The effect of this influence is however not completely understood. The section will examine the impact of incident delay warning messages on the Surrey police section of the M25.

6.4.2 Background

Several studies have reported wide ranging values of motorist reaction to messages displayed on variable message signs. Hidas and Awadalla (2003) reported evidence of traffic diversion in the range of 5% through 80% (Wardman et al., 1997). In London, Hounsell et al (1998) and Chatterjee et al (2002) surveyed driver's views on VMS with 54% of responders stating they would divert at the very next opportunity, when presented with an accident delay message on VMS. Approximately a third of drivers (32%) however stated that they would not divert at all. Another questionnaire study (Swann et al., 1995) found that drivers diverted in 16% of the cases when a message indicated there was a problem on their route in the Forth Estuary area, near Edinburgh. Another study in Scotland, Messmer et al. (1998),

also using questionnaires, showed that drivers expressed higher levels of confidence with the accuracy of information displayed by VMS when compared to other sources of traffic information. In and around Amsterdam, Emmerink et al (1996) reported that VMS or Route Information Amsterdam signs “sometimes” influenced the behaviour of up to 70% of motorway users. They showed that women and commuters are more reluctant to be influenced by this information and that flexibility of arrival time is of no importance in VMS influence, with drivers who have the possibility of late arrival at their destination less inclined to change their route.

Tarry and Graham (1995) assessed the impact of VMS upstream of key decision point junctions when the most commonly used messages were displayed on the Midland Driver Information System (MDIS) in the Midlands area of the UK. They found diversion rates of 27% through 40% when messages reporting accidents with instructional advice to use the West route around Birmingham were displayed. When messages displaying warnings of congestion, but no instructional advice, were used the diversion rate was much lower, 2-5%.

Much research has also suggested that motorist response is highly dependent on message content, subjects network knowledge and on the extent of any implied diversion (Hato et al., 1995; Zhao et al., 1995; Bonsall et al., 1995; Bonsall and Merrall, 1997; Bonsall and Palmer, 1998; Mast and Ballas, 1976 and Wardman et al. 1997).

6.4.3 Data Description

Three sets of data were used to assess the influence of Variable Message Signs on the M25.

Godstone Incident Data

Detailed in section 4.3.2.

Variable Message Sign Databases

Whenever a message sign is activated on the road network the following information is recorded:

- Date and time of signal activation
- Who set the sign (Either automatic through MIDAS or manually by a controller)
- The type of sign
- The location of the sign (Including motorway, marker post and carriageway)
- The aspect (legend) set
- The reason for setting
- Date and time of de-activation
- Any faults are also recorded

This information is recorded at the relevant police control office from where the signs were set and provides a legal record of all settings. The relevant information for this study was obtained in database form from Mott MacDonald, Glasgow, who maintain the records of the Highways Agency.

MIDAS Traffic Data

The Motorway Incident Detection and Signalling (MIDAS) system records traffic data 24 hours a day in 1-minute averages on:

- flow
- speed
- headway
- occupancy
- vehicle length category

The data is stored in binary form and a program called TDAS (Traffic Data Analysis System) version 1.0 is used, within Microsoft Access, to extract relevant information. Both the TDAS program and MIDAS data was also obtained from MacDonald, Glasgow.

6.4.4 Method

VMS activation databases were examined for operator set messages giving advanced warning of incident related delays over the study area for the study period. These messages were then matched with incidents recorded in the Godstone incident data. This data was then used to identify the required MIDAS traffic flow data. All of the information was then filtered for consistency and accuracy giving a total of 7 incidents with 25 VMS activations.

MIDAS traffic flow data was analysed at every off-slip road downstream of an activated VMS for the period of sign activation as recorded in the databases.

6.4.5 Results

Example 1

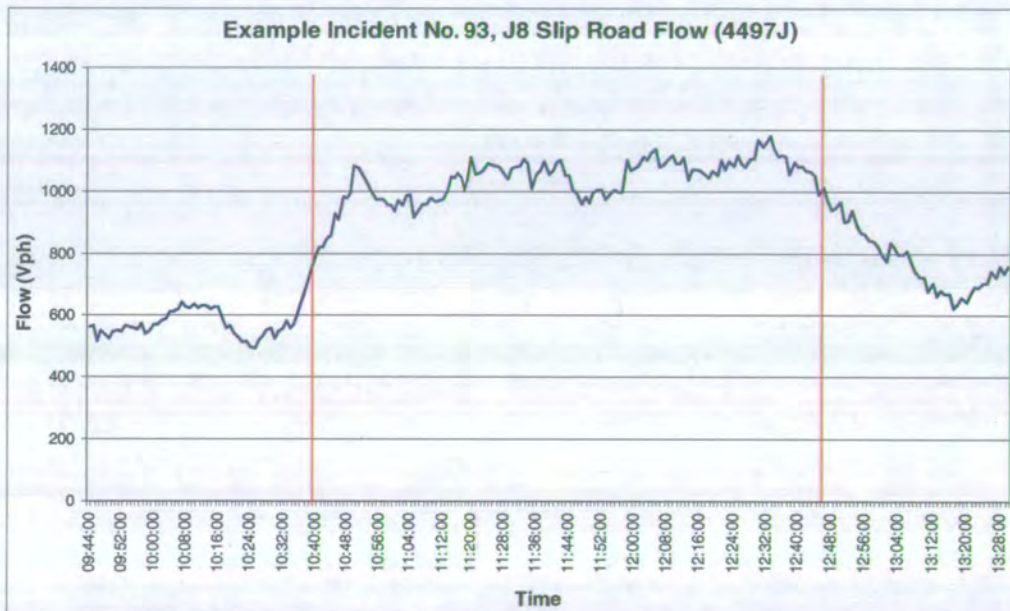


Figure 6.25 VMS Effectiveness Junction 8 Slip Road Traffic Flow – Example 1

A suicide occurred on 08/11/2003 at 4696A on the M25, between junctions 9 and 10, Godstone study incident number 93. The incident occurred at 10:01, lanes were cleared at 12:37 and the incident was all clear at 13:35. Six VMS signs, with motorist information, were activated at approximately 10:35 at 4435A (J6-J7), 4442A (J6-J7), 4474A (J7-J8), 4483A (J7-J8) and 4598A (J8-J9), with relevant logs shown in table 6.13. Traffic flows were taken at the three slip roads off the

motorway downstream of the VMS signs at junctions 7 (4455J), 8 (4497J) and 9 (4617J). VMS activations and de-activations are shown as red lines on figure 6.25 and 6.26.

Table 6.13 VMS Effectiveness VMS Logs – Example 1

Settings Archive							
Log Counter	OnDateTime	By	Type	Device	Aspect Code	Reason	OffDateTime
8182	08/11/2003 10:34:54	OIF 4	MSS	MSS M25/4435A	LONG DELAYS AFTER J9	ACCIDENT	08/11/2003 12:45:23
8183	08/11/2003 10:34:54	OIF 4	MSS	MSS M25/4474A	LONG DELAYS AFTER J9	ACCIDENT	08/11/2003 12:43:59
8184	08/11/2003 10:34:55	OIF 4	MSS	MSS M25/4483A	ACCIDENT AFTER J9	ACCIDENT	08/11/2003 12:43:50
8185	08/11/2003 10:35:00	OIF 4	MSS	MSS M25/4442A	ACCIDENT AFTER J9	ACCIDENT	08/11/2003 12:45:10
8186	08/11/2003 10:35:51	OIF 4	MSS	MSS M23/3336B	M25 J9 ACCIDENT	ACCIDENT	08/11/2003 12:44:35
8187	08/11/2003 10:35:53	OIF 4	MSS	MSS M23/3327B	LONG DELAYS AFTER J9	ACCIDENT	08/11/2003 12:44:24
8188	08/11/2003 10:37:40	OIF 4	MSS	MSS M25/4598A	ACCIDENT AFTER J9	ACCIDENT	08/11/2003 11:37:34
8194	08/11/2003 11:37:34	AUTO MID	MSS	MSS M25/4598A	QUEUE AHEAD	AUTOMATIC	08/11/2003 11:41:34
8198	08/11/2003 11:41:34	AUTO MID	MSS	MSS M25/4598A	ACCIDENT AFTER J9	AUTOMATIC	08/11/2003 12:42:22

At 4455J (J7) only limited if any response to signal activation was seen but at 4497J (J8), figure 6.25, and 4617J (J9) figure 6.26, the flow on the slip road increases greatly following the sign activation. At junction 8 the flow increases approximately 47% from approximately 560 vehicles per hour to approximately 1060 vehicles per hour and equates to an increase of approximately 1130 less vehicles joining the queue ahead. At junction 9 a flow increase can also be seen, increasing from approximately 420 vehicles per hour to 870 vehicles per hour, a 52% increase. Approximately 907 extra vehicles used the slip while the signs were activated. It should be noted however that the flow is a lot less stable than junction 8 and may have been influenced by the length of queue from the incident.

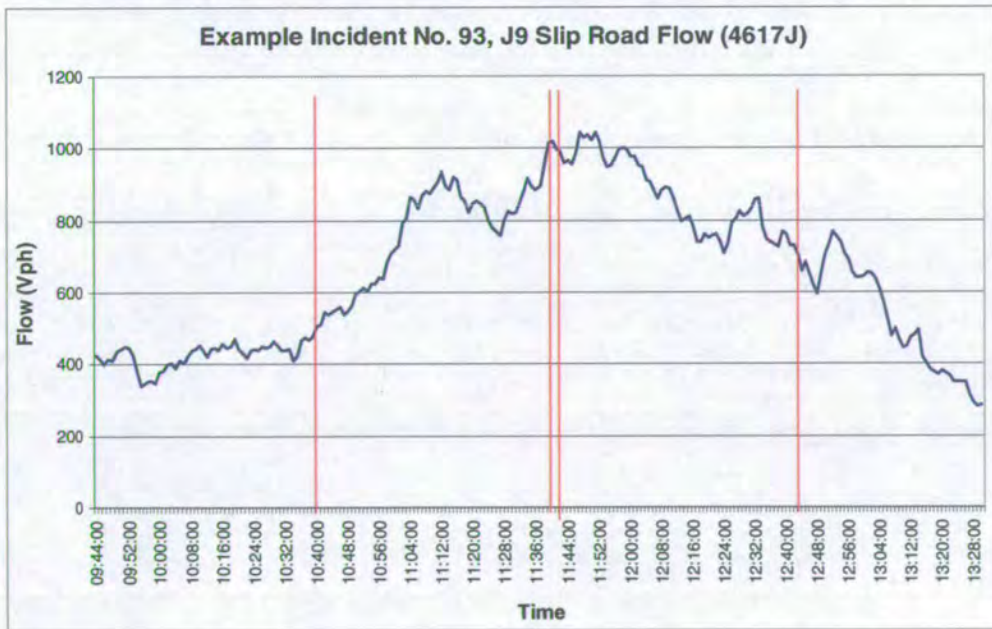


Figure 6.26 VMS Effectiveness Junction 9 Slip Road Traffic Flow – Example 1

Example 2

On 05/12/2003 a vehicle overturned between the slip roads at junction 8 (4506B) of the anticlockwise M25. The incident occurred at 11:50 and blocked 2 lanes, all lanes were opened and the incident was cleared by 13:04. Six VMS signs were activated at 12:07 by Traffic Control Centre (TCC) at 4876B (J13-J12), 4838B (J12-J11), 4764B (J11-J10), 4756B (J11-J10), 4677B (J10-J9) and 4669B (J10-J9). Traffic flows were taken at four junctions downstream of the VMS signs at junctions 12 (4843L), 11 (4806L), 10 (4727L) and 9 (4637L)

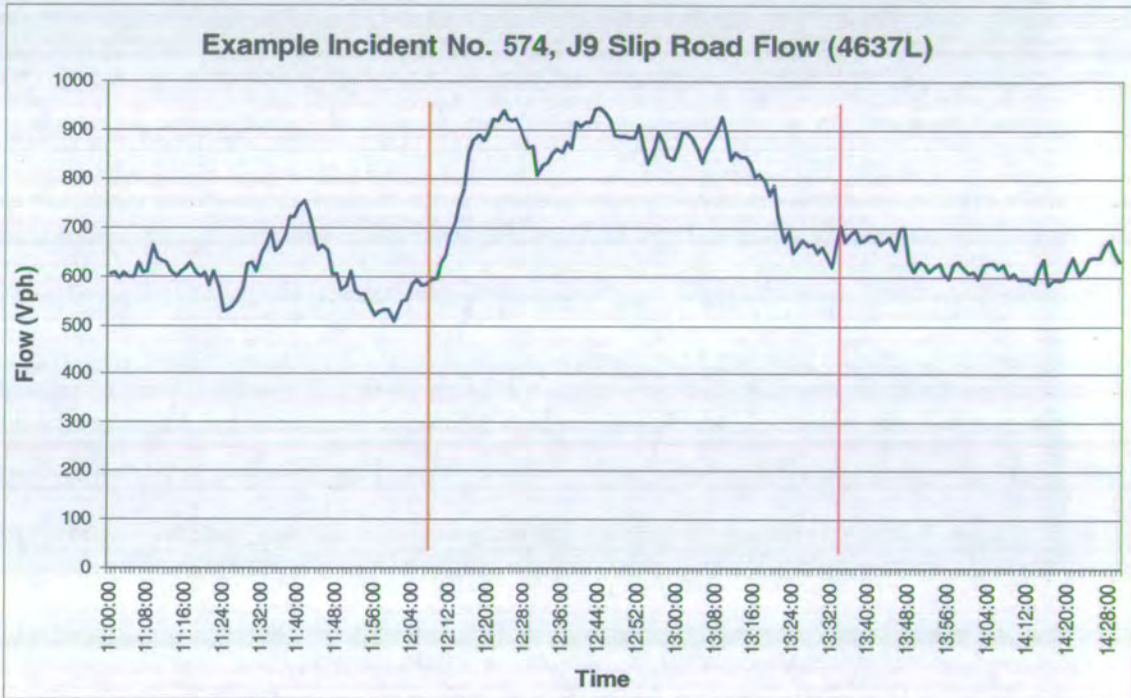


Figure 6.27 VMS Effectiveness Junction 9 Slip Road Traffic Flow – Example 2

The flows at the junctions 12, 11 and 10 slip roads (4843L, 4806L and 4727L) show that there was very little or no reaction to the VMS message. The flow at junction 9 (figure 6.27) however shows a clear reaction to the VMS signal activation, increasing flow from approximately 625 vehicles per hour to 860 vehicles per hour, a 27% increase.

Table 6.14 VMS Effectiveness VMS Logs – Example 2

Settings Archive							
Log Counter	OnDateTime	By	Type	Device	Aspect Code	Reason	OffDateTime
6023	05/12/2003 12:07:57	AUTO TCC	MSS	MSS M25/4669B	M25 J9-J8 ACCIDENT	AUTOMATIC	05/12/2003 13:34:57
6024	05/12/2003 12:07:58	AUTO TCC	MSS	MSS M25/4838B	M25 J9-J8 ACCIDENT	AUTOMATIC	05/12/2003 13:07:31
6025	05/12/2003 12:07:59	AUTO TCC	MSS	MSS M25/4756B	M25 J9-J8 ACCIDENT	AUTOMATIC	05/12/2003 13:07:32
6026	05/12/2003 12:07:59	AUTO TCC	MSS	MSS M25/4764B	M25 J9-J8 ACCIDENT	AUTOMATIC	05/12/2003 13:07:32
6027	05/12/2003 12:07:59	AUTO TCC	MSS	MSS M25/4876B	M25 J9-J8 ACCIDENT	AUTOMATIC	05/12/2003 13:07:32
6028	05/12/2003 12:08:01	AUTO TCC	MSS	MSS M25/4677B	M25 J9-J8 ACCIDENT	AUTOMATIC	05/12/2003 13:07:31

6.4.6 Discussion

In a number of cases, in terms of traffic flow, there were clear reactions to VMS legends with up to 52% increase of flow on the next downstream slip road recorded. In other cases however there was no reaction whatsoever. Success of a VMS message appears to be dependant on whether an appropriate diversion is available and the distance of the VMS message from the incident. For example, diverting between junction 8 and 6 to junction 5 is straightforward, with the A25 running parallel for some of the road's length, but easy diversions are not available at all exits. Local knowledge will also assist drivers with the choice of a diversion.

Several incidents occurred during or continued through the peak periods of the day, therefore making it is very hard to see any effect of the VMS messages as the traffic flow was naturally increasing and decreasing with demand. There were also some data inconsistencies with loops failing sporadically. At several incidents the MIDAS system overrode the operator set messages, to warn of queuing traffic ahead, and reinstated it once the alert was cleared. This may have caused some motorists not to be warned of the non-recurrent delays ahead.

A selection of mixed messages showing for example "Accident after junction X" followed on the next VMS by "Long delays after junction X" have the greatest impact. On the M25 there are an abundance of VMS in most locations so the above type of messages should be easily displayed. The blanket setting of messages on every available VMS should be avoided, especially long distances from an incident, as it could lead to sign blindness with motorists missing very import tactical messages from the police such as "Debris in road". Many motorists may also find this method very annoying, especially if they are not travelling as far as the incident. Some messages were somewhat vague, for example "M25 J7-J5 Accident" possibly

leading to motorist confusion. As previously stated a combination of two messages could avoid these issues, one giving the problem and another giving the impact.

6.4.7 Section Summary

It has been shown that motorists do acknowledge the presence of VMS messages and in some cases react to them, with up to a 52% increase of flow at downstream slip roads recorded. The motorist diversion rates could be influenced by an appropriate alternate route and by the level of local knowledge of the motorists.

As it has been shown that VMS messages influence motorist route choice, the use of VMS should be encouraged to provide more information. This in turn will reduce driver stress, increase safety, improve journey time reliability and minimise the effects of congestion and incidents.

6.5 Chapter Conclusions

This chapter has presented a review of motorway matrix signals and signs in use on the motorway and trunk road network in Britain and their functions. The effectiveness of matrix signals and signs was examined including compliance rates with mandatory signals and the impact of variable messages on driver route choice. Conclusions for each section are detailed below.

Section Three

An assessment of motorists' compliance with motorway matrix signals was presented. A total of 60 incidents and 105 red "X" matrix signal activations were examined. It was found that compliance with overhead gantry matrix signals is very variable. In addition, the following key findings emerged:

- 23,788 offences of driving under a red "X" matrix signal were recorded, which represented 15.26% of traffic.
- 396.47 average offences of driving under a red "X" matrix signal per incident, with 226.55 average offences of driving under a red "X" matrix signal per signal activation

- The average traffic speed was 9.55 mph less than the posted advisory or mandatory speed limit at the incident scene
- For multiple signal activation compliance was greater with the signals closest to the incident scene, but in general, compliance fell with the distance from the incident scene.
- Many differences were found between the MIDAS section and the Controlled Motorway sections of the M25.

It was concluded that motorway matrix signals are effective for the majority of the time but are completely reliant on motorists to comply with their instructions. Subsequently, although motorway matrix signals can be an effective tool in traffic management and delay reduction, matrix signals should not be solely relied upon for incident responder and motorist protection, and traffic management at an incident scene. Motorway matrix signals should only be seen as a form of emergency traffic management that should be physically reinforced as soon as possible to ensure safety.

Compliance rates could be improved by the use of enforcement cameras, but a more user friendly method would be to educate motorists of the reasons for the settings of signals and why they should be complied with. A national safety awareness campaign would be beneficial.

Section Four

This section assessed the impact of variable messaging signs on delay experienced by motorists, and consequently the level of reliance that should be put on the use of variable messaging signs in the management of traffic to reduce delay.

It has been shown that motorists do acknowledge the presence of VMS messages and in some cases react to them, with up to a 52% increase of flow at downstream slip roads recorded. The motorist diversion rates could be influenced by an appropriate alternate route and by the level of local knowledge of the motorists.

7 Optimal Deployment Strategies for Incident Support Units

7.1 Introduction

Rapid response to traffic incidents is essential for the effective management of non-recurrent congestion. As stated previously in section 5.4.3, the total delay due to an incident is proportional to the square of the incident duration, it can be seen that even a very short reduction in response times can have a large influence on an incident's impact.

By optimally locating ISUs at strategic sites around the M25 road network their response time can be minimised to reduce the impact of incidents and also ensure that they comply with their contractual response time requirements. Goolsby (1971) found that a 2 minute reduction in response time saved 411 vehicle-hours of delay for a one-lane accident, reinforcing the importance of rapid response.

This chapter will examine optimal deployment strategies for incident support units on the M25 road network. This will be completed via the development of a computer model that will determine the shortest response route for a particular network setup. This shortest response route in turn will produce the shortest travel (response) time for each ISU vehicle. Four location strategies will then be considered to optimally locate ISUs on the M25 and for each strategy the optimal number of ISUs is determined. The objective is to minimise the total travel time to incidents with the minimum number of ISU vehicles required to meet the service provider's contractual response time.

This chapter is structured as follows:

- **Section Two.** A background is presented on optimal deployment strategies. This includes a literature review of previous applications and methods.
- **Section Three.** An introduction to network analysis is presented, including details on how to represent a road network as a matrix and obtain the shortest route and minimal travel time between locations.

- **Section Four.** The development of the optimal deployment computer model and location strategies are discussed.
- **Section Five.** The results from the computer model are summarised and discussed. The optimal strategy and number of ISUs is also presented.
- **Section Six.** Once the M25 model had been validated, a more complex M25 Sphere model is considered.
- **Section Seven.** An operational comparison is presented to show the differences between theory and practice.
- **Section Eight.** Chapter summary and conclusions.

7.2 Background

The problem of optimal deployment of ISUs is similar to that of emergency service locations. There has been much research into optimal placement strategies for emergency vehicles, such as police patrols in relation to crime and fire stations and paramedics in relation to high incident frequency areas.

Many location-allocation models have been utilised to minimise response times, with the first by Cooper in 1964 (Cooper, 1964). A set covering model to locate emergency service facilities was proposed by Toregas et al. (1971), with the basic inputs to the model being: a set of demand points, a set of potential vehicle locations and a the set of demand points that can be covered by the specified location, within the accepted response time.

Set covering models have been used by a number of authors in locating ambulances and other emergency service vehicles including Voltz (1971), Walker (1974), Plane and Hendrick (1977), Daskin and Stern (1981), Goldberg and Paz (1990) and Goldberg et al (1990).

Toregas' model was however viewed as being too conservative in that an identical service was provided to every demand point, whether it was required or not. Church and ReVelle (1974) suggested maximising the number of covered demand locations

which could be covered within a specific service standard using a given number of vehicles. He used this maximum covering model for locating emergency vehicle depots. Later it was used by Eaton et al. (1985) to locate medical rescue services in the city of Austin, Texas. It was also used by Daskin (1982) and Belardo et al (1984).

A fire engine relocation model by Kolesar and Walker (1974) was a dynamic model for emergency response. Any unassigned emergency vehicles in stations were optimally repositioned, when a fire-related incident occurred, to minimise the loss in coverage from the dispatched vehicles.

A stochastic emergency response model employing a hypercube model for dispatching strategies and location plans was presented by Larson (1974). Based on the hypercube model, Larson (1975) presented an approximate procedure for computing selected performance characteristics of an urban emergency service system.

The location of fire companies in Denver, Colorado, USA has been studied by Plane and Hendrick (1977). A hierarchical objective function for the set covering problem was developed. The level of fire service was held constant, while the costs were lowered. This paper resulted in a saving of approximately \$1.2 million annually through the optimisation of the Denver fire department.

A computer program for specifying the number of police vehicles which should be in a geographical area was developed by Chaiken and Dormont (1978). The program determined the minimum number of police vehicles needed to meet specified performance criteria. A further algorithm for deploying a crime directed patrol force was developed by Chelst (1978). The optimisation problem examined the police unit allocation within high crime zones to maximise the probability of a police patrol intercepting a crime.

A maximal expected covering location model for locating emergency response vehicles was proposed by Daskin (1983). It was based on the idea that during emergency times not all vehicles allocated to serve a particular zone in the network would be available. Zografos et al. (1993) used a districting model to obtain optimal locations of vehicles which would minimise the total average incident response workload per vehicle on freeways, subject to a constraint on the maximum number of available vehicles.

Saccomanno and Allen (1988) presented a model for locating emergency response capability for hazardous goods transportation on a road network. The model was treated as a minimum set covering problem with a minimum acceptable level of response at all potential spill sites. Matrix reduction techniques were used to obtain a non-redundant set of candidate sights for response capability. The model was then applied to a rural road network in southwest Ontario, Canada.

A mixed-integer programming model for the simultaneous location, dispatching and routing of incident response vehicles was developed by Daskin (1987). A similar model by Pal and Sinha (1997) also used the mixed-integer programming method to determine the optimal locations for response vehicles that minimised annual response vehicle costs, given the frequencies of incidents on the network, and constrained by the maximum number of vehicles.

Nathanail and Zografos (1995) developed a simulation tool for evaluating the effectiveness of freeway incident response operations. A priority list of incidents was created so that when multiple incidents needed response the effect of loss in coverage was minimised. It was also noted that response from multiple vehicles to incidents could reduce the response time.

Ball and Lin (1992) proposed a reliability model for emergency service vehicle location. The model used a set of demand points, a set of vehicles and a set of locations for vehicle depots to assess how reliable a system was at achieving targets. Ball viewed the problem as one of optimising the reliability of the system, where

failure was defined as the inability of a vehicle to respond to a demand call within an acceptable amount of time.

Of more relevance to this study are the papers by Zografos et al (1993), Wilminik and Immers (1996), Petty et al (1997) and Joseph and Chang (2002).

Zografos et al (1993) attempted to optimally deploy a fleet of traffic-flow restoration units (TFRUs) to minimise freeway incident delays from incidents. By reducing the dispatch and travel (response) time of the TFRUs they expected to produce substantial savings in incident delay. Wilminik and Immers (1996) applied a model to determine possible locations of additional tow truck services in the road network around Utrecht in Holland. Using a simulation model they evaluate various location strategies and number of vehicles. They found that if the allocation of vehicles is based on shortest travel time total incident delay was reduced by 6%. Additionally if an additional tow vehicle was made available during peak hours peak delays would be reduced by 42%. Petty et al (1997) presented a methodology for determining the optimal locations for freeway service patrol tow trucks. They demonstrated their methodology on the I-880 interstate near Los Angeles, using estimated benefit cost values. Finally Joseph and Chang (2002) used an inter-programming method to locate emergency response vehicles on the capital beltway around Washington DC. They demonstrated that four units could be optimally placed to provide a reduced average response time of 5 minutes.

7.3 Network Analysis

Since time began, man has used primitive forms of optimal location, whether he was looking for a place to live or for defence. This may have centred on personal demands for food, water and safety but it demonstrates how long this process has been in existence and how much it has advanced to its present day form.

7.3.1 Basic Definitions

To analyse a network the road network must be reduced to its most basic form, consisting of nodes joined by links. By definition the links in a highway network are stretches of highway. The network must be simplified so that information about the

direction, shape and length are ignored whilst emphasising the essential structure, stating which locations (nodes) are linked directly and which are not.

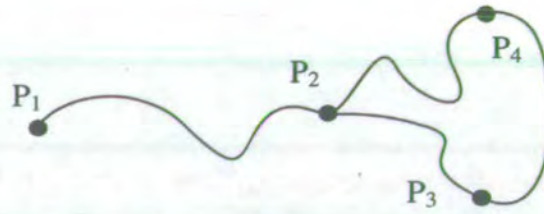


Figure 7.1 Original Road Network.

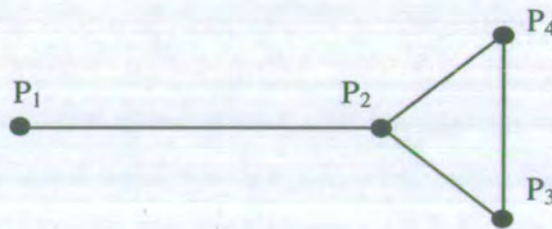


Figure 7.2 Simplified Road Network.

For example figure 7.1 shows roads linking four towns (links joining nodes). In figure 7.2 the road network is simplified in such a way that the links are shown as straight lines. This emphasises the essential structure of the network through confining itself to stating which places are linked directly and which are not. In network analysis figure 7.2 represents the kind of network which is termed a Graph. The branch of mathematics which concerns itself with studying the properties of figures like this which consist of points and lines joining them is called graph theory. In the notation of graph theory the places (points or nodes) on the network are called vertices and each route or link joining two places is called an edge.

In reducing the network to its essential structure, the following guidelines must be adhered to:

- Each network has a finite number of places
- Each link joins two different places
- A pair of places is joined by no more than one route.

Graph theory can be viewed as a part of a type of geometry called topology. Topology is a very basic kind of geometry concerned with those properties which remain unchanged under continuous transformations of the object. Topology is mainly concerned with whether objects are connected or not. It is not primarily interested in the length or orientation of their links.

Therefore in terms of topology all of the networks and graphs shown below, in figure 7.3, are identical.

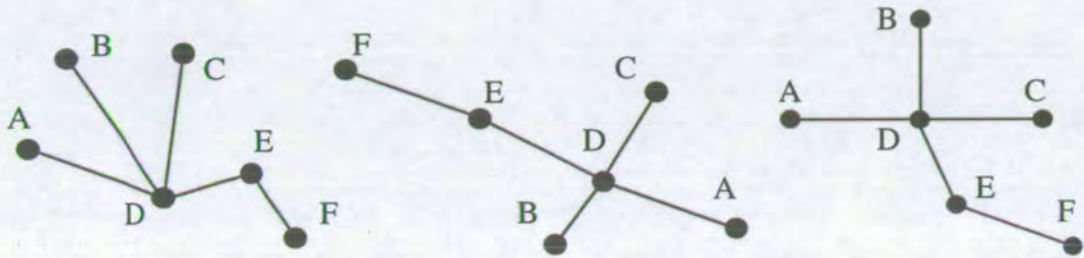


Figure 7.3 Diagrams of Example Networks.

The topological distance between two places is the number of edges on the shortest path between them. In the above networks (figure 7.3) the topological distance from A to D is 1, from A to B is 2 and from A to F is 3. This is true in all of the four graphs as they are identical topologically. Topology measures links on a binary scale of measurement (either 1 or 0). If two places are linked this is recorded as a “1”. Zero indicates the absence of a link.

7.3.2 Network Connectivity

The networks shown in figure 7.3 have 5 edges and just enough links to make it possible to travel from any of its 6 vertices (v) to any other. Networks with $(v-1)$ links are called branching networks or trees. In these networks the following rules apply:

1. There is only one path between any two places and
2. No circuits are possible - return journeys follow the same path as the outward journey. If the number of links was to equal the number of nodes then circuits would be possible.

River networks have the same form as branching networks though they only flow in one direction.

Given a graph or network with v vertices and e edges the beta index (β) provides us with a very simple measure of connectivity by taking the number of links as a ratio of the number of nodes.

$$\beta = e/v \quad [\text{Eq. 7.1}]$$

In figure 7.3, $\beta = 5/6$. The greater the connectivity, the larger is β . A network with no links has $\beta = 0$.

Representing Networks as Matrices

Any graph or network can be represented by a matrix. The example shown in figure 7.4 demonstrates how to represent a network as a matrix. The rows and columns of the matrix represent the nodes of the network.

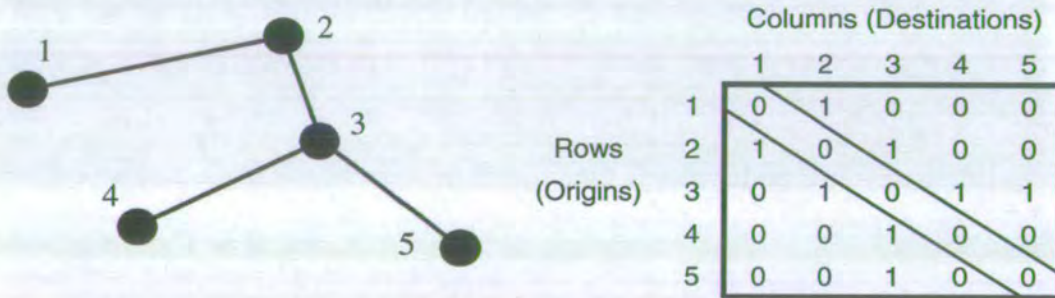


Figure 7.4 Example Network and Connectivity Matrix

When placed in a row, the node is being considered as an origin of a route and when placed in a column, as a destination. When a direct link exists between an origin and a destination a 1 is placed in the appropriate element, a_{ij} , of the matrix and a 0 if there is no direct link. There is a link from the first node to the second node therefore the cell in the first row and second column of the matrix contains a 1. There is no direct link from the first node to the third node therefore the cell in the first row and third column of the matrix contains a 0. By convention diagonals are given a value of 0 as there is no link between a node and itself. Therefore this connectivity matrix essentially includes all the main information contained within the network and has the additional advantage that it makes the information easy to manipulate

mathematically. The matrix in figure 7.4 demonstrates how symmetry about its main diagonal axis shows that two way traffic is permitted on all routes. The connectivity matrix can just as easily represent one way travel by entering a value of 1 in element a_{ij} if flow is allowed from node i to node j and a value of 0 in element a_{ji} if flow is not allowed in the other direction.

7.3.3 Shortest Route and Minimal Travel Times

If the connectivity matrix is squared, the resulting matrix gives the number of two-link routes between nodes. If the initial connectivity matrix is cubed, it then gives the number of three-link routes and so on. Using the respective link length and link speed it is then possible to establish the shortest time between any two nodes. The result of this is a matrix containing the minimum route times from every node to every other node where a route is possible.

The shortest route between any two nodes in a network can be found using the following method:

1. Define the connectivity of the network (i.e. take each individual node and state which other nodes it is directly linked taking into consideration the flow of traffic, also noting the link length and free-flow travel speed).
2. Construct a connectivity matrix of dimensions $i \times j$ (where $i = j =$ number of nodes in the network) containing one's and zero's using the connectivity data.
3. For every element a_{ij} in the connectivity matrix, calculate the duration of a journey along the route using the respective link length and link free-flow travel speed information (and any additional factors to take account of slowing due to congestion, etc.). Place this calculated value in element b_{ij} in a new route-times matrix. This matrix will eventually have dimensions $i \times j$ and contain the shortest times for all possible routes between all nodes.
4. Apply a power of 2 to the initial connectivity matrix to produce a matrix which indicates how many two-link connections there are for every node.

5. For every non diagonal element a_{mn} in the route times matrix that has yet to be assigned a value, look in the new powered matrix to see if there is a possible two-link route between nodes m and n .
6. If there is a possible two-link route, use the route times matrix to find the instance where an element x in row m and element x in column n are non-zero and find the sum of the two elements. If there are several possible two-link routes between m and n (i.e. a value greater than 1 found in element _{mn} in the new powered matrix) then find every instance where element x in row m and element x in column n are non-zero and compare the sums in each instance to find the lowest value and hence the shortest route.
7. Put this shortest route time into the route times matrix as element b_{mn} .
8. Repeat for every element of the route times matrix.
9. Repeat process 5, after applying a power increased by 1 to the initial connectivity matrix.
10. Repeat until all possible route times have been found.

The result of this is a matrix containing the route times from every node to every other node where a route is possible.

This route times matrix is the main focus of this investigation. Once the route times matrix is obtained, various deployment strategies can then be investigated to establish the minimal total travel time to respond to incidents.

7.3.4 The Objective Function

Integer variables are used to define whether a location is to be used as a position for an ISU. The following notation is used to represent the location problem:

- j Indicates an incident site
- i Indicates the possible location of an ISU
- K Is the number of ISUs provided
- I Indicates the set of possible locations for ISUs
- J Indicates the set of possible incident sites
- p_j Probability that an incident occurs at a particular site j .
- t_{ij} Travel time from location i to incident site j .

The objective function of the formulations for ISU locations can be set to minimise the total travel time or the maximum response time. The formulation gives a placement similar to the strategy where the vehicles are close to the locations of high incident occurrence.

Variables:

- x_i = 1 if an ISU is located at i
= 0 if not
- z_{ij} = 1 if an ISU at i serves site j
= 0 if not

The total travel time to all incidents for all vehicles for the whole time horizon can be expressed as:

$$\sum_{i \in I} \sum_{j \in J} p_j t_{ij} z_{ij}$$

Minimising the result of this function will minimise the expected total travel time.

This can be constrained with the condition:

$$\sum_{i \in I} x_i \leq K$$

This ensures that the number of vehicles located is not greater than the number available. The constraint:

$$z_{ij} \leq x_i$$

ensures that only if an ISU is located at a particular site, an incident can be served by that location.

The constraint:

$$\sum_{i \in I} z_{ij} = 1$$

means that each possible incident site needs to be served by only one vehicle. Using this function it is possible to evaluate possible vehicle arrangements.

7.4 Computer Modelling

The model was constructed within Mathworks' MATLAB software. MATLAB is a technical computing language and interactive environment for algorithm development, data visualisation, data analysis, and numeric computation. All of the data for the model was input into Microsoft Excel spreadsheets, to simplify data processing.

To establish the effectiveness of the model the main M25 motorway ring was constructed first, before the more complicated M25 Sphere road network.

7.4.1 Node Definition

The M25 consists of 33 junctions numbered sequentially (1A, 1B, 2, ..., 29, 30, 31). Each junction is specified as a node and is numbered sequentially, giving 66 nodes in total. These will be joined by one-way links. Each junction will be represented by a pair of nodes with each being linked by additional links of negligible length. These additional links preserve connectivity without interfering with travel times or statistical analysis. As there are clockwise and anti-clockwise carriageways with only one-way traffic, two separate rings are defined, joined at the nodes (junctions). Accurate location information was obtained from Carillion's ISU CAD data as it records all incident locations using the Global Positioning System (GPS) to aid in

dispatching the ISUs to incidents. All marker posts, SOS boxes (emergency roadside telephones) or feature on the side of the carriageway, such as gateways, are contained within the data. This information was manually checked for consistency and accuracy. Finally, the locations were plotted on electronic 1:25000 scale Ordnance Survey maps, using GIS software, to ensure graphically the accuracy of locations.

All of the location information was collated into a Microsoft Excel spreadsheet table which defined the nodes and their coordinates, which is included in appendix C.

7.4.2 Node Connectivity

Once the network's nodes had been defined they needed to be connected. Node connectivity was manually calculated and inputted into a Microsoft Excel spreadsheet table. This worksheet contained all information to be inputted into the connectivity matrix. A selection of the Excel file is shown in appendix D

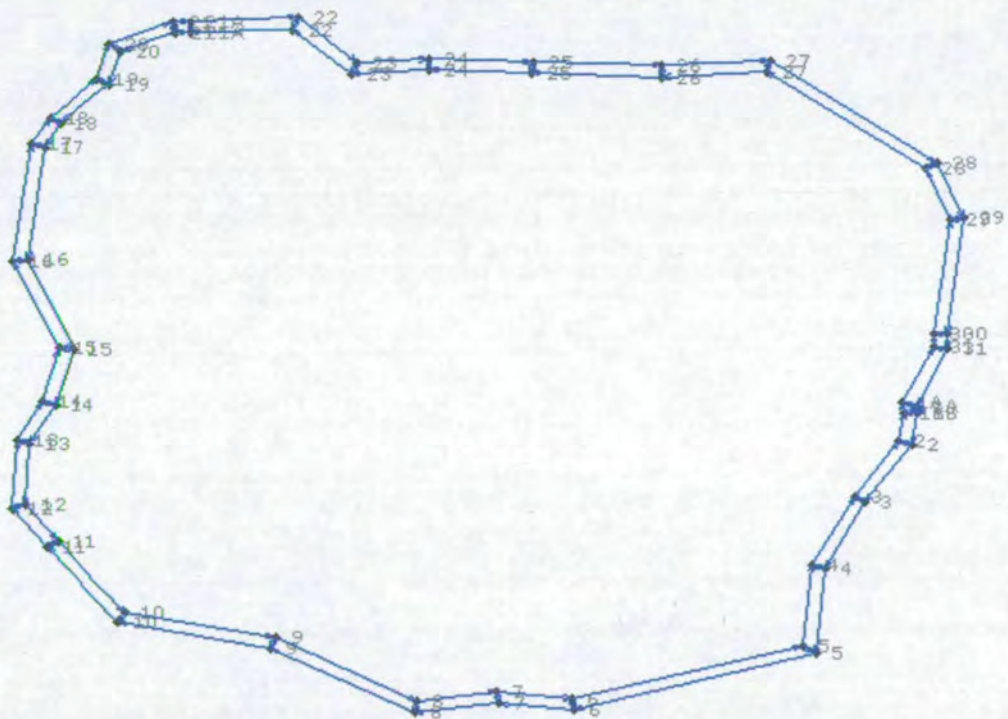


Figure 7.5 Plot of the M25 as a Transport Network.

7.4.5 ISU Response Speed and Range

The optimal location of the ISUs is dependent on how far they can travel within their contractual 20 minute response time. Their range is entirely dependent on the average speed they can achieve between notification of the incident and arrival at the scene. A conservative approach has been chosen in that the average assumed response speed is 20 mph. This is equivalent to having to respond the full distance using only the hard shoulder which has a nominal 20 mph speed limit for safety. Table 7.1 shows the response ranges depending on average response speed over 20 minutes. It can be seen that in free flowing traffic the range available would be much greater.

An ISU located at a node on the clockwise carriageway could serve incidents just as well if it was positioned on the same node but on the anti-clockwise carriageway. Therefore, there are effectively 33 possible ISU locations.

Table 7.1 Response Speeds and Ranges.

Speed (MPH)	Speed (KPH)	Range (Miles)	Range (Km)	Remarks
10	16	3.33	5.33	
20	32	6.67	10.67	Hard Shoulder Limit
30	48	10	16	
40	64	13.33	21.33	
50	80	16.67	26.67	
60	96	20	32	LGV Speed Limit
70	112	23.33	37.33	Motorway Speed Limit

7.4.6 Travel Time

An incident can occur at any point along a link. Should an incident occur on a link just short of a junction, and should an ISU be stationed at that particular junction, it cannot simply travel the short distance back along the link to the incident in the contra-flow link direction. The travel time to an incident on an incident therefore includes the time taken to travel along the entire length of that link.

7.4.7 Location Strategies

There are many ways to position ISUs on a road network. Previous methods have included just using practical experience to deploy vehicles or using a length of string equivalent to the response time and speed laid over a map of the road network.

The different proposed strategies will be compared by defining a quantitative factor that measures the strategy's effectiveness. The cumulative travel time (response time) will be used:

$$\text{Cumulative travel time} = \sum_{i \in I} \text{number of incidents } x_i \min_{j \in J} (T_{ij})$$

In addition to a lower cumulative travel time, ISUs should experience lower running costs and potentially more time available for routine network maintenance.

Four ISU location strategies will be examined:

1. Even spacing - junctions
2. Even spacing - distance
3. Traffic flow
4. Incident frequency

Strategy One

The simplest strategy employed will involve spacing ISUs evenly around the road network by junction. Ideally this would give good overall coverage to respond to incidents which can occur anywhere. However due to the random nature of motorway junctions which are spaced at unequal distances, potentially this can leave areas of poor coverage where there are long stretches between junction. Areas where junctions are very close together subsequently will have very unnecessary high ISU coverage.

Strategy Two

The second strategy is similar to the first, in that it also spaces the ISUs evenly around the road network, however this strategy's spacing is calculated on distance. The results for this strategy should be an improvement on that of strategy one,

making better use of the ISU resources and spreading them more consistently around the network.

Strategy Three

Strategy three uses historical traffic flow data to locate ISUs in order to cover incidents where they will have the greatest impact. This strategy is intended to minimise the congestion related with incidents by giving a higher priority to areas where more motorists would be affected by an incident.

Strategy Four

Finally, strategy four involves using historical ISU CAD records to position the ISUs at locations with the highest probability of incident occurrence. This strategy will generally reduce response times to most incidents as on average there is greater ISU coverage in areas of high incident occurrence. Areas of low incident probability will consequently experience higher response times.

7.4.8 Model Assumptions

- This model assumes that the responding ISUs are always available and always at their allocated location. In reality however the ISUs may already be dealing with an incident, carrying out minor maintenance tasks on the network or the ISU operatives may be having a break. It should be noted though that these tasks may actually reduce response times as well as increase them depending on the vehicle location.
- An assumption is made that the travel speed of the ISU vehicle is fixed. A worst case scenario was taken in that the speed was 20mph, the highest speed allowed on a hard shoulder. The further assumption is therefore that the hard shoulder will always be clear – one which may not always be true in reality.
- In considering the distributions of incidents, the optimisation model has assumed that incidents occur at the nodes. This of course may not occur in reality.
- This model also does not account for the time taken at junctions, for example changing directions while responding to incidents.

7.5 Results

The four specified strategies were examined for 1 to 20 ISUs. The results from the analysis are shown in table 7.2. It can be seen there is great variability between the presented strategies. The four strategies are also shown graphically in figure 7.7.

Strategy One

Strategy one used even spacing based on junctions. For 20 ISUs it was the third best strategy with a total estimated incident response time of 144.57 vehicle hours. As already stated, due to the random nature of motorway junctions spaced at unequal distances, some areas were left with poor coverage where others had unnecessary high ISU coverage. As the number of ISUs was decreased the response improved in relation to the other strategies. This is due to the influence of junction distances having less of an effect. To guarantee 100% 20 minute ISU coverage a minimum of six vehicles would be required.

Strategy Two

Strategy two used even spacing based on distance. This strategy for 20 ISUs had the lowest total estimated incident response time, 63.7 vehicle hours. This is due to the even spacing of vehicles around the network providing consistent coverage. Strategy one also required the lowest number of ISUs, five, to provide 100% 20 minute coverage.

Table 7.2 Summary of ISU Location Strategies Results

Number of ISUs	Total Incident Response Time (Hours)			
	Strategy 1	Strategy 2	Strategy 3	Strategy 4
	Even Spacing Junctions	Even Spacing Distance	Traffic Flow Spacing	Incident Frequency Spacing
20	144.57	63.675	240.135	66.34
19	150.67	89.135	324.695	71.4
18	152.32	92.01	325.67	108.44
17	160.72	95.79	335.57	117.94
16	164.42	105.24	344.22	132.36
15	201.97	135.105	368.07	140.16
14	215.885	156.395	379.37	145.36
13	262.645	156.18	609.665	155.425
12	299.12	212.95	627.265	194.05
11	268.43	194.48	1074.005	226.945
10	323.825	212.06	1075.655	246.91
9	343.965	309.87	1100.735	256.85
8	380.805	331.73	1148.135	338.98
7	468.595	385.59	1505.155	512.365
6	492.37	424.885	2017.51	565.69
5	708.595	518.295	2230.635	705.61
4	849.41	630.75	2312.21	842.41
3	990.095	964.25	2412.36	1022.245
2	1340.95	1356.83	2561.355	2324.325
1	2740.895	2740.895	2652.255	2662.2

Strategy Three

Strategy three used the historical traffic flow records to distribute ISUs around the network. This was the worst of the four strategies with almost four times the total estimated incident response time of strategy two. It also required the most ISU vehicles, thirteen, to guarantee 100% 20 minute coverage. As this strategy only utilised traffic flow data it meant that the majority of vehicles were all grouped around the busier south western sections of the M25 rather than being spread across the network. This resulted in some incidents having very short response time but also some having very high.

Strategy Four

Strategy four used historical incident data to distribute ISUs around the network. This strategy achieved the second best results with 20 ISUs, very close to strategy two. As the number of ISUs dropped below eight the performance did not match strategy two however but did match strategy one, also requiring six ISUs to guarantee coverage. This strategy meant that the majority of incidents were attended

within a short time but as the ISUs were concentrated around these high incident locations other areas experienced larger response times.

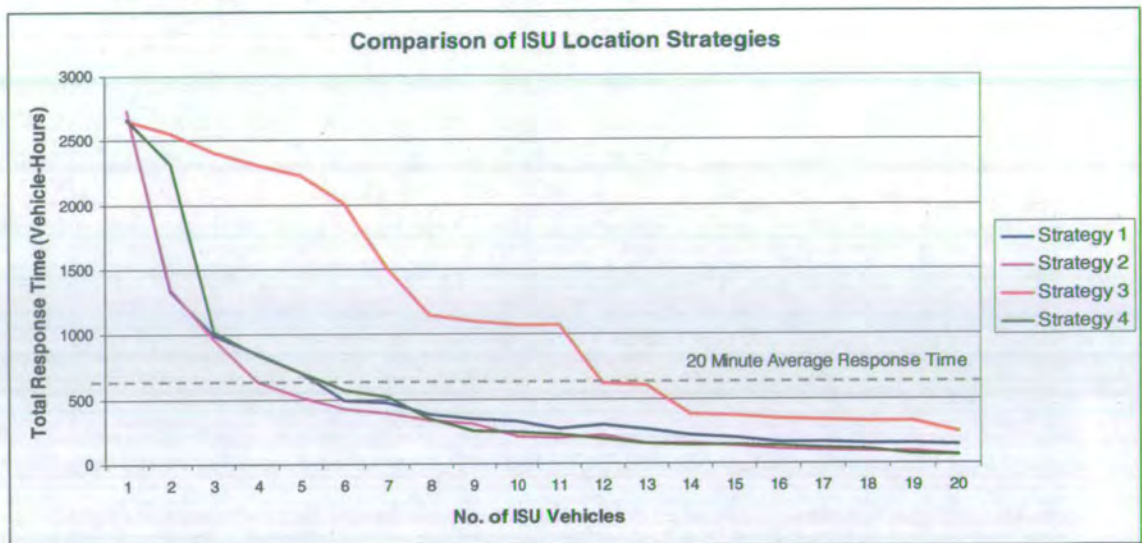


Figure 7.7 Comparison of ISU Location Strategies

7.5.1 Summary

It can be seen that there is great variability between ISU deployment strategies. Strategy two, using even spacing based on distance, was shown to be the best to locate ISUs on the M25. This strategy only required five optimally positioned ISU vehicles to guarantee a 20 minute response time to incidents given a response speed of 20 mph and thus is proposed as the optimal deployment strategy for the M25 network.

A plot of this deployment strategy, represented by red circles, placed on the M25 network is shown in figure 7.8. However, whilst it has been shown that this is an optimal deployment strategy for the M25 network, it does not consider the whole of the M25 Sphere. The next section discusses the widening of the investigations to cover the whole network.

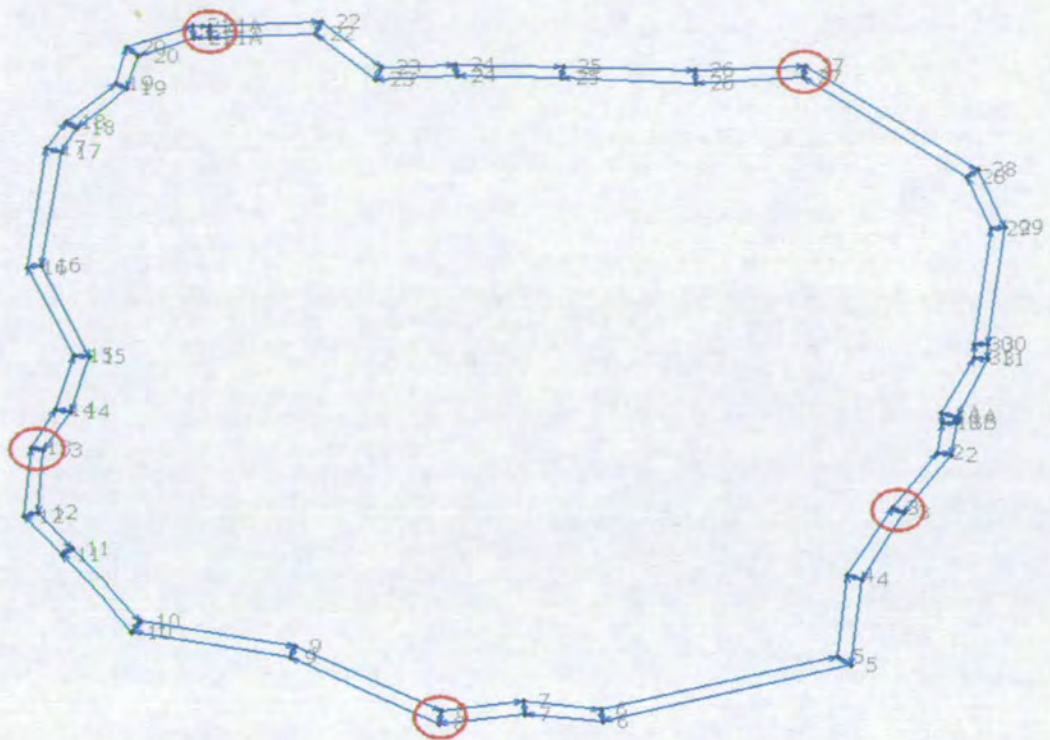


Figure 7.8 Plot of M25 Network Showing Optimal ISU Locations.

7.6 M25 Sphere

The model shown in figure 7.8 is a 33 node network of the M25 motorway. In reality Carillion manage the more complex 236 node M25 Sphere and thus consideration needs to be made of the modelling of such a network.

As before all of the location information was collated into a Microsoft Excel spreadsheet table which defined the nodes and their coordinates. For this network however there were many more nodes than the M25. Emergency turnaround points were added to the main M25 ring and all other M25 Sphere roads, including the M11, M20, M23, M26, M4, A1(M), M1, A3 and M3, were also added to the node definitions. By adding these other roads it necessitated a more complex definition of each junction, thus increasing the number of nodes, to allow access for ISUs to reach incidents. Several junctions were simplified from their real geometry as this is not required for the network analysis. In total the M25 Sphere network required 236 nodes to be manually defined.

Once the nodes had been defined the node connectivity was defined. This was far more complex than the M25 network and required 497 links to be defined. The much larger number is mainly due to the increased complexity of junctions defined within the network.

As with the M25 network all node definitions and connection information was manually checked for consistency and accuracy. Additionally the network was plotted on electronic 1:25000 scale Ordnance Survey maps, using GIS software, to ensure graphically the accuracy of locations. A graphical plot, from MATLAB, of all nodes and links is shown in figure 7.9.

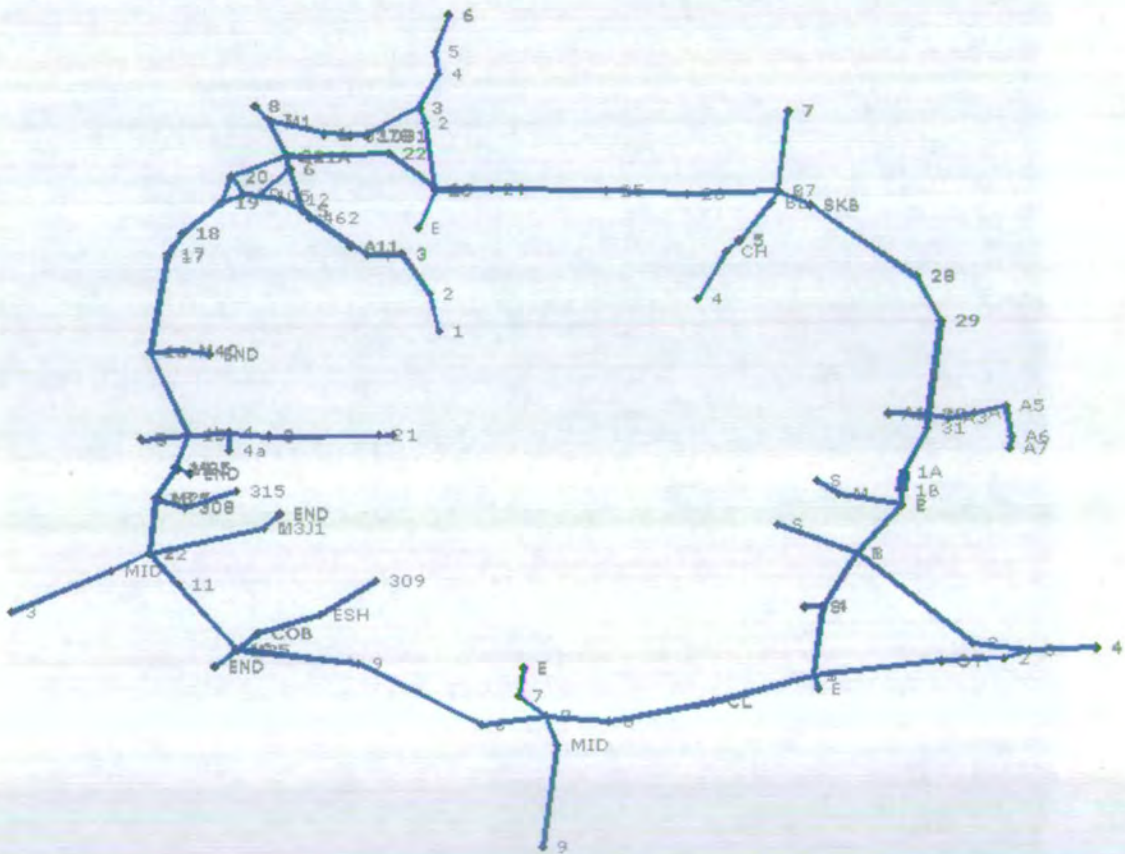


Figure 7.9 Plot of the M25 Sphere as a Transport Network.

Incident demand rates and ISU response speed were applied as detailed above in sections 7.4.4 and 7.4.5.

7.6.1 Modelling

The new M25 Sphere was then run to evaluate the shortest route and minimal travel times for the network to evaluate new complete ISU strategies. The same method as the M25 network was utilised as detailed in 7.3.3.

Unfortunately the revised model for the M25 Sphere however did not run successfully. It is thought that the model required too many iterations were required and that limitations with the developed MATLAB program would not allow full analysis of all values. This is clearly an area for further work.

7.7 Operational Comparison

Currently on the M25 Sphere Carillion operate a fleet of sixteen ISUs who have on average a response time of approximately 12 minutes for the complete M25 Sphere, not just the M25 ring. These vehicles are currently located around the network using practical experience. They currently achieve their contractual 20 minute response time approximately 95% of the time. The missed 5% is usually due to extraordinary circumstances or during peak periods where travel times are lengthened.

Using the developed M25 network model with the selected location strategy (Strategy no. 2, discussed in Section 7.5.1) the ISUs would be expected to achieve complete coverage and an average response time of 16.6 minutes for five ISUs. Seven ISUs would be required to achieve a 12 minute response time using the same deployment strategy but would also add some redundancy to the system.

A like for like operational comparison unfortunately can not be done due to the failure of the complete M25 Sphere model. It is likely though that this method of optimal deployment could provide operational savings for the service provider and an improved service for the general public.

7.8 Chapter Conclusions

To optimise the response times for a fleet of ISUs is clearly of utmost importance to the service provider. In the case of Carillion on the M25 Sphere, there is a

contractual obligation for a significant proportion of incidents to be responded to within 20 minutes during day time hours. To manage this, the service provider must therefore deploy the fleet of ISUs optimally. This deployment has two main factors:

- the location of ISU vehicles,
- the number of ISU vehicles.

This chapter has examined optimal deployment strategies for incident support units on the M25 road network via computer models which were developed to establish the shortest route and minimum travel times between any two nodes of the modelled road network. The approach used was to model just the M25 motorway (a network with a total of 33 nodes). A model of the whole of the M25 Sphere network (236 nodes) was discussed in section 7.6 but this was shown to be too computationally complex to analyse in this study. The intention was to apply four location strategies to these models, each strategy considering a varying number of vehicles (1-20). These strategies were outlined in section 7.4.7.

It was found that the strategy which provided a combination of the shortest response time for the lowest number of vehicles was strategy two (see figure 7.7) which was based on a geographically even distribution of ISUs around the network. The worst performing strategy was number three which was based on biasing the location towards those parts of the network with the greatest traffic flows.

That strategy two should be the best performing is what would be expected – the strategy itself is based on the assumption that for the model's even traffic congestion (i.e. represented by a fixed speed) equal spacing will provide minimum response times. However, three of the strategies actually gave very similar results in that the optimal number of vehicles only varied by 1 vehicle. In reality, is this a practical strategy? It may not always be possible to locate an ISU at the location that the strategy indicated is the best position. The model is based on the assumption that ISUs are at nodes – i.e. junctions, but junction design, layout and operational differences may mean this is not always possible.

The possible surprise in these results was with strategy number three. In this case the number of ISU vehicles needed to meet the 20 minute cut off was more than double that of the other three – 13 vehicles. Clearly this strategy was not ideal but closer inspection reveals that because these results were based on averages – the results are made up of the response times to incidents at each node, i.e. 33 – there were actually wide variations. A lot of incidents occurred in the higher traffic flow areas and these received very good response times – but this was at the expense of those incidents at the nodes that had lower traffic flows and thus, through the strategy, fewer ISUs.

In reality the actual location of the ISU vehicles is based on somewhat more arbitrary decisions. By coincidence, Carillion have the same number of depots on the M25 Sphere as the optimal number of ISUs shown by strategy two (five) and these are the default positions of the vehicles. They currently use a total of sixteen units (see section 7.7) but these need to service the whole of the M25 Sphere and the model only considers the M25 itself. Further, on a day to day basis the location for any one vehicle can and will change. The main principle is that they are located in ‘safe’ areas – of which there are many, such as service areas or larger junctions – but as Carillion also employ the ISUs to do maintenance also they could be at any single point on the whole network. Direct comparison is thus very difficult.

What has been shown in this chapter is that it is possible to develop strategies for the optimal location of ISU vehicles. It has also shown that these strategies can meet the operational and contractual requirements for the network and that this management approach could work in a live situation. The model is flexible enough to allow for changes in incident frequency and locations or temporary network changes (such as highway renewals) and thus could be implemented easily. Further work needs to be done to enhance the model for more complex networks, such as the 236 node M25 Sphere, but this is essentially a computationally more advanced version of the optimisation model presented.

8 Conclusions and Future Work

8.1 Introduction

It has been estimated that incidents on motorways and trunk roads in Britain account for approximately 25% of all congestion, which costs the British economy an estimated £750million a year (National Audit Office, 2005). Incidents represent any non-recurrent occurrence or unplanned event that creates a temporary reduction in roadway capacity, which in turn impedes the normal flow of traffic (TRB, 2003). Incident management programmes have been developed to mitigate non-recurring congestion from incidents. Incident management is the process by which incidents are cleared from the road returning them to normal traffic conditions. The purpose of incident management programmes is to rapidly detect, verify and clear temporary obstructions from roads to restore normal traffic flow as quickly as possible. In Britain the Highways Agency, as the operator of the British strategic road network, developed the Incident Support Unit (ISU) to support the effective management of incidents.

This study has investigated the nature and impact of incidents and the incident management process on the M25 Sphere. This conclusion chapter will reflect on the work presented here in the following sections.

- **Section Two.** This section will provide a summary of each chapter within the thesis.
- **Section Three.** The original project aims and objectives will be re-examined in this section with a conclusion of and how and where they were met
- **Section Four.** Specific points that have emerged will be detailed. Key findings of interest or practical value and benefit will be detailed.
- **Section Five.** Finally, potential further work will be identified and discussed.

8.2 Thesis Summary

A summary of each chapter within this thesis is presented below.

- **Chapter 1.** Chapter 1 provided an overview of the problems addressed within this research study and the basic project approach and the methods used to address the problems. The research aims and objectives were also established.
- **Chapter 2.** Chapter 2 presented an examination of the motorway incident management process and provided a background to this work on the M25 London Orbital Motorway. The five stages of incident management- detection, verification, response, clearance and recovery- were detailed, with programme stakeholders identified and their roles and responsibilities at motorway incidents examined. An introduction to the M25 London orbital motorway was also presented, including the history, future and current maintenance and management arrangements. The Highways Agency's approach to incident management in Britain was also described with their response capabilities through Incident Support Units and Traffic Officers examined in detail. Finally an incident management programme comparison between Britain and four US states was carried out.
- **Chapter 3.** Chapter 3 presented a review of the ISU service on the M25 motorway, operated by the HA's service provider Carillion plc, including quantitative (analysis of incident data) and qualitative examinations (via questionnaire survey), and a benefit-cost estimation. An analysis of ISU attended incidents, an estimation of ISU benefits and qualitative police and ISU operative survey results was presented.
- **Chapter 4.** Chapter 4 described the influence and role of ISUs on the M25 Sphere. A detailed study of all incidents which occur on the road network was undertaken. To enable this, motorway incident data was

collected by the author through observing motorway operations at a police control room.

- **Chapter 5.** Chapter 5 examined the influence of motorway incidents on traffic flow. Their impact on the capacity of the roadway was studied and the impact of rubbernecking investigated. Investigations and analysis were undertaken to evaluate the impact of incidents on motorways including the total delay experienced.
- **Chapter 6.** Chapter 6 presented a review of motorway matrix signals and signs in use on the motorway and trunk road network in Britain. Applications of the discussed signals and signs were also detailed. The effectiveness of matrix signals and signs was examined. This included compliance rates with mandatory signals and the impact of variable messages on driver route choice.
- **Chapter 7.** Chapter 7 examined optimal deployment strategies for incident support units on the M25 road network. This was completed via the development of a computer model that determined the shortest response route for a particular network setup. This shortest response route in turn produced the shortest travel (response) time for each ISU vehicle. Four location strategies were considered to optimally locate ISUs on the M25 and for each strategy the optimal number of ISUs was determined. The objective was to minimise the total travel time to incidents with the minimum number of ISU vehicles required to meet the service provider's contractual response time.

8.3 Evaluation of Aims and Objectives

In chapter 1, the original aims and objectives of this work were introduced. It is important that now, at the end of the work, these objectives are considered in the light of the research that took place, and conclusions made as to whether the objectives were met.

The four original objectives and their discussions follow:

- **Present a review of British incident management practices.** This study presented a review of incident management practices in Britain and in the US in chapter 2 and satisfied this objective. The Highways Agency's approach to incident management in Britain, with particular emphasis on the M25 Sphere, was examined in detail, specifically their response capabilities through Incident Support Units and Traffic Officers. The key stakeholders in incident management on trunk roads were identified and their roles and responsibilities at motorway incidents investigated. This review has highlighted the importance of communication, coordination and cooperation in producing a successful incident management partnership, which in turn will return a reduction in delay associated with incidents and improve the safety of responders and motorists.
- **Produce a critical evaluation of the Incident Support Service on the M25 Sphere.** A critical evaluation and review of the ISU service on the M25 Sphere was conducted using quantitative (analysis of incident data) and qualitative examinations (via questionnaire survey) methods and is presented in chapter 3. A benefit-cost estimation of the service was also presented.
- **A comprehensive analysis of incident characteristics, frequency and duration on the M25 Sphere.** An analysis of incidents on the M25 Sphere was undertaken to understand the key characteristics, frequency and duration of incidents. The analysis allowed the influence and role of ISUs on the M25 Sphere to be fully understood. Several sources of incident data were utilised for the analysis, including the collection of 28 days of data by the author at a police control room on the M25. This collected data is one of the most valuable outcomes from this research, as such a comprehensive recording of incidents and subsequent incident

management operations has not been undertaken until now. Through the presentation of the results of this analysis in chapter 4 this objective has been satisfied.

- **Provide an optimal deployment strategy for Incident Support Units on the M25 Sphere.** This objective has been partially satisfied by the development of an optimal deployment model for the M25 motorway. This was accomplished via computer models which were developed to establish the shortest route and minimum travel times between any two nodes of the modelled M25 road network. The approach used was to model just the M25 motorway (a network with a total of 33 nodes). A model of the whole of the M25 Sphere network (236 nodes) was discussed in section 7.6 but this was shown to be too computationally complex to analyse in this study. Four location strategies, outlined in section 7.4.7, were applied to these models with each strategy considering a varying number of vehicles. The optimal locations and number of ISU vehicles to satisfy the minimum contractual response time to incidents was then established, providing an optimal deployment strategy for ISUs on the M25.

8.4 Specific Conclusions

This section will detail specific points that have emerged during this research. Key findings of interest or practical value and benefit will be detailed below.

1. An overview of the characteristics of incidents attended by ISUs on the M25 Sphere road network for the period between September 2001 and August 2003 has been shown. Incident frequency, timings and locations were examined.
 - ISUs attended on average 24 incidents per day. However a maximum of 76 support requests were received on one day, showing the variability of demand.

- The majority of ISU requests, 24%, were for debris clearance.
 - The average response time for all ISUs was 12.5 minutes. This is considerably shorter than the contractually required 20 minute response time.
 - The frequency of support requests from the emergency services has steadily increased since the introduction of ISUs in September 2001. This shows the increasing recognition given to the ISUs by the emergency services.
2. A positive response towards the ISU service on the M25 Sphere was received from the surveyed police officers. Overall feedback regarding the ISUs was positive and it can be concluded that the ISU service provided on the M25 Sphere is of benefit. In addition, valuable feedback was received that could be used to improve the service. This has, in turn, been fed back to the service provider and these points are listed below:
- Improvements could be made between ISU operatives and police officers, thereby improving efficiency and effectiveness. Additionally further training will now be offered to ISU operatives to improve safety.
 - Significant feedback has shown that future developments should focus on (1) Improved direct communications; (2) Improved use of mobile variable message signs and electric light arrows; and (3) improved integrated training between the various emergency and response services.
 - It is suggested that future work should include a repeat of the presented survey to continually assess performance.
3. The cost effectiveness of the ISU service was investigated using an incident impact computer programme, IMPACT, to estimate incident induced delay. The model was modified and updated for use on the British motorway network and an analysis completed, detailing the impact of ISUs on the M25 Sphere. The following can be drawn from the analysis:
- IMPACT can be successfully adapted for use on the UK motorway network.

- It was estimated that ISUs reduced delay due to attended incident on the M25 by approximately 200,000 vehicle hours, or 11%.
 - This estimated delay saving equates to £2.08 million savings per year and an approximate benefit/cost ratio of 1.3:1. This shows that the ISU service is beneficial and that deployment and support of this service should be continued.
4. The collection and analysis of motorway incident data on the south western part of the M25, from Surrey Police's Godstone motorway control room, was examined. Twenty-eight days of daily incident data was collected, through observations by the author. The data was examined and incident frequency, durations, locations and ISU involvement were established. The following are the key points that can be concluded from the analysis undertaken:
 - An average frequency of 16.1 incidents per day was observed, with the majority, 64.7%, breakdowns.
 - 31% of incidents occurred in-lane.
 - ISUs were requested to attend 21.33% of all incidents, including 40% of all accidents, and had an average response time of 12 minutes.
 5. It was shown that it was possible to analyse data collected from motorway matrix signal accident activation records. The analysis of this data was however very labour intensive, requiring manual identification and summary of each incident.
 6. It was shown that incidents on motorways significantly reduce the available capacity of the road, by an amount greater than just the proportion of original capacity physically blocked.
 7. Rubbernecking can significantly reduce the flow and speed of traffic on the opposite carriageway to an incident. The safety of operatives and other motorists can also be compromised. Several factors were identified to have an influence on rubbernecking:

- roadway characteristics,
 - number and type of emergency vehicles,
 - vehicle lighting on scene (number of flashing blue lights),
 - severity of incident,
 - whether motorists can actually see the incident,
 - location of incident within carriageway
 - general light levels.
8. It has been shown that it is possible to calculate the delay associated with motorway incidents.
9. Compliance with overhead gantry matrix signals was found to be very variable. From a total of 60 incidents and 105 red “X” matrix signal activations, 23,788 offences of driving under a red “X” matrix signal were recorded, which represented 15.26% of traffic. It was concluded that motorway matrix signals are effective for the majority of the time but are completely reliant on motorists to comply with their instructions.
10. It was shown that motorists do acknowledge the presence of VMS messages and in some cases react to them, with up to a 52% increase of flow at downstream slip roads recorded, following the activation of a message.
11. Optimal deployment strategies for incident support units on the M25 road network were investigated. A computer model of the M25 motorway was developed and analysed with four different location strategies and different number of ISU vehicles. The strategy based on a geographically even distribution of ISUs around the road network was found to be the optimum strategy for meeting the contractual response time with the minimum number of vehicles.

8.5 Recommendations for Future Work

A number of questions have been raised during this study which have been left for future research. The following are a selection of research topics that should be addressed in the future.

8.5.1 ISU Qualitative Assessment Questionnaire

In order to compare and contrast the results from the qualitative survey presented in chapter 3, regarding the assessment of the ISU service, the survey should be repeated for other Highways Agency areas. This would also help to enable “best practice” to be identified and implemented across the network.

The presented ISU assessment questionnaire should also be repeated on the M25 Sphere, every couple of years to ensure standard are maintained, if not improved. In particular, this would provide valuable information to the service provider regarding the quality of the provided service, and alert them to any issues, including concerns regarding the safety and the safe conduct of their operatives. Additionally the internal opinions and views of their operatives would be established.

8.5.2 New Data Sources

The management of traffic on British trunk roads has changed rapidly during this research project. The Highways Agency have gone from a network manager-responsible for maintaining and building roads- to a network operator- becoming a first responder to incidents and providing front line incident management support to the emergency services.

This new role has rapidly increased the volume of data that is and will become available from sources such as the Regional Control Centres and National Traffic Control Centre. These new information sources should be investigated to evaluate their value in assessing the incident management process.

8.5.3 Effect of Loop Detector Spacing

Over the majority of the Highways Agency road network, where inductive loops are installed, they are spaced nominally at 500 metres. New pilot road projects such as the Active Traffic Management pilot have loops installed at 100 meters spacing. The effect of this spacing should be investigated. This increased spacing frequency will also enable more accurate estimations of the impact of incidents and new traffic management techniques and their influence on traffic flow than is currently available.

8.5.4 Optimal Deployment

An analysis into optimal deployment strategies should be undertaken for the full M25 Sphere road network. This would enable a realistic comparison to the actual operation to be undertaken. For this full examination, the use of marker posts as nodes would significantly increase the accuracy of the assessment. The demand rates for each marker post could be calculated, further enhancing the model. However the complexity of the network would be increased considerably which may prove impractical due to the volume of node definition and connectivity information.

The accuracy of optimal deployment strategies could be improved with more precise estimation of the following factors:

- Influence of speed on response times. Instead of assuming an arbitrary speed between locations a realistic average response speed could be investigated. The use of new GPS and data logging equipment would enable the exact position of an ISU to be recorded, along with the amount of time and the route taken to the incident location.
- The amount of delay experienced at junctions. Whenever a responding vehicle has to change directions to an opposite carriageway they will experience delay. This delay could be estimated again by using new GPS tracking data. Delay estimates for each different junction could impact the chosen incident deployment strategy.

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Appendix A RISC FDOT Incentive Towing Contracts

Consistent with the FDOT Open Roads Policy, Florida's Turnpike Enterprise, who maintain Florida's toll roads, has adopted an innovative clearance strategy by implementing the Roadway Incident Scene Clearance (RISC) Program in order to significantly reduce the time it takes to clear major accidents and incidents. The program involves an enhanced contract with recovery operators that include incentives for quick clearance and disincentives for delayed clearance. Previously recovery operators were paid by the hour for their service with some unscrupulous operators "dragging their heels" to get paid more, which was not conducive to quick clearance.

As part of the new contracts the recovery operator should respond to requests for vehicle recovery and clearance services within fifteen minutes, 24 hours a day, 7 days a week. Once the recovery agent confirms the request they must arrive at the incident scene with all contractual equipment, personnel and vehicles within one hour. All RISC contractors are specially qualified with very heavy duty recovery equipment and highly trained operators who know how to safely and quickly clear roadways. The RISC program is in addition to the normal rotational tow list currently used by FHP for typical incidents on the Turnpike system.

The contractor's initial response must include (FDOT Turnpike Enterprise, 2005):

1. One 50-Ton Hydraulic, extendable, fixed boom, ultra heavy duty recovery wrecker with a boom structural rating of 100,000 lbs. A minimum of two planetary winches with a manufacturers rating of 50,000 lbs. each and 200 ft. of ¾" cable. The boom should extend a minimum of 150" beyond the tailgate. The boom shall elevate to a working height of 21 ft. The truck chassis shall be a minimum of 62,000 lbs. gross vehicle weight. The unit shall be equipped with an under reach tow unit with a capacity of 50,000 lbs. The truck chassis must be designed for or reinforced for severe service. The drive line shall also be severe service and geared for the low end, high torque

applications frequently required for quick clearance and relocation of loaded, wrecked heavy trucks - in some cases while they are still overturned.

2. One 35-Ton Hydraulic, extendable boom, heavy duty wrecker with a boom structural rating of 60,000 lbs. A minimum of two winches each with a 35,000 lbs. manufacturers rating and 200 ft. of ¾" cable. The boom shall extend beyond the tailgate a minimum of 120". The boom shall elevate to a working height of 18 ft. The truck chassis shall be a minimum of 50,000 lbs. gross vehicle weight. The unit shall be equipped with an under reach tow system with a capacity of 35,000 lbs.
3. One Recovery Support Vehicle with an enclosed or utility body and a roof mounted DOT approved MUTCD Type B arrow board. The truck should be fully equipped with MUTCD traffic control devices (signs, sign stands and cones etc.) and the additional tools, equipment and material listed.

Additionally the following heavy equipment and trucks must be available, if required:

- One heavy-duty skid steer loader with bucket, broom, and fork attachments;
- One tilt bed, hydraulic, lowboy semi-trailer with a 35 ton capacity, 48 ft. bed and a 20,000 lb. winch with 75 ft. of 5/8" cable;
- 1 x Tandem axle tractor with a sliding fifth wheel;
- 1 x Rubber tired, articulated, heavy construction end loader with a minimum 2 yard bucket.

Contractually, each recovery vehicle should carry at least the minimum of the following tools, supplies and rigging:

- Alloy (grade #8) chain: 2 x 3/8"x 10', 2 x 5/8"x 10' and 4 x ½"x 10'
- Two pair (4), wide profile, 50 ton, nylon recovery straps
- Four heavy duty snatch blocks (working load matched to the wrecker)
- Various hooks, clevis' and chokers (matched to the wrecker capacity)
- 1 x High Pressure air cushion (24"x24") with control module and hose

- 4 x 4-foot, hardwood timbers (4"x6")
- 8 x 2-foot, hard wood cribbing (4"x4")
- 1 x Extension ladder (20ft)
- 1 x 36" bolt cutters
- 2 x BC Fire extinguishers (10 lbs.)
- 1 x Long handle axe
- 1 x Long handle shovels (flat blade)
- 2 x Long handle shovels (round blade)
- 2 x Street brooms
- 4 x Wheel chocks
- 1 x 5 ft. Pike bar
- 1 x Crow bars (36")
- 1 x Sledge hammer (10-12 lbs)
- 2 x Large capacity trash cans
- 1 x Hydraulic jack (20 ton)
- 1 x Plug/spill kits, fully stocked
- Angle iron or aluminium, wide flange various lengths
- 1 x Complete brake release kit: (hand tools, hoses, glad hands, numerous fittings and brake caging bolts)
- 2 x Heavy duty, Industrial flashlights
- 12 x Thirty-six (36) inch, 12lb. reflective traffic cones stamped with the FDOT certified product number
- 4 Dozen 30-minute highway flares
- 120 lbs. or 30 gal. of oil dry or approved absorbent
- 50 ft. of rope (1/2")
- 4 x load binders, transport chains and cheater pipe
- 1 x Tarpaulin (20 ft x 20 ft.)
- 2 x Rolls of duct tape
- 2 x Sewer drain or inlet covers (mud flaps acceptable)
- 1 x Complete mechanics hand tool set
- 1 x Complete first-aid kit

Also, each recovery support vehicle should carry at least the minimum of the following tools, supplies and rigging

- 60 x Thirty-six (36) inch, 12lb. reflective traffic cones stamped with the FDOT certified product number
- 4 x Fabric, MUTCD approved Incident Mgt. Warning signs
- 4 x Portable sign stands for 48" warning signs (see above)
- 1 x Gas powered cut-off saw
- 4 x 500-watt Auxiliary flood lights w/stands
- 1 x Portable air compressor
- 1 x Air impact wrench with sockets
- 1 x Air powered metal chisel
- 1 x Acetylene/Oxygen cutting torch
- 2 x Bolt cutters (36")
- 4 x Long handle shovels (flat blade)
- 2 x Long handle shovels (round blade)
- 2 x Aluminium or plastic coal or grain shovels
- 4 x Street brooms
- 1 x Adjustable drum moving dolly
- 2 x Hand trucks
- 1 x Pallet puller
- 1 x Dock plate with clamps
- 2 x Large Tarpaulins (20 ft. x 20 ft.)
- 12 x 30-minute Highway flares
- 200 lbs. or 50 gals. of oil dry or approved absorbent
- 1 Roll of rubber floor runner (36" wide)
- 10 lbs. of 16D nails
- Numerous softwood 2x4 studs
- 2 Rolls of heavy duty (80 gauge) stretch wrap with dispenser
- 4 Rolls of duct tape
- Sufficient load binders and securing chain for a 30 ton load

- 1 Case of heavy duty, 55 gallon trash bags
- 1 Roll of heavy gauge plastic sheeting
- 1 x Complete first-aid kit
- 4 x pallets of filled dry sandbags (approximately 200 1/2-filled standard woven plastic sandbags).

Once the recovery contractor has arrived at the incident scene with all contractual equipment and within the contractual response time they have ninety minutes, after the notice to proceed, to remove and clear all incident involved vehicles, cargo, debris and non-hazardous vehicle fluids from all travel lanes and open them to traffic. If this is achieved the contractor will receive a flat rate emergency response and mobilisation payment of \$2,500. This quick clearance incentive is in addition to any compensation for actual vehicle recovery and towing services, which the recovery contractor would seek from the owner of the vehicle or their insurance company. If however the contractor is requested and arrives at the incident scene with all contractual equipment and within the contractual response time but are no longer required, they will be paid a flat rate service charge of \$ 600.00. This payment will ensure that the contractor will always respond without the threat of not being paid. Any additional equipment that is requested from the recovery contractor would incur an additional Trucks and Heavy Equipment Response and Mobilization payment of \$ 1,000. The contractor would receive no incentive performance payment if all travel lanes are not open to traffic ninety minutes after the notice to proceed. Also, if the contractor has not completed the removal and clearance of the vehicles, non-hazardous cargo, debris, and vehicle fluids after three hours from the notice to proceed, and all travel lanes are not open to traffic, they would be fined a flat rate of \$ 600. An additional \$600 would also be levied for each additional hour or \$10 per minute it takes the contractor to completely open the roadway to traffic.

The RISC scheme does appear to have many benefits, with recovery contractors responding very quickly with all necessary equipment to clear carriageways quickly. It is however questionable whether this system would increase safety as recovery contractors may “cut corners” to ensure quick clearance and bonus payments.

Appendix B Signal Law

All motorway matrix signals are covered in law by the Traffic Signs Regulations and General Directions 2002 (HMSO, 2002) and if not complied with, offences are covered by the Road Traffic Act 1988 (HMSO, 1988) and the Road Traffic Offenders Act 1988 (HMSO, 1988).

The Highway Code (HMSO, 2004) states the meaning of a red “X” with red flashing lights as “Do not proceed further in this lane” and rule number 232 also states:

Red flashing lights:

If red lights on the overhead signals flash above your lane (there may also be a red ‘X’) you must not go beyond the signal in that lane. If red lights flash on a signal in the central reservation or at the side of the road, you must not go beyond the signal in any lane.

Within the Traffic Signs Regulations and General Directions 2002 a red “X” lane closure signal is covered by regulations 10(1), 10(2), 37 and 38 as well as directions 46, 50, 51, 52 and 56. The signal is shown in diagram 6031.1 and is referred to as such within the document. The signal is described as a “light signals for the control of vehicular traffic on motorways and all purpose dual carriageway roads” and its meaning is expressed as “vehicular traffic proceeding in the traffic lane immediately below the signals shall not proceed beyond them in that lane”.

If the instructions of the signal, as detailed in the Traffic Signs Regulations and General Directions 2002, are not complied with, section 36 of the Road Traffic Act 1988 will apply and the offenders will be prosecuted as per instructions within the Road traffic Offenders Act 1998 (HMSO, 1988)

Below are the relevant extracts form the Traffic Signs Regulations and General Directions 2002 (HMSO, 2002), Road Traffic Act 1988 (HMSO, 1988) and the Road Traffic Offenders Act 1988 (HMSO, 1988).

Extracts from the Traffic Signs Regulations and General Directions 2002 (HMSO, 2002)

Application of section 36 of the Road Traffic Act 1988 to signs and disqualification for offences

10. - (1) Section 36 of the 1988 Act shall apply to each of the following signs –

(k) the light signals prescribed by regulation 37 and shown in diagrams 6031.1 and 6032.1 when indicating one of the prohibitions prescribed by regulation 38.

(2) The following signs are hereby specified for the purposes of column 5 of the entry in Schedule 2 to the Road Traffic Offenders Act 1988 relating to offences under section 36 of the 1988 Act –

(g) the light signals prescribed by regulation 37 and shown in diagrams 6031.1 and 6032.1 when indicating one of the prohibitions prescribed by regulation 38.

Light signals for the control of vehicular traffic on motorways and all purpose dual carriageway roads

37. - (1) Subject to paragraph (4), light signals for the control of vehicular traffic entering or proceeding along a motorway, shall be –

(a) of the size, colour and type shown in diagram 6031.1 or 6032.1; and

(b) operated in accordance with the requirements specified in paragraph (2).

(2) The requirements are that –

(a) each lamp shall show an intermittent red light at a rate of flashing of not less than 60 nor more than 90 flashes per minute, and in such a manner

that the lights of one vertical pair are always shown when the lights of the other vertical pair are not shown; and

- (b) the red cross or the white symbol shown in diagram 6031.1 or 6032.1 shall be illuminated by a steady light when the red lights are flashing.
- (3) Light signals for the control of vehicular traffic entering or proceeding along an all-purpose dual carriageway road may also be the size, colour and type prescribed by paragraph (1) and operated in accordance with the requirements specified in paragraph (2).
- (4) Light signals for the control of vehicular traffic –
- (a) entering a motorway by means of a slip road; or
 - (b) entering a motorway which is a roundabout may, instead of complying with paragraphs (1) and (2), be of the size, colour and type prescribed by regulation 33 or 34.

Significance of light signals prescribed by regulation 37(1)

38. - The significance of the light signals prescribed by regulation 37(1) shall be as follows -

- (a) when placed beside the carriageway of a road, they shall convey the prohibition that vehicular traffic on that carriageway (other than vehicles being used in the circumstances described in regulation 36(1)(b)) shall not proceed beyond the signals; and
- (b) when displayed on a gantry over the carriageway, they shall convey the prohibition that vehicular traffic (other than vehicles being used in the circumstances described in regulation 36(1)(b)) proceeding in the traffic lane immediately below the signals shall not proceed beyond them in that lane,

Matrix signs for motorways and all-purpose dual carriageway roads

46. - (1) a sign for conveying to traffic on a motorway or an all-purpose dual carriageway road information or a warning, requirement, restriction, prohibition or speed limit –

- (a) relating to or arising out of temporary hazardous conditions on or near the motorway or dual carriageway road;

(5) Where a matrix sign mounted on a gantry or other structure is so placed that a traffic lane of the carriageway passes directly beneath it, the warning, requirement, restriction, prohibition or speed limit conveyed by the sign shall apply only to vehicular traffic facing that sign and proceeding along the traffic lane passing directly beneath it.

Extracts from the Road Traffic Act 1988 (HMSO, 1988)

Section 36 of the Road Traffic Act 1988

36. - (1) Where a traffic sign, being a sign-

- (a) of the prescribed size, colour and type, or comply with
- (b) of another character authorised by the Secretary of State under the provisions in that behalf of the Road Traffic Regulation Act 1984,

has been lawfully placed on or near a road, a person driving or propelling a vehicle who fails to comply with the indication given by the sign is guilty of an offence.

(2) A traffic sign shall not be treated for the purposes of this section as having been lawfully placed unless either-

- (a) the indication given by the sign is an indication of a statutory prohibition, restriction or requirement, or
- (b) it is expressly provided by or under any provision of the Traffic Acts that this section shall apply to the sign or to signs of a type of which the sign is one;

and, where the indication mentioned in paragraph (a) of this subsection is of the general nature only of the prohibition, restriction or requirement to which the sign relates, a person shall not be convicted of failure to comply with the indication unless he has failed to comply with the prohibition, restriction or requirement to which the sign relates.

(3) For the purposes of this section a traffic sign placed on or near a road shall be deemed -

(a) to be of the prescribed size, colour and type, or of another character authorised by the Secretary of State under the provisions in that behalf of the Road Traffic Regulation Act 1984, and

(b) (subject to subsection(2) above) to have been lawfully so placed, unless the contrary is proved.

(4) Where a traffic survey of any description is being carried out on or in the vicinity of a road, this section applies to a traffic sign by which a direction is given—

(a) to stop a vehicle,

(b) to make it proceed in, or keep to, a particular line of traffic, or

(c) to proceed to a particular point on or near the road on which the vehicle is being driven or propelled, being a direction given for the purposes of the survey (but not a direction requiring any person to provide any information for the purposes of the survey).

(5) Regulations made by the Secretary of State for Transport, the Secretary of State for Wales and the Secretary of State for Scotland acting jointly may specify any traffic sign for the purposes of column 5 of the entry in Schedule 2 to the Road Traffic Offenders Act 1988 relating to offences under this section (offences committed by failing to comply with certain signs involve discretionary disqualification).

Road traffic Offenders Act 1988 (HMSO, 1988)

(1) Provision creating offence	(2) General nature of offence	(3) Mode of prosecution	(4) Punishment	(5) Disqualification	(6) Endorsement	(7) Penalty points
<i>Offences under the Road Traffic Act 1988 (continued.)</i>						
RTA section 36	Failing to comply with traffic signs.	Summarily	Level 3 on the standard scale.	Discretionary, if committed in respect of a motor vehicle by failure to comply with an indication given by a sign specified for the purposes of this paragraph in regulations under RTA section 36.	Obligatory if committed as described in column 5.	3

Extract from Schedule 2, Road traffic Offenders Act 1998 (HMSO, 1998).

Appendix C M25 Network Node Definition

Minimising Incident Impact on the M25 Sphere					
Optimal Positioning of Incident Support Units					
Definition of the M25 Sphere as a transport network					
Defining nodes and their coordinates					
Unique junction name	Junction number	Track	Node number	nodal x coordinate / m	nodal y coordinate / m
M25J1AA	1A	A	1	557	748
M25J1BA	1B	A	2	557	743
M25J2A	2	A	3	554	720
M25J3A	3	A	4	526	678
M25J4A	4	A	5	502	630
M25J5A	5	A	6	496	568
M25J6A	6	A	7	352	528
M25J7A	7	A	8	307	533
M25J8A	8	A	9	257	526
M25J9A	9	A	10	172	574
M25J10A	10	A	11	81	593
M25J11A	11	A	12	39	649
M25J12A	12	A	13	18	677
M25J13A	13	A	14	22	726
M25J14A	14	A	15	36	754
M25J15A	15	A	16	46	793
M25J16A	16	A	17	20	856
M25J17A	17	A	18	31	942
M25J18A	18	A	19	42	961
M25J19A	19	A	20	71	989
M25J20A	20	A	21	78	1015
M25J21A	21	A	22	116	1030
M25J21AA	21A	A	23	126	1030
M25J22A	22	A	24	190	1033
M25J23A	23	A	25	225	1000
M25J24A	24	A	26	267	1002
M25J25A	25	A	27	329	1000
M25J26A	26	A	28	406	997
M25J27A	27	A	29	470	1000
M25J28A	28	A	30	569	925
M25J29A	29	A	31	585	884
M25J30A	30	A	32	575	800
M25J31A	31	A	33	575	789
M25J1AB	1A	B	34	548	750
M25J1BB	1B	B	35	549	743
M25J2B	2	B	36	546	722
M25J3B	3	B	37	520	682
M25J4B	4	B	38	494	633
M25J5B	5	B	39	488	574
M25J6B	6	B	40	351	536
M25J7B	7	B	41	306	542
M25J8B	8	B	42	259	535
M25J9B	9	B	43	175	582

Appendix D Extract of M25 Network Node Connectivity

Minimising Incident Impact on the M25 Sphere									
Optimal Positioning of Incident Support Units									
Definition of the M25 as a transport network - Defining connectivity									
Link FROM node <name>	Link FROM node <number>	Link TO node <name>	Link TO node <number>	link name	Free flow speed between nodes / kmph	Free flow speed between nodes / mph	Length of link / km	Length of link / miles	probability of incident on link
M25J1AA	1	M25J1BA	2	M25J1AJ1B	96	60	1.6	1	0.0011
M25J1BA	2	M25J2A	3	M25J1BJ2	96	60	1.6	1	0.0048
M25J2A	3	M25J3A	4	M25J2J3	96	60	5.28	3.3	0.0107
M25J3A	4	M25J4A	5	M25J3J4	96	60	6.4	4	0.0059
M25J4A	5	M25J5A	6	M25J4J5	96	60	6.4	4	0.0080
M25J5A	6	M25J6A	7	M25J5J6	96	60	15.68	9.8	0.0267
M25J6A	7	M25J7A	8	M25J6J7	96	60	4.8	3	0.0112
M25J7A	8	M25J8A	9	M25J7J8	96	60	5.28	3.3	0.0117
M25J8A	9	M25J9A	10	M25J8J9	96	60	12	7.5	0.0470
M25J9A	10	M25J10A	11	M25J9J10	96	60	9.6	6	0.0379
M25J10A	11	M25J11A	12	M25J10J11	96	60	8	5	0.0288
M25J11A	12	M25J12A	13	M25J11J12	96	60	3.68	2.3	0.0123
M25J12A	13	M25J13A	14	M25J12J13	96	60	5.28	3.3	0.0230
M25J13A	14	M25J14A	15	M25J13J14	96	60	3.2	2	0.0160
M25J14A	15	M25J15A	16	M25J14J15	96	60	3.2	2	0.0149
M25J15A	16	M25J16A	17	M25J15J16	96	60	8.8	5.5	0.0171
M25J16A	17	M25J17A	18	M25J16J17	96	60	9.28	5.8	0.0208
M25J17A	18	M25J18A	19	M25J17J18	96	60	2.4	1.5	0.0048
M25J18A	19	M25J19A	20	M25J18J19	96	60	4	2.5	0.0128
M25J19A	20	M25J20A	21	M25J19J20	96	60	2.08	1.3	0.0037
M25J20A	21	M25J21A	22	M25J20J21	96	60	4.8	3	0.0032
M25J21A	22	M25J21AA	23	M25J21J21A	96	60	1.28	0.8	0.0016
M25J21AA	23	M25J22A	24	M25J21AJ22	96	60	7.2	4.5	0.0085
M25J22A	24	M25J23A	25	M25J22J23	96	60	4.8	3	0.0048
M25J23A	25	M25J24A	26	M25J23J24	96	60	4.48	2.8	0.0117
M25J24A	26	M25J25A	27	M25J24J25	96	60	8.8	5.5	0.0288
M25J25A	27	M25J26A	28	M25J25J26	96	60	6.08	3.8	0.0128
M25J26A	28	M25J27A	29	M25J26J27	96	60	7.2	4.5	0.0310
M25J27A	29	M25J28A	30	M25J27J28	96	60	12.8	8	0.0262
M25J28A	30	M25J29A	31	M25J28J29	96	60	4.48	2.8	0.0267
M25J29A	31	M25J30A	32	M25J29J30	96	60	8.8	5.5	0.0251
M25J30A	32	M25J31A	33	M25J30J31	96	60	1.28	0.8	0.0069
M25J31A	33	M25J1AA	1	M25J31J1A	96	60	3.2	2	0.0069
M25J1AB	34	M25J31B	66	M25J1AJ31	96	60	3.2	2	0.0000
M25J1BB	35	M25J1AB	34	M25J1BJ1A	96	60	1.6	1	0.0000
M25J2B	36	M25J1BB	35	M25J2J1B	96	60	1.6	1	0.0149
M25J3B	37	M25J2B	36	M25J3J2	96	60	5.28	3.3	0.0000
M25J4B	38	M25J3B	37	M25J4J3	96	60	6.4	4	0.0064
M25J5B	39	M25J4B	38	M25J5J4	96	60	6.4	4	0.0080
M25J6B	40	M25J5B	39	M25J6J5	96	60	15.68	9.8	0.0304
M25J7B	41	M25J6B	40	M25J7J6	96	60	4.8	3	0.0166
M25J8B	42	M25J7B	41	M25J8J7	96	60	5.28	3.3	0.0251
M25J9B	43	M25J8B	42	M25J9J8	96	60	12	7.5	0.0464
M25J10B	44	M25J9B	43	M25J10J9	96	60	9.6	6	0.0262
M25J11B	45	M25J10B	44	M25J11J10	96	60	8	5	0.0262
M25J12B	46	M25J11B	45	M25J12J11	96	60	3.68	2.3	0.0112
M25J13B	47	M25J12B	46	M25J13J12	96	60	5.28	3.3	0.0133
M25J14B	48	M25J13B	47	M25J14J13	96	60	3.2	2	0.0166
M25J15B	49	M25J14B	48	M25J15J14	96	60	3.2	2	0.0128
M25J16B	50	M25J15B	49	M25J16J15	96	60	8.8	5.5	0.0278
M25J17B	51	M25J16B	50	M25J17J16	96	60	9.28	5.8	0.0133
M25J18B	52	M25J17B	51	M25J18J17	96	60	2.4	1.5	0.0069
M25J19B	53	M25J18B	52	M25J19J18	96	60	4	2.5	0.0053
M25J20B	54	M25J19B	53	M25J20J19	96	60	2.08	1.3	0.0016
M25J21B	55	M25J20B	54	M25J21J20	96	60	4.8	3	0.0037
M25J21AB	56	M25J21B	55	M25J21AJ21	96	60	1.28	0.8	0.0021
M25J22B	57	M25J21AB	56	M25J22J21A	96	60	7.2	4.5	0.0027
M25J23B	58	M25J22B	57	M25J23J22	96	60	4.8	3	0.0064

Appendix E MATLAB Network Analysis Script

```
% Optimal positioning of Incident Support Units (ISU's)
%
% Definition of the M25 Sphere as a transport network - Defining
nodes and their coordinates
%
clear
% Import nodal coordinates from Excel95 worksheet into MATLAB
variables
excelfile='C:\Documents and
Settings\s9738758\Desktop\Optimal\MATLAB\M25.xls';
sheetname='node_definition';
[numdata,txtdata]=xlsread(excelfile, sheetname);
%
% Extract nodal names and nodal coordinates matrix from imported
worksheet
nodenames=txtdata([8:size(txtdata,1)],2);
coords=numdata([1:size(numdata,1)],[2 3]);
clear txtdata numdata
%
% Plot nodes and node names on matrix ij axes (origin n upper left)
mapfig=1;
figure(mapfig)
clf
nodes=plot(coords([1:size(coords,1)],1),coords([1:size(coords,1)],2)
,'k. ');
%
isunodes=[3 5 6 8 9 11 16 20 23 25 27 28 30];
dia=20;
for n=1:size(isunodes,2)

isucoords(n,[1:2])=[(coords(isunodes(n),1)+coords(isunodes(n)+33,1))
/2-dia/2 (coords(isunodes(n),2)+coords(isunodes(n)+33,2))/2-dia/2];
h=rectangle('position',[isucoords(n,1) isucoords(n,2) dia
dia],'curvature',[1 1]);
set(h,'facecolor','none','edgecolor',[0.75 0 0])
end
```

```

%
for n=1:size(coords,1)
    nodelabels(n)=text(coords(n,1),coords(n,2),['
char(nodenames(n))]);
end
set(nodelabels,'fontname','verdana', 'fontsize', [8], 'color', [0.5
0.5 0.5])
%
% Import connectivity information from Excel95 worksheet into MATLAB
variables
sheetname='node_connectivity';
[numdata,txtdata]=xlsread(excelfile, sheetname);
%
connect(:,1)=numdata(:,1);
connect(:,2)=numdata(:,3);
connect(:,3)=numdata(:,5);
connect(:,4)=numdata(:,6);
connect(:,5)=numdata(:,7);
connect(:,6)=numdata(:,8);
connect(:,7)=numdata(:,9);
connect(:,8)=numdata(:,11);
connect(:,9)=numdata(:,12);
connect(:,10)=numdata(:,13);
connect(:,11)=numdata(:,14);
connect(:,12)=numdata(:,15);

connect=connect([1:size(connect,1)], [1 2 3 5 7 8 9 11]);

% Extract connectivity information from imported worksheet
%connect=numdata([1:size(numdata,1)], [2 4 6 8 10 12 13 15]);
%clear txtdata numdata
%
% Plot links as lines between nodes
head=5; % size of arrowhead
splay=0.3; % gradient of arrowhead

```

```

maxinc=max(connect([1:size(connect,1)],5));
for n=1:size(connect,1)
    if ~isnan(connect(n,2))
        fromnode=connect(n,1);
        tonode1=connect(n,2);
        xcoords=( [coords(fromnode,1) coords(tonode1,1)] );
        ycoords=( [coords(fromnode,2) coords(tonode1,2)] );
        inc=(connect(n,5)/maxinc);
        % draw link
        arrowfunc([xcoords ycoords head splay inc]);
        L=(connect(n,4)*1000);
        % max speed on that link /km/h
        speedkm=connect(n,3);
        speedm=speedkm*(1000/3600);
        % calculate duration / s
        duration=L/speedm;
        linklabels(n)=text(sum(xcoords)/2,sum(ycoords)/2,
char([int2str(duration) 's']));
        % write the durations for routes between adjacent nodes
        (every individual link)
        routetimes(fromnode,tonode1)=duration;
        %if there is a second link from the node
        if ~isnan(connect(n,6))
            tonode2=connect(n,6);
            xcoords=( [coords(fromnode,1) coords(tonode2,1)] );
            ycoords=( [coords(fromnode,2) coords(tonode2,2)] );
            % draw link
            inc=0;
            arrowfunc([xcoords ycoords head splay inc]);
            L=(connect(n,8)*1000);
            % max speed on that link /km/h
            speedkm=connect(n,7);
            speedm=speedkm*(1000/3600);
            % calculate duration / s
            duration=L/speedm;

linklabels(n+size(connect,1))=text(sum(xcoords)/2,sum(ycoords)/2,
char([int2str(duration) 's']));
        routetimes(fromnode,tonode2)=duration;

```

```

        end
    else
        routetimes(n,1)=0;
    end
end
linklabels=nonzeros(linklabels);
set(linklabels,'fontname','verdana', 'fontsize', [8],'color',[0.5
0.5 0.5], 'visible', 'off')
axis auto
axis equal
axis xy
axis off
set(mapfig,'color',[1 1 1])
pause
%
% Produce the connectivity matrix for 1-link routes (i.e. which
nodes are adjacent to each other?)
for n=1:size(routetimes,1)
    for o=1:size(routetimes,2)
        if routetimes(n,o)~=0
            onelinks(n,o)=1;
        else
            onelinks(n,o)=0;
        end
    end
end
end
%
% Add n-link route durations to the existing 1-link route times in
the route times matrix
solved=0;
pow=2;
disp(['Please wait while route times are calculated...'])
while solved==0
    solved=1;
    morelinks=onelinks^pow;
    pow=pow+1;
    for n=1:size(onelinks,1)
        for o=1:size(onelinks,2)
            if n~=o % if not a diagonal element

```


Appendix F Publications

1. "The Influence of Incident Support Units on Accident Rates and Durations on the M25, the London Orbital Motorway", Universities' Transport Study Group Conference, January 2004.
2. "An Analysis of Incidents on Europe's Busiest Motorway, the M25, compared to UK motorways and US interstates", Transportation Research Board Annual Conference, January 2005.
3. "An analysis of incident characteristics, frequency and duration on the M25 motorway", Proceedings of the Institution of Civil Engineers, Transport. Accepted.

The Influence of Incident Support Units on Accident Rates and Durations on the M25, the London Orbital Motorway.

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Abstract

To date, previous studies of accidents on British motorways have been very limited. As part of a study into the role of Incident Support Units on the M25, the London orbital motorway, an analysis of road traffic accidents was undertaken. Historical accident data was obtained from motorway matrix signal databases, from two control rooms around the M25. The databases were manually analysed with 38,755 matrix signal activations and 3,399 accidents identified, for the study period between January 2000 until December 2002. Accident frequency, durations and locations were then examined.

It was found that the average frequency was 3.1 accidents per day or 0.05 accidents per mile for the study area. The highest occurrence of accidents was found to be between 5pm and 6pm. On average the recorded accidents lasted 1 hour 1 minute and 22 seconds long with those occurring between 10pm and 8am lasting the longest. The distribution of accidents along the 62.5 mile long study area showed that the section between junction 7 and 8 had the highest accident rate of 85.31 accidents per mile for the study period.

Introduction

Road traffic accidents are an unfortunate part of road travel. It has to be accepted that accidents will happen whatever programs are introduced to reduce the chance of an accident occurring. With this in mind, the best ways of mitigating the effects of an accident must be discovered and implemented. This study will facilitate a better understanding of where and when accidents happen on the M25.

The M25 motorway (figure 1) is approximately 117 miles in length with some sections carrying more than 200,000 vehicles a day. As Europe's busiest motorway, congestion is a major problem. Each year, traffic congestion leads to millions of hours of vehicle delays and causes significant losses in productivity, increases in fuel consumption and environmental pollution.

The rising demand for use of motorway networks has not been met with corresponding increases in capacity. This has led to an ever-increasing level of daily congestion. Recurring congestion from excess volume of vehicles is expected but non-recurring or "incident" congestion is unpredictable. Incidents cause bottlenecks, slowing and frequently stoppages in the flow of vehicles. As the flow of traffic slows following an accident, a queue builds upstream of the incident, and continues until the blockage is cleared and flow restored. Additionally "rubbernecking" can reduce the flow in opposing lanes. Due to the backlog of vehicles it can take a long time after the incident for the accumulated traffic to dissipate. This issue can be compounded with the problem of secondary incidents. Incident management programs have been developed to mitigate non-recurring congestion from incidents. The purpose of these programs is to rapidly detect, verify and clear temporary obstructions from roads to restore normal traffic flow as quickly as possible. This non-

recurring congestion can be minimised by clearing incidents as quickly as possible or by diverting traffic before vehicles are caught in the traffic backup.

To mitigate non-recurrent congestion, rapid response and clearance is essential. To assist in this the Highways Agency has deployed a fleet of Incident Support Units (ISUs) on the M25 and other congested roads throughout England.

This investigation of accidents on the M25 has been undertaken as part of a study into the role of ISUs on the road network. It is the intention to study the frequency, duration and location of accidents, and ultimately reduce traffic impacts of accidents through the allocation of ISUs and personnel.



Figure 1 Map of roads within M25 Sphere (Highways Agency, 2003).

Background

There is limited literature on accident analysis on motorways in Britain. However, more is available on US freeway incident and accident characteristics (Pal et al (1988), Skabardonis et al (1997), Giuliano (1996), Jones et al (1995), Golob et al (1987), Skabardonis (1999)). Other studies for major cities in the US have been useful sources of information as reported traffic conditions are similar to that of the M25. However, many were carried out in the 1960's and 1970's (Skabardonis et al (1997)) when drivers and vehicles were very different. More recent studies into the characteristics of incidents were undertaken in Seattle (Jones et al (1995)) and Los Angeles (Skabardonis et al (1997), Giuliano (1996), Golob et al (1987), Skabardonis (1999)). These studies used archived accident records as data with Skabardonis et al (1997 and 1999) collecting comprehensive field data to determine incident and accident patterns.

Data Description

The data for this paper was taken from matrix signal settings archives, in a database format, for two control rooms on the M25, made available by the Highways Agency. Godstone and Heston control rooms record signal settings for the southern part of the M25, between junction 2 and 17, covering approximately 62.5 miles in total length. The databases were supplied in monthly form with all signal activations recorded. In total the data covered all days from 1st January 2000 to 31st December 2002 – 1,096 days.

The signal settings archive databases contain all information relevant to the setting of the signal:

- Log counter,
- On date and time,
- Operator who set the signals,
- Signal location (Motorway, marker post, direction, lane)
- Signal setting,
- Reason for setting (Accident, congestion, incident, debris, etc.)
- Off date and time.

Queries were run on the settings archive databases and all activations for accident only reasons were extracted. The extracted data was then manually analysed to separate individual accidents. In total, 38,755 matrix signal activation were examined and 3,399 accidents were identified.

Matrix Signals

Motorway matrix signals are electronic signs that are used to inform motorists about speed restrictions, lane closures, or even adverse weather conditions. These motorway traffic control signals are usually set for safety reasons. They are a simple method of incident management and allow the police to control traffic and warn motorists from control rooms before any responding vehicles get to the incident scene.



Figure 2 Example of gantry matrix signals.

On the M25 there are two basic types of mounting for matrix signals - gantry based and central reservation post mounted. The gantry based system, usually on busier road sections, provides control for each lane of traffic and is more flexible as there is a different signal for each lane on the road. Figure 2 shows an example of gantry based matrix signals on the M25. The signals in figure 2 are displaying a warning of queuing traffic ahead, signified by a "Q". Figure 3 shows an example of a central reservation post mounted matrix signal. The post mounted signals cannot display as much information as a gantry system as there is only one signal to provide information to all 3 or 4 lanes.



Figure 3 Example of central reservation post mounted matrix signal.

A wide variety of information can be displayed on the matrix signals. The signs can be used to display temporary reduced speed restrictions to try and control speeds near incident scenes. Emergency lane closures can also be achieved using the signals before responders and any proper traffic management (cones and warning signs) arrives at an incident scene. This is helpful in order to protect stranded motorists and warn of debris blocking a lane of the carriageway. A graphic showing most of the available directions is shown in figure 4. The information displayed on the signals is enforceable; motorists disobeying their messages can be prosecuted.

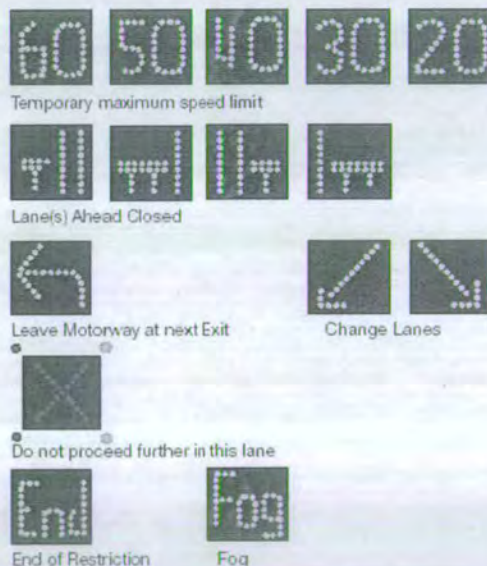


Figure 4 Examples of matrix signal messages. (Roads Service, 1999).

M25 – London Orbital Motorway

The M25 motorway is the orbital motorway (beltway) that encircles London (Figure 1). It is not quite a full circle - the only break is to the east of London, when it crosses the river Thames via the Dartford Crossing (consisting of two tunnels and a bridge). The M25 was designed as a bypass for London and the surrounding towns giving substantial traffic relief for communities, particularly from heavy goods traffic.

It is approximately 117 miles in length and is dual three lane carriageway or dual four lane carriageway in the busier areas. It also has left lane hard shoulders over the majority of its length. Since its completion in 1986 it has become one of the busiest motorways in Europe, coming under ever increasing strain. The busiest western section of the M25 regularly carries up to 200,000 vehicles per day.

Incident Support Units

With sections of the M25 carrying an average of 200,000 vehicles a day even a minor accident can bring traffic to a halt very quickly. To help mitigate the impact of incidents on the road users of the M25, a new joint initiative by the Highways Agency, Mouchel and Carillion has been initiated. A fleet of sixteen ISUs are on standby 24 hours a day, 365 days a year to solve problems on the M25 and adjoining roads (known as the M25 Sphere). These vehicles are dedicated maintenance vehicles that do small maintenance activities on the network, but are available whenever an incident occurs or their presence is requested by the emergency services. These vehicles are placed at strategic locations around the road network and are monitored by GPS allowing the nearest vehicle to be dispatched. They are manned by specialist two man crews, equipped with cones, warning signs, environmental protection packs and suitable equipment to deal with most situations and carry out emergency maintenance and repairs.

The aim of this service is to provide assistance to the emergency services and reduce the impact of an incident on the road network. The role of Carillion's Incident Support Units (ISUs) is to:

- Provide immediate response to incidents on the network,
- Provide emergency, short term lane closures,
- Deal immediately with minor, incident related debris.

Accident Data Analysis

Accident Frequency

Analysis showed that for the period of the study, there were 3,399 recorded matrix signal accidents activations (table 1). In 2000 and 2001 there were 1120 accidents - exactly the same number. In 2002 however, the number of accident signal activations increased to 1,159.

Table 1 Comparison of accident data for different years.

	Year			
	All	2000	2001	2002
Total Number of Matrix Signal Accident Activations	3399	1120	1120	1159
Mean Duration (Mins)	01:01:22	00:59:28	00:59:34	01:05:04
Standard Deviation (Mins)	01:49:59	01:56:35	01:42:36	01:50:46
Median Duration (Mins)	00:33:26	00:30:08	00:32:49	00:37:22

The increase in the number of accidents is contrary to expectation as several incident management programs have been instigated or modified over the 3 year study period.

The average accident frequency was found to be 1,133 per year, 94.42 per month and 3.1 per day for the study area. Over the 62.5 miles of the study area this equates to an average of 18.13 accidents per mile per year, 1.51 accidents per mile per month and 0.05 accidents per mile per day.

Figure 5 shows the variability of recorded accidents by days of the week. The plot of data for all years shows that the larger number of accidents occurs on Fridays with 582 accidents or 17.1% of all accidents in the study period. It can also be seen from figure 5 that, as expected, there are fewer accidents on Saturdays and Sundays. This is because there are fewer vehicles using the motorway at the weekend. The individual years data, also plotted, is fairly consistent giving confidence in the combined data.

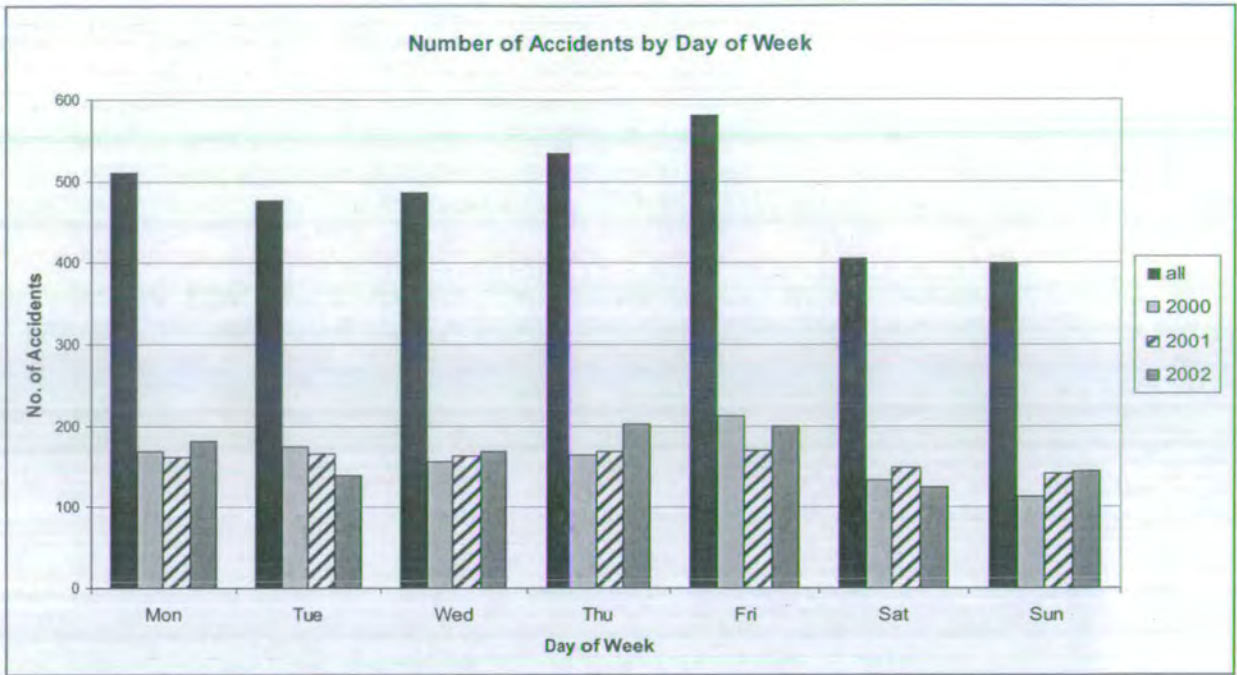


Figure 5 Graph of accidents by day of the week.

Examination of the accidents by month showed some interesting variability, as shown in figure 6. The months in the spring season (Feb – May) were the lowest for the combined data with the period from October to January recording the highest number of accidents. Individual year’s data shows greater variability however. In January there were 44 accidents between 2000’s records and 2001’s records. There were also 51 accidents between 2000 and 2002 in October. This variability requires further investigation as influencing factors, such as weather, were not available to this study.

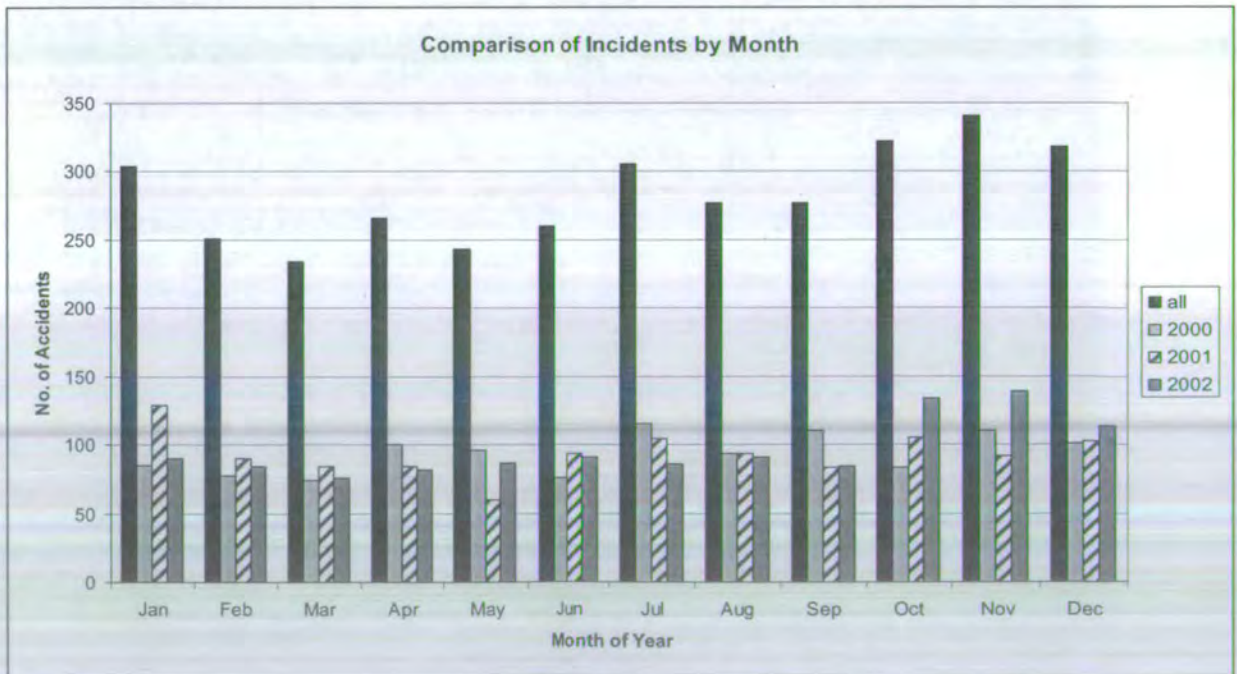


Figure 6 Graph of accidents by month.

A review of accident rates per year and per day for each day of the week and every month was carried out. It was found that the worst day for accidents was a Monday in December with an average of 21.67 accidents per year or 4.643 accidents per day for the study area of the M25. In

contrast the minimum accident rate is a Saturday in May, with 5.67 accidents per year and 1.417 per day.

Table 2 Distribution of accidents by time of day.

Time of Day	Total Number of Accidents	Average Accident Rate (Accidents per Day)
00:00 to 01:00	65	0.059
01:00 to 02:00	44	0.040
02:00 to 03:00	44	0.040
03:00 to 04:00	38	0.035
04:00 to 05:00	34	0.031
05:00 to 06:00	69	0.063
06:00 to 07:00	119	0.109
07:00 to 08:00	139	0.127
08:00 to 09:00	160	0.146
09:00 to 10:00	179	0.163
10:00 to 11:00	167	0.152
11:00 to 12:00	220	0.201
12:00 to 13:00	204	0.186
13:00 to 14:00	200	0.182
14:00 to 15:00	190	0.173
15:00 to 16:00	216	0.197
16:00 to 17:00	259	0.236
17:00 to 18:00	288	0.263
18:00 to 19:00	234	0.214
19:00 to 20:00	185	0.169
20:00 to 21:00	123	0.112
21:00 to 22:00	91	0.083
22:00 to 23:00	65	0.059
23:00 to 24:00	65	0.059

The number of accidents changes throughout the day. Table 2 and figure 7 show the variability of all accidents during the day. It can be seen that the higher level of accidents occurred between 5pm and 6pm. The total of 288 accidents, or 8.5% of all accidents, during the evening peak period, has a rate of 0.263 accidents per day. The minimum number of accidents occurs between 4am and 5am with only 34 accidents over the study period. The data shown generally follows the number of vehicles on the road with the majority of all accidents when the road network is near or exceeding capacity. Further work has to be done on the timings of accident occurrence, as the influence of traffic flows has not been examined.



Figure 7 Graph of number of accidents by time of day for all years.

Accident Durations

For the 3,399 accidents, the total accident duration was calculated as the difference between the time that the first signal was activated until the last signal was deactivated. The average duration of all accidents was 1hour, 1minute and 22seconds. For the year 2000 the average accident duration was 59 minutes, 28 seconds, in 2001 the average was 59 minutes, 34 seconds and in 2002 it was 1 hour, 5 minutes and 4 seconds.



Figure 8 Comparison of accident duration distributions.

Figure 8 shows the distribution of durations for all accidents. The distribution shows that approximately 50% of all accidents last less than 40 minutes, 75% of all accidents last less than 80 minutes and 90% of all accidents last less than 120 minutes.

Table 3 Comparison of A-D test results for duration distributions.

A-D Test Value	Year		
	2000	2001	2002
Fitted Distribution			
lognorm	1.708	3.249	2.605
InvGauss	2.151	3.663	3.313
Pearson5	3.589	5.562	4.694
Expon	29.96	18.95	18.2
ExtValue	+Infinity	39.06	40.27
Logistic	+Infinity	+Infinity	57.92
Triang	1970	1800	1649
Uniform	2652	2483	2352
Student	7634	7686	8109
Pareto2	+Infinity	+Infinity	+Infinity
Rayleigh	+Infinity	+Infinity	+Infinity
Pareto	+Infinity	+Infinity	+Infinity
Normal	+Infinity	+Infinity	+Infinity
Erf	+Infinity	+Infinity	+Infinity

Theoretical statistical distributions were fitted against the recorded accident durations. A selection of fourteen distributions were examined and the Anderson-Darling (A-D) test used to measure the goodness of fit between the data and the theoretical distributions. In the A-D test, the lower the number indicates a better fit. A review of the A-D test results for the trialed distributions is shown in Table 3. It can be seen that the lognormal distribution provides the best fit to the recorded

accident durations. This agrees with previous American studies (Giuliano (1996), Jones et al (1995), Golob et al (1987), Skabardonis (1999)) of incident analysis.

A review of average accident durations by day of the week and month showed that on average the longest accidents are on Sundays in August at 2 hours 6 minutes 18 seconds in length and the shortest are Saturdays in December at 29 minutes 54 seconds. On average Wednesdays have the shortest accidents and Sundays have the longest durations. During a day the average duration of accidents varies by as much as 1 hour 56 minutes 57 seconds as shown in figure 9. The average duration is reasonably constant between 8am and 10pm but between 10pm and 8am the durations are greatly increased with the maximum average duration between 1am and 2am of 2 hours 43 minutes 33 seconds. Extended durations through the night time period could be due to the extra time additional equipment can take to reach an accident scene, but is more likely to be. It could also be because accidents may be more severe at night. Unfortunately severity data was not made available to this study.

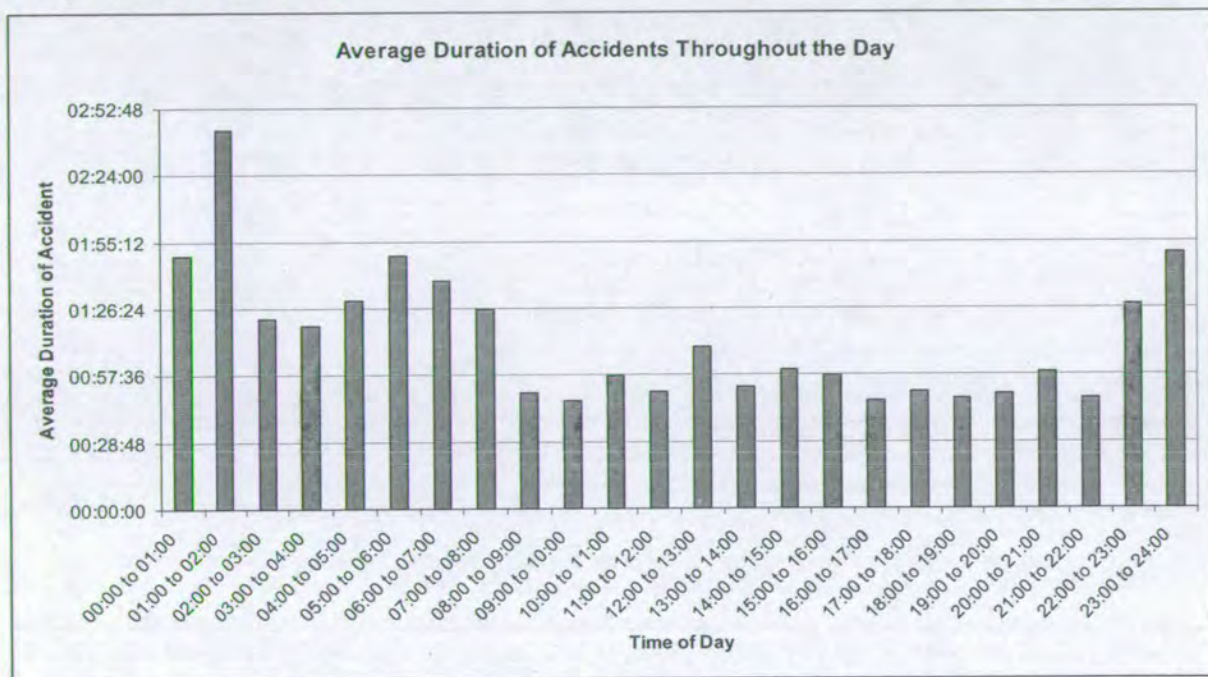


Figure 9 Graph of average duration throughout the day for all years.

Accident Locations

The matrix signal databases included the marker post location of the activated signal. The location of the first activated signal was extracted and then manually sorted into junction-by-junction groups. The number of accidents by junction locations is shown in figure 10. Also shown is the line of the normalized accidents or accidents per mile - the number of accidents in each section have been divided by the mileage of the section. It can be seen that for a straight count of accidents then the section between junctions 5 and 6 has the highest occurrences of accidents. However, this section is one of the longest in the sample, so when it is normalized then it is below the average accident rate. The highest rate of accidents per mile is for the section between junctions 7 and 8, which is 85.31 accidents per mile for the study period.

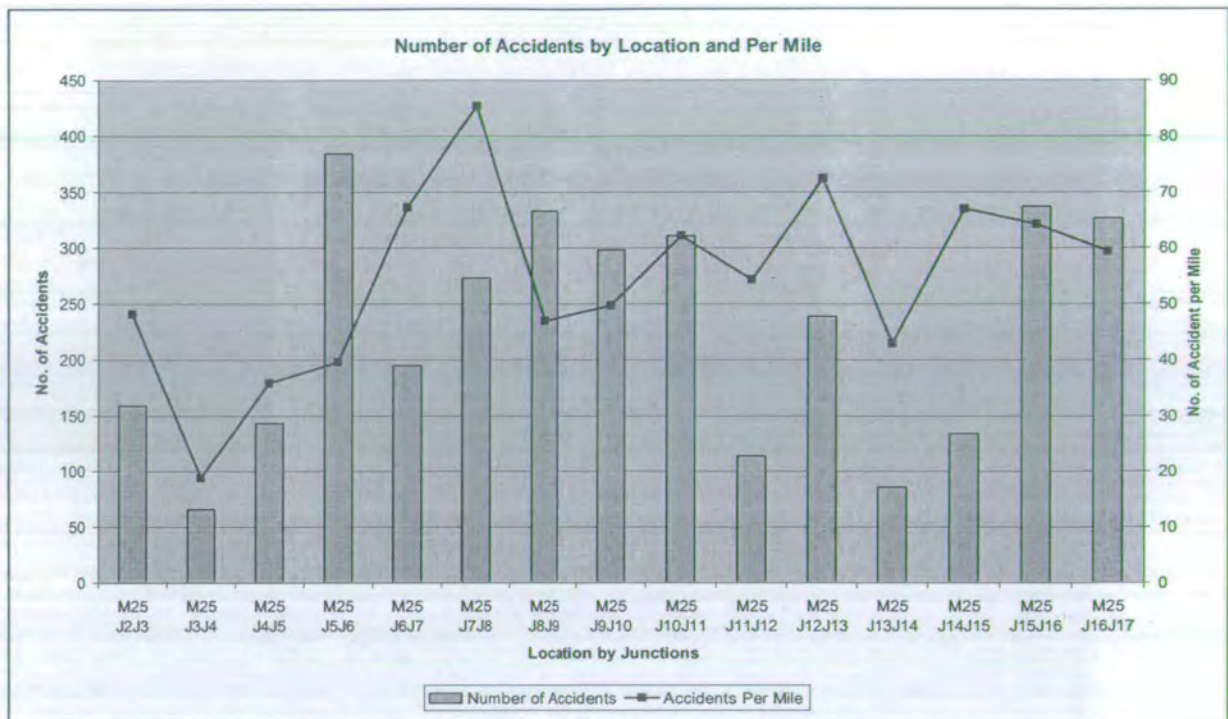


Figure 10 Graph of accident locations by junctions.

Application of Findings

The results from this study will enable the current incident management program currently in operation on the M25 to be re-evaluated. It will also allow the standby locations of the ISUs to re-examined thus enabling response times to be lowered.

Conclusions

This paper has shown an overview of the characteristics of accidents on the southern part of the M25 London orbital motorway for the period between January 2000 and December 2002. Accident frequency, durations and locations were examined.

It was found that:

- The average frequency of accidents was 3.1 accidents per day or 0.05 accidents per mile per day for the study area. The majority of recorded accidents occurred on a Friday. The spring months were found to have the lowest number of occurrences and the winter months were found to be the highest. Between 5pm and 6pm was found to have the highest occurrence of accidents.
- The average accident duration for the study period was 1 hour 1 minute 22 minutes. Accident durations increased over the study period. A lognormal distribution was shown to fit recorded durations. Sundays in August were shown to have the longest durations. Accident durations through the day were examined with the longest accident durations between 10pm and 8am.
- The spatial distribution of accidents was established across the southern section of the M25. The majority of accidents have occurred between junctions 5 and 6 but between junctions 7 and 8 had the highest accident rate of 85.31 accidents per mile for the study period.

Acknowledgements

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An Analysis of Incidents on Europe's Busiest Motorway, the M25, compared to UK motorways and US interstates.

By

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ABSTRACT

To date, previous studies of incidents on British motorways have been very limited. As part of a study into the role of Incident Support Units on the M25, the London orbital motorway, an analysis of road traffic incidents was undertaken. Motorway incident data was collected through CCTV observations at Surrey Police's Godstone motorway control room. The collected data covered the Surrey Police section of the M25 between Clacket Lane services and junction 14, for a 4 week period between 5th November 2003 until 11th December 2003. Incident frequency, durations, locations, detection times, notification methods and Incident Support Unit involvement were examined.

It was found that the average incident frequency was 16.1 incidents per day for the study area and the highest occurrence of incidents was found to be between 11:00 and 12:00. On average the recorded incidents lasted 1 hour 9 minutes, with those occurring in the evening peak period lasting the longest. The distribution of accidents along the study area showed that the section between Junction 9 and 10 had the highest incident rate for the study period.

A comparison of incident characteristics between US and UK studies was also conducted. Incident rates between Britain and the US were found to be substantially different and Incident durations in the UK were found to be between double and triple those of the US. Possible reasons for these differences are discussed in the text.

INTRODUCTION

Road traffic incidents are an unfortunate part of road travel. Incidents are random events that reduce the capacity of a road and include accidents, breakdowns, spilled loads and any other event that could cause delay.

It has to be accepted that incidents will happen whatever programs are introduced to reduce the chance of an incident occurring. With this in mind, the best ways of mitigating the effects of an incident must be discovered and implemented. This study will facilitate a better understanding of where and when incidents happen on the M25.

The M25 motorway is the orbital motorway that encircles London (figure 1). It was designed as a bypass for London and the surrounding towns giving substantial traffic relief for communities, particularly from heavy goods vehicle traffic. It is approximately 117 miles in length and is dual three lane carriageway or dual four lane carriageway in the busier areas. It also has left lane hard shoulders over the majority of its length. Since its completion in 1986 it has become one of the busiest motorways in Europe, coming under ever increasing strain. The busiest western section of the M25 regularly carries up to 200,000 vehicles per day. As Europe's busiest motorway, congestion is a major problem. Each year, traffic congestion leads to millions of hours of vehicle delays and causes significant losses in productivity, increases in fuel consumption and environmental pollution.

The rising demand for use of motorway networks has not and cannot be met with corresponding increases in capacity. This has led to an ever-increasing level of daily congestion. Recurring congestion from excess volume of vehicles is expected but non-recurring or "incident" congestion is unpredictable. Incidents cause bottlenecks, slowing and frequently stoppages in the flow of vehicles. As the flow of traffic slows following an incident, a queue builds upstream of the incident, and continues until the blockage is cleared and flow restored. Additionally "rubbernecking" can reduce the flow in opposing lanes. Due to the backlog of vehicles it can take a long time after the incident for the accumulated traffic to dissipate. This issue can be compounded with the problem of secondary incidents. Incident management programs have been developed to mitigate non-recurring congestion from incidents. The purpose of these programs is to rapidly detect, verify and clear temporary obstructions from roads to restore normal traffic flow as quickly as possible. This non-recurring congestion can be minimized by clearing incidents as quickly as possible or by diverting traffic before vehicles are caught in the traffic backup.

To mitigate non-recurrent congestion, rapid response and clearance is essential. To assist in this the Highways Agency has deployed a fleet of Incident Support Units (ISUs) on the M25 and other congested roads throughout England.

This investigation of incidents on the M25 has been undertaken as part of a study into the role of ISUs on the road network. It is the intention to study the frequency, duration and location of incidents, and ultimately reduce traffic impacts of incidents through the allocation of equipment and personnel.

This study compares UK data with US data due to the limited research available on British motorways.

BACKGROUND

There is limited literature on incident analysis on motorways in Britain, with the exception of Roberts et al (1). Their study, in 1992 and 1993, provides a review of incidents on British motorways. They assessed incidents at 10 motorway control rooms, to establish incident rates and durations on motorway links for the British Department of Transportation. Multi-channel time-lapse video from CCTV cameras and historical police records were used.

There is more information available on US freeway incident characteristics (Pal et al (2), Skabardonis et al (3), Giuliano (4), Jones et al (5), Golob et al (6), Skabardonis et al (7) and Bertini et al (8)). Other studies for major cities in the US have been useful sources of information as reported traffic conditions are similar to that of the M25. However, many were carried out in the 1960's and 1970's (3) when drivers and vehicles were very different. More recent studies into the characteristics of incidents were undertaken in Seattle (5), Portland (8) and Los Angeles (3, 4, 6, 7). These studies used archived accident records as data with Skabardonis et al (3 and 7) collecting comprehensive field data, using probe vehicles, to determine incident and accident patterns. This data will be referred to in more detail within the analysis and comparison.

DATA DESCRIPTION

The data, for this paper, was collected through observations, using closed-circuit television (CCTV), at Surrey Police's Godstone Motorway Control Room. A total of four weeks (28 days) of incident data were collected from between November 5th to December 11th. Every day, incident information was collected for a 12 hour period between 7am and 7pm.

Godstone Motorway Control Room manages Surrey Police's strategic roads which include the M25, M23, M3 and other major trunk roads. This paper is only concerned with incidents that occurred on their section of the M25, between Clacket Lane Motorway Services (marker post 4335) and junction 14 (marker post 4919), 58.4 kilometers (36.3 miles). The AADT over the study area ranged from 140,000 to 200,000 vehicles per day.

The complete survey area is covered by an extensive network of CCTV cameras, emergency roadside telephones (EMT) and gantry matrix signals for speed and lane controls. The matrix signals are used by the Motorway Incident Detection and Automatic Signaling (MIDAS) system. The MIDAS system covers the area between junction 6 and junction 16 and uses information on flows, speed and occupancy from a large number of loop detectors, spaced at approximately 300 and 500 meters, to trigger and impose speed limits on that section through the overhead gantry matrix signals and VMS. This is known as the variable speed limit zone and attempts to "smooth-out" the traffic flow, therefore reducing the stop-start and wave effect brought on by heavy traffic flow. In theory, this should create a more efficient network, keep congestion at a minimum and improve safety. The data recorded from loop detectors used by the MIDAS system have also been collected

When an incident was notified to the control room, the following information was recorded on incident characteristics:

- Time of notification,
- Type of incident (Breakdown, Accident, Debris, Vehicle Fire, Animal, etc.),
- Time travel lanes were cleared,
- Time incident was cleared,
- Day of week,
- Method of notification,
- Location (Marker post, direction, junctions, lane),
- Number of lanes blocked,
- Weather conditions,
- Light conditions,
- Road conditions,
- Length of queue (if available),
- Occurrence of secondary accidents,
- Whether an ISU was required,
- Time of ISU request and arrival,
- Type and number of vehicles involved,
- Any other relevant details (times of matrix signal activations, VMS messages and timings, Type, number and timings of emergency and recovery vehicles at incident scene, etc.).

A total of 450 incidents were recorded for the study area throughout the study period.

INCIDENT SUPPORT UNITS

With sections of the M25 carrying an average of 200,000 vehicles a day even a minor incident can bring traffic to a halt very quickly. To help mitigate the impact of incidents on the road users of the M25, a new joint initiative by the Highways Agency, Mouchel Parkman and Carillion has been implemented. A fleet of sixteen ISUs are on standby 24 hours a day, 365 days a year to solve problems on the M25 and adjoining roads (known as the M25 Sphere). These vehicles are dedicated maintenance vehicles that do minor maintenance activities on the network, but are available whenever an incident occurs or their presence is requested by the emergency services. The ISUs are placed at strategic locations around the road network and are monitored by GPS, allowing the nearest vehicle to be dispatched. They are manned by specialist two man crews, equipped with cones, warning signs, environmental protection packs and suitable equipment to deal with most situations and carry out emergency maintenance and repairs. They are neither allowed nor responsible for removing vehicles from travel lanes, but do provide emergency traffic management to protect incident scenes.

The aim of this service is to provide assistance to the emergency services and reduce the impact of an incident on the road network. The role of Carillion's Incident Support Units is to:

- Provide immediate response to incidents on the network,
- Provide emergency, short term lane closures,
- Deal immediately with minor, incident related debris.

INCIDENT DATA ANALYSIS

INCIDENT FREQUENCY

The incident records were analyzed to derive the incident type proportions and summary statistics are shown in table 1 and figure 2.

Figure 2 shows the breakdown of incident types. For the study period there were 291 breakdowns that accounted for approximately 64.7% of all incidents and were followed by accidents at 20.2% and debris with 9.1% of the total 450 incidents. The estimated incident rate for the study area was 2.32 incidents per million vehicle km (3.74 incidents per million vehicle miles). In comparison Bertini et al (8) found that breakdowns accounted for 50% and accidents accounted for 15% of all incidents and Skabardonis et al (7) found 86.6% of incidents were breakdowns and 6.5% were accidents. As Skabardonis et al (7) used probe vehicles instead of CCTV, for data capture, they will have witnessed more breakdowns than this study as only breakdowns notified to the control room were logged.

Table 1 illustrates the type and the lateral locations of incidents on the carriageway. The locations are classified as where the incident was first observed, so it may have occurred in the live lanes but by the time it was detected and verified the incident may have cleared to the shoulder. It can be seen that the predominant incident type recorded was breakdowns on the hard shoulder, approximately 55% of all incidents. In-lane accidents accounted for 45.1% of all accidents and 9.1% of all incidents. Approximately 29.3% of all recorded incidents occurred in-lane and had the potential to cause delay to motorists. The majority of accidents, 66.11%, involve only two vehicles and 80% of accidents involve three vehicles. 50.5% of accidents involved a Large Goods Vehicle (LGV) and 34% of all accidents included a foreign LGV, which is very concerning as they comprise less than 10% of the LGV traffic. Foreign LGV's however only accounted for 1.37% of all breakdowns with LGV's accounting for 5.84%.

In contrast, Skabardonis et al (7) observed that the proportion of in-lane incidents was about 10.7% on I-10, Skabardonis et al (3) on I-880 showed 4.6% occurred in-lane and FHWA (Lindley (9)) also presented values of approximately 4%. Bertini et al (8) however observed 29.3% in-lane incidents using historical data from the Portland area. Roberts et al (1) estimated that 6% of incidents occurring on the motorway network had the potential to interfere with free-flowing traffic in the running lanes. Skabardonis et al (3) do admit that if CCTV had been used to observe incidents, rather than probe vehicles, the number of in-lane incidents would have been higher.

Shown in figure 3 are the percentage breakdowns of lanes blocked by noted incidents. As shown, 69% of incidents blocked only the hard shoulder and only 7.6% of lane blocking incidents blocked two or more lanes. Less than 1% of incidents blocked 3 or more lanes which is much lower than Bertini et al (8) who reported that 3% of incidents blocked all lanes.

An average of 16.1 incidents/day was observed during the study period, within the study area, with an average of 10.39 breakdowns and 3.25 accidents per day. For each collection day there were on average 2.32 incidents per million vehicle-km (3.73

incidents per million vehicle-miles). The number of incidents was approximately the same for each direction of the study area with only 3.5% difference between clockwise and anti-clockwise carriageways.

Figure 4 shows the variability of recorded accidents by days of the week. The plot of data shows, for weekdays, that the larger numbers of incidents occur on Fridays with 74 incidents or 16.4% of all incidents in the study period. This is expected as more vehicles use the M25 on a Friday than on any other day and gives an incident rate of 2.41 incidents per million vehicle-km (3.88 incidents per million vehicle-miles). It can also be seen from figure 4 however that, unexpectedly, there are more incidents on a Tuesday

Also unexpectedly there are more incidents on Saturdays than any other day of the week giving an incident rate of 3.36 incidents per million vehicle-km (5.42 incidents per million vehicle-miles). With Sunday also very high compared to weekdays, this may be due to the fact that motorists using the M25 at the weekend may be less prepared or experienced for driving on an extremely busy motorway, compared to weekday commuters. It should also be noted that the majority of incidents on weekends were breakdowns, 72% of all incidents compared to an average of 61.5% on weekdays. Even though there were more incidents at weekends, less of them occurred in-lane: on average 21.8% of incidents in-lane compared to 35.4% on weekdays. Vehicle fires also occurred more often at weekends than on weekdays.

The number of incidents changes throughout the day and generally corresponds to the number of vehicles on the road, with the majority of all incidents when the road network is near or exceeding capacity, shown graphically in figure 5. There are however two exceptions to this between 11:00 – 12:00 and 14:00 – 15:00 where the incident rates are higher than expected. Further work has to be done on the timings of incident occurrence, as the discrepancies occur in uncongested low flow periods. The temporal variation in the occurrence of incidents can be used to enhance the ISU program by optimizing staffing shift patterns.

Figure 6 illustrates the different ways that incidents were notified to the motorway control room. As can be seen, emergency roadside telephones (EMT) are the most frequent method of notification with 236 uses or 52.4%. This is then followed by 999 (British 911 emergency number) emergency calls with 25.1% and then police patrols with 5.8%. The remainder of incidents were either observed by CCTV from the control room or reported by the Highways Agency, including ISUs, other emergency services or various breakdown agencies.

For the entire study period there were only 4 secondary accidents and all were very minor, damage only accidents. Other incidents types however had even fewer secondary effects with only two debris incidents struck before clearance. This may be a result of the MIDAS system quickly reducing speed limits, following incidents, and stopping other vehicles meeting stationary queues at high speed.

INCIDENT DURATIONS

For the 450 incidents observed, the total accident duration was calculated as the difference in the time from when the incident was first observed until all lanes,

including the hard shoulder were cleared. The average duration of all incidents was 1 hour, 9 minutes. This duration is approximately three times that of Skabardonis et al (7) incident duration of 20.7 minutes and double the duration of Bertini et al (8) study in Portland at 33 minutes. The British study by Roberts et al (1) found the average incident duration of 46 minutes for several UK motorways. This longer duration may be due to many locations on the M25 being rural and having longer distances between junctions compared to other study areas as emergency and recovery vehicles having to travel further to an incident scene. The average duration of a travel lane being blocked was 32 minutes. The longest incident duration, and travel lane blockage duration, observed was 6 hours 40 minutes and involved extensive infrastructure damage that had to be repaired immediately for safety reasons. Accidents had the longest durations of all incidents, at 81 minutes, approximately 6 minutes longer than breakdowns, at 75 minutes. Debris incidents in general lasted 19 minutes and all other incidents, including vehicle fires, animals and pedestrians, lasted approximately 49 minutes on average.

Figure 7 shows the distribution of durations for all incidents. The distribution shows that approximately 50% of all incidents last less than 60 minutes, 75% of all incidents last less than 90 minutes and 90% of all incidents last less than 140 minutes.

During a day the average duration of incidents varies by as much as 37 minutes, as shown in figure 8. Also shown in figure 8 are lane closure durations throughout the day with the period between 13:00-14:00 hours having the greatest average duration of 58 minutes. The duration of an accident was affected by the number of lanes blocked (severity) with one lane accidents having an average duration of 85 minutes and lane closure duration of 29 minutes. Two lane accidents had an average duration of 92 minutes and lane closure duration of 39 minutes. Three lanes and over accidents had an average duration of 283 minutes and lane closure duration of 209 minutes though the sample size was very small for more severe accidents.

As this study was constantly observing traffic flows, using CCTV, several incidents were actually observed before the control room had been notified. This enabled approximate detection times to be established. For the incidents that were discovered there was on average 5 minutes between the incidents occurring and the control room being notified.

INCIDENT LOCATIONS

The location of each incident was recorded to the nearest marker post. These are spaced at 100 meter intervals along the full length of the study area. The spatial distribution of incidents, organized by junctions, is shown in figure 9.

It can be seen that for a straight count of incidents, then the section between junctions 8 and 9 has the highest occurrences of incidents. However, when incident rates are considered, the section between junctions 9 and 10 has the highest rate of incidents at 2.87 incidents per million vehicle km (4.63 incidents per million vehicle-miles). This information can be used to enhance the ISU program as the standby locations can be altered in relation to the spatial locations of incidents.

INCIDENT SUPPORT UNIT INVOLVEMENT

Incident support units were requested to attend 21.33% of all incidents during the study period. They attended 44% of all accidents, 5% of breakdowns and 63.41% of debris incidents. After being requested, the ISUs had an average response time of 12 minutes over 96 incidents. Further research will have to be conducted to fully understand the influence of ISUs on the M25 road network.

COMPARISON BETWEEN UK AND US INCIDENT DATA

Table 2 shows a comparison between this study's findings regarding incident characteristics and three other studies: Roberts et al (1), Skabardonis et al (7) and Bertini et al (8). It can be seen that there are few similarities between studies.

Average incident duration varies by as much 28 minutes between the M25 and Interstate 10. Durations in the UK are between double and triple those of the US. Does this imply that US incident management practices are better than UK practices?

Incident rates between Britain and the US are vastly different with an average incident rate of 6.91 incidents per million vehicle kilometers from Britain compared to 92.8 in the US. This may be due to different driving styles, vehicles, vehicle regulations, driving distances, weather and many other factors such as incident recording. The difference between percentages of in-lane incidents appears to increase with more recent studies. Very minor incidents may not have been captured in this study thus increasing the in-lane percentage. The percentage in this study and the Portland study (8) are however both greater than the two older studies in the comparison. The differences could also be due to different traffic densities. The percentage of accidents could also be due to the age of the study, again with the two more recent studies having greater percentages of accidents occurring. The lower accident percentages may also be due to the total number of incidents as the studies with the higher incident rates have lower percentages. Again the age of studies may be the cause of the differences between studies as more modern vehicles are less prone to breaking down.

APPLICATION OF FINDINGS

The results from this study will enable incident management programs currently in operation on the M25 to be re-evaluated. The findings will also be used to investigate impact of incidents on traffic flow and the associated delays. The influence of incident management strategies will also be investigated.

CONCLUSIONS

This paper has shown an overview of the characteristics of incidents on the south western part of the M25 London orbital motorway for the period between 5th November 2003 until 11th December 2003. Incident frequency, durations and locations were examined.

It was found that:

- The average frequency of incidents was 16.1 incidents per day or 2.32 incidents per million vehicle-km (3.74 incidents per million vehicle-miles) for the study

area. The majority of recorded accidents occurred on a Saturday. Between 11:00 and 12:00 was found to have the highest occurrence of accidents.

- The average incident duration for the study period was found to be 1 hour, 9 minutes.
- The spatial distribution of accidents was established across the study section of the M25. The majority of incidents occurred between junctions 8 and 9 but between junctions 9 and 10 had the highest incident rate for the study period.
- Incident characteristics between US and UK studies were compared.

ACKNOWLEDGEMENTS

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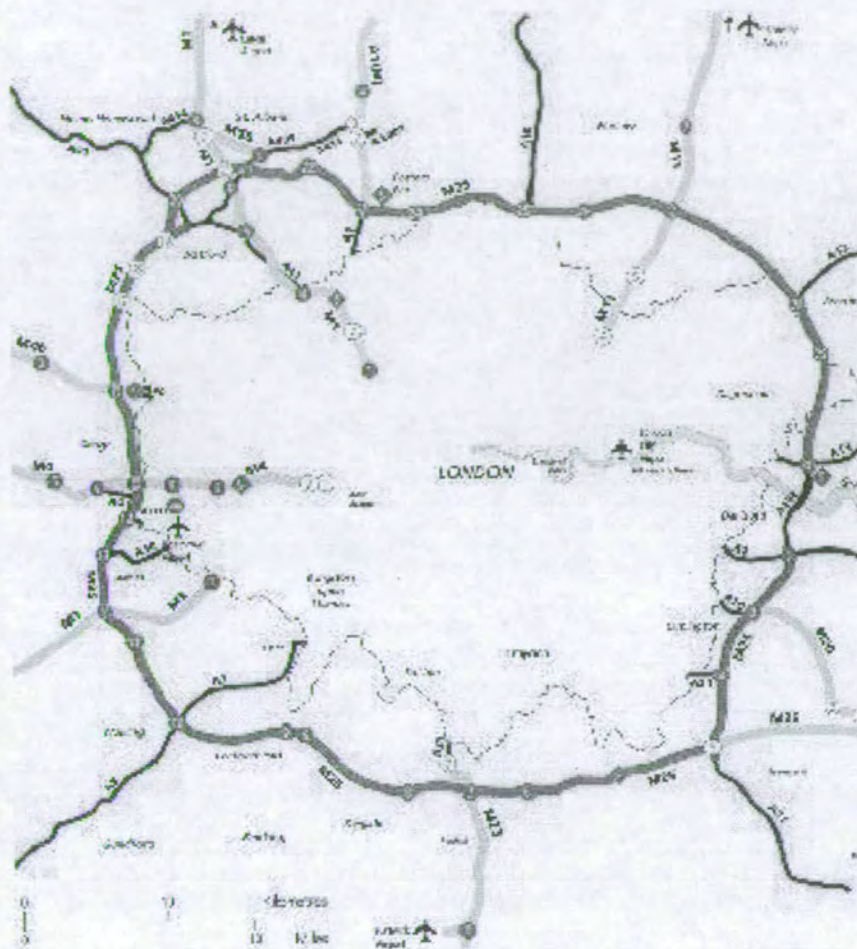


FIGURE 1 Map of roads within M25 Sphere (10).

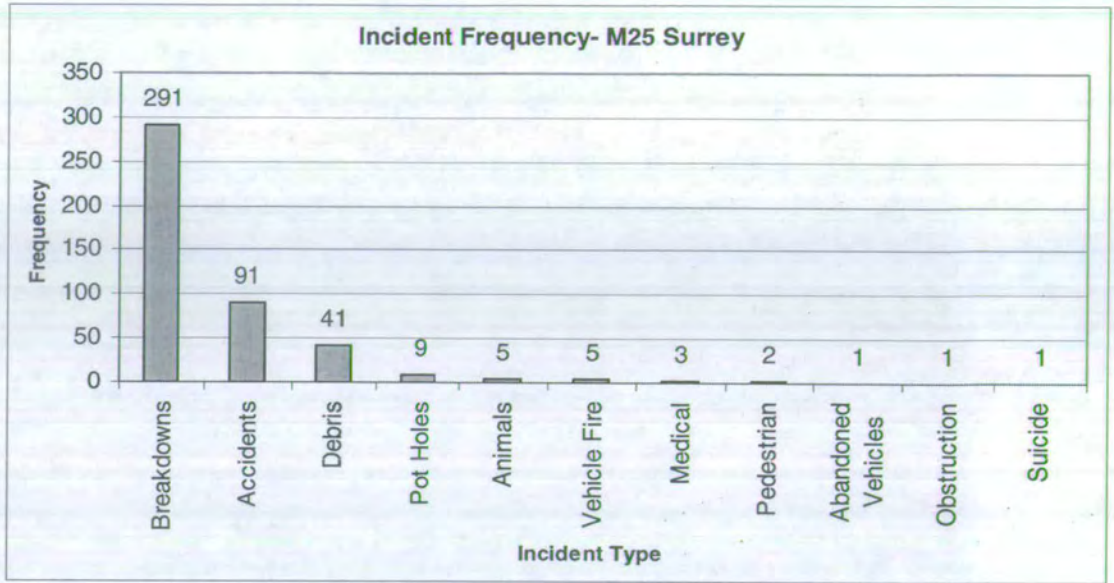


FIGURE 2 Breakdown of incident types.

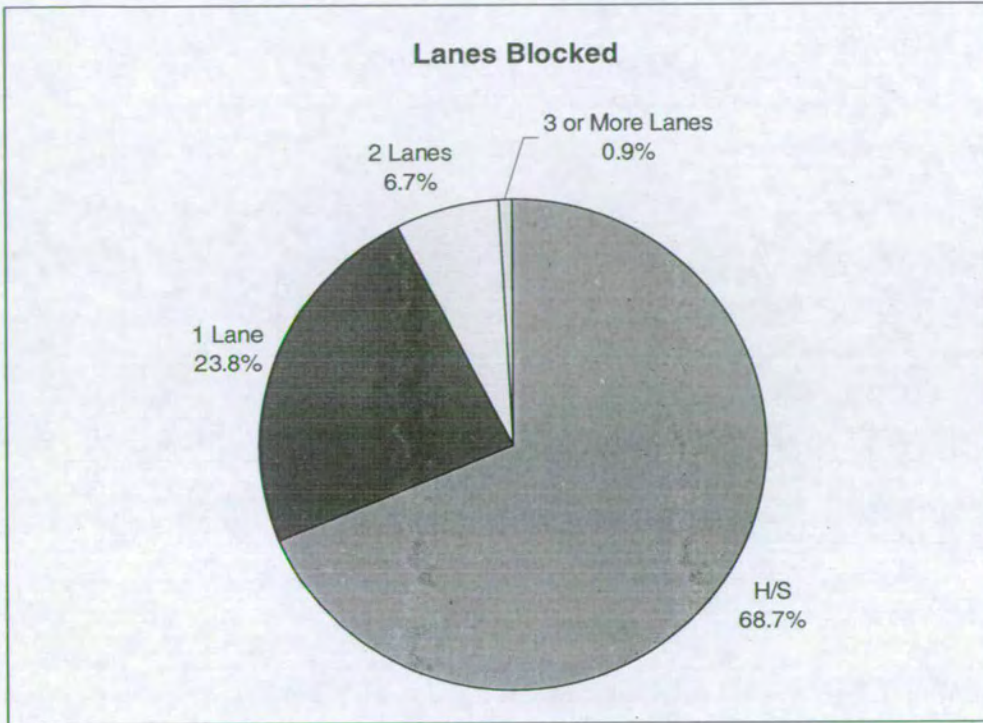


FIGURE 3 Lanes blocked by percentage.

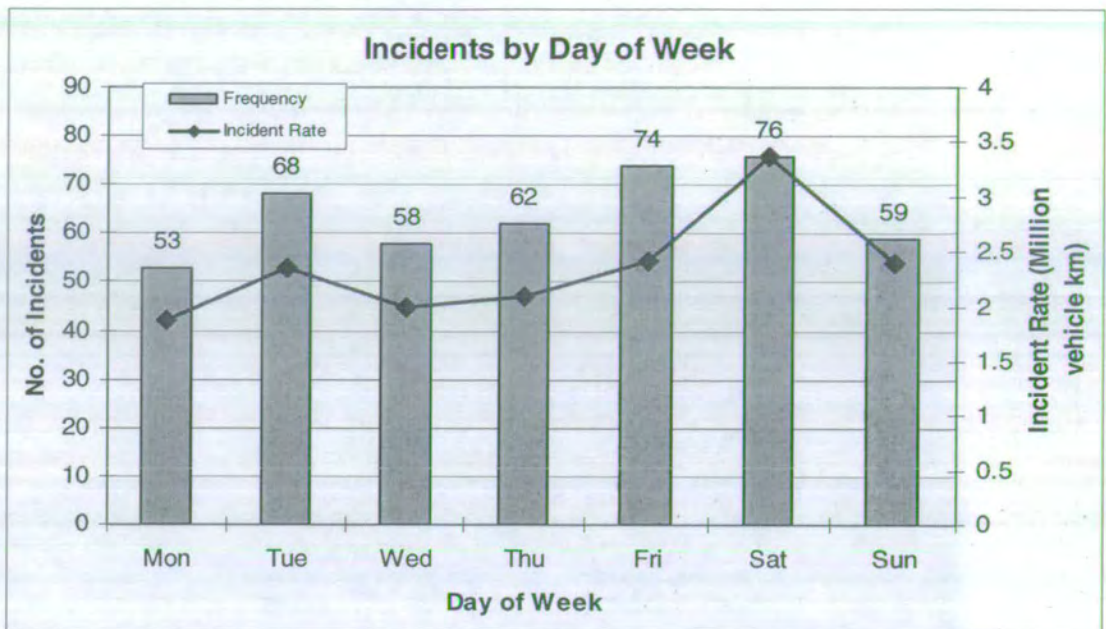


FIGURE 4 Incidents by day of Week.

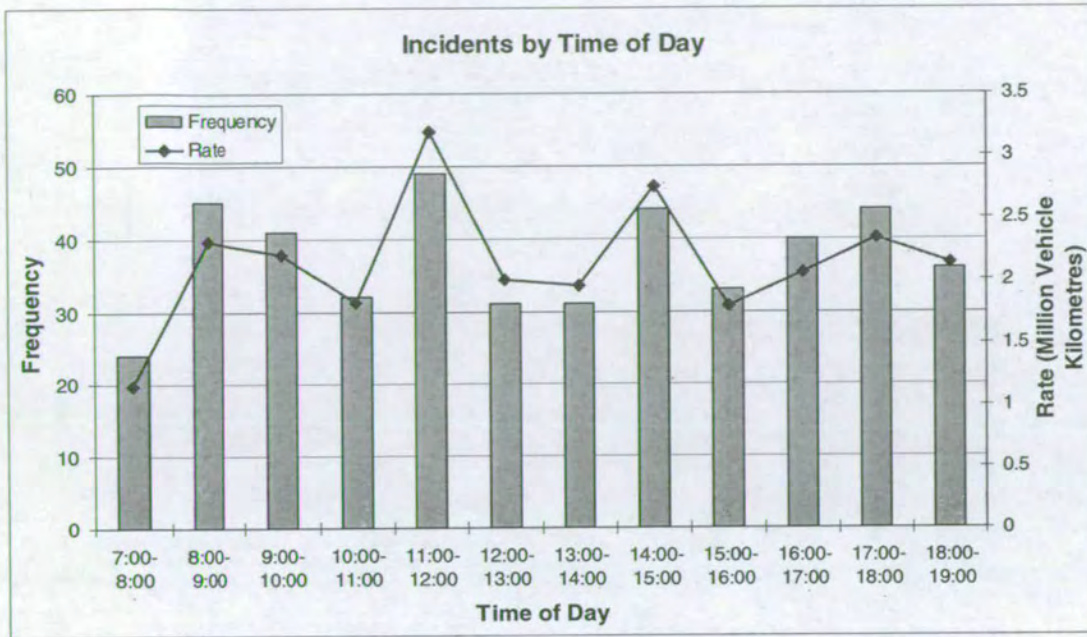


FIGURE 5 Incidents by time of day.

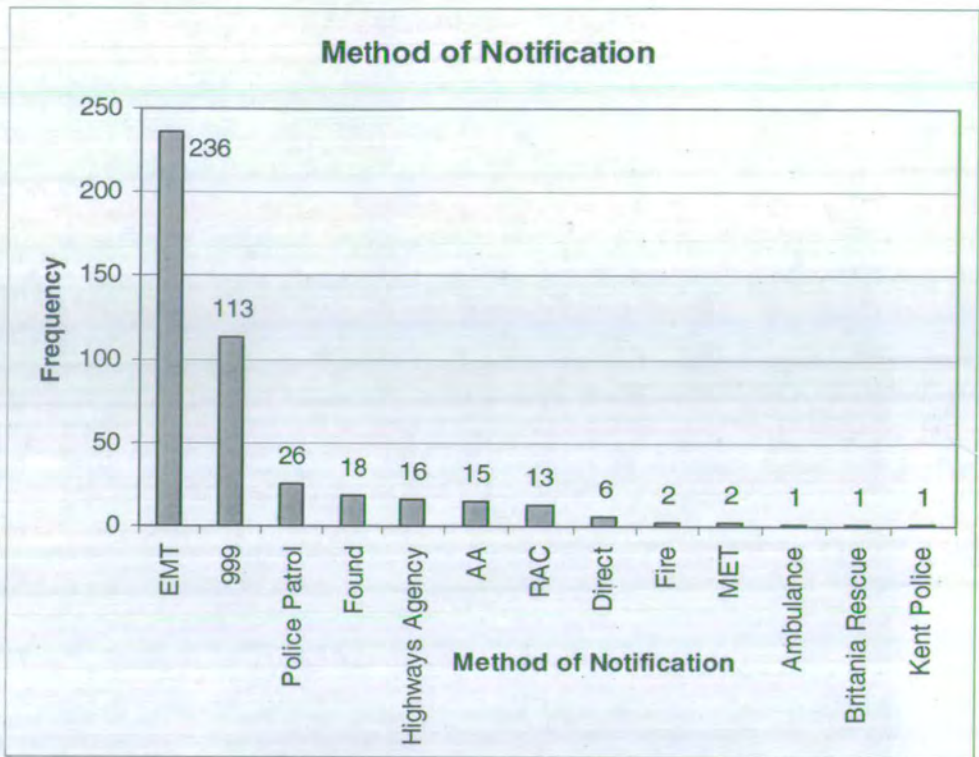


FIGURE 6 Method of Notification.

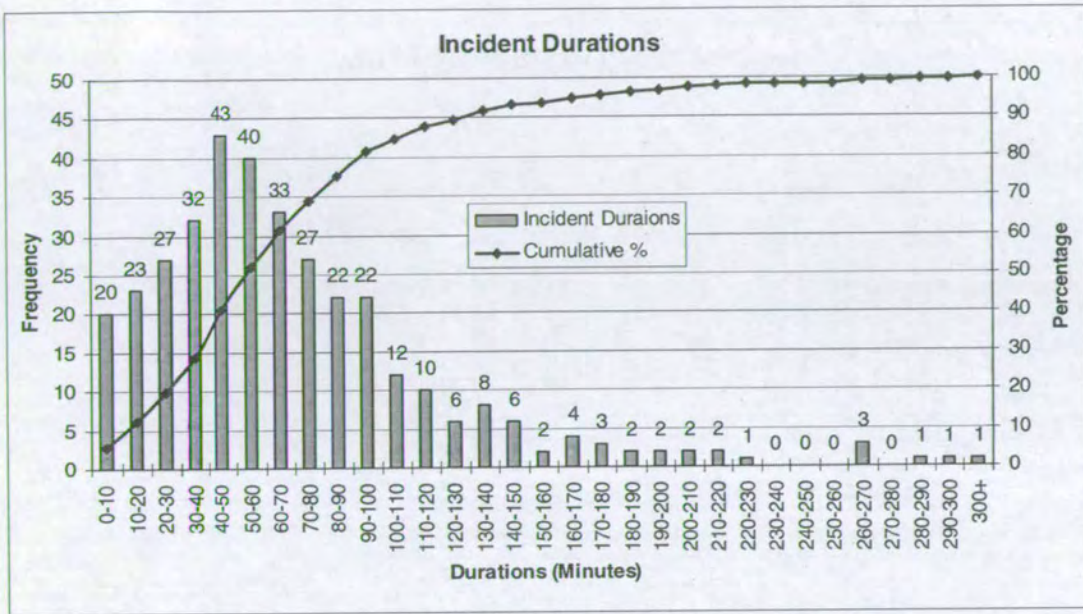


FIGURE 7 Distribution of durations for all incidents

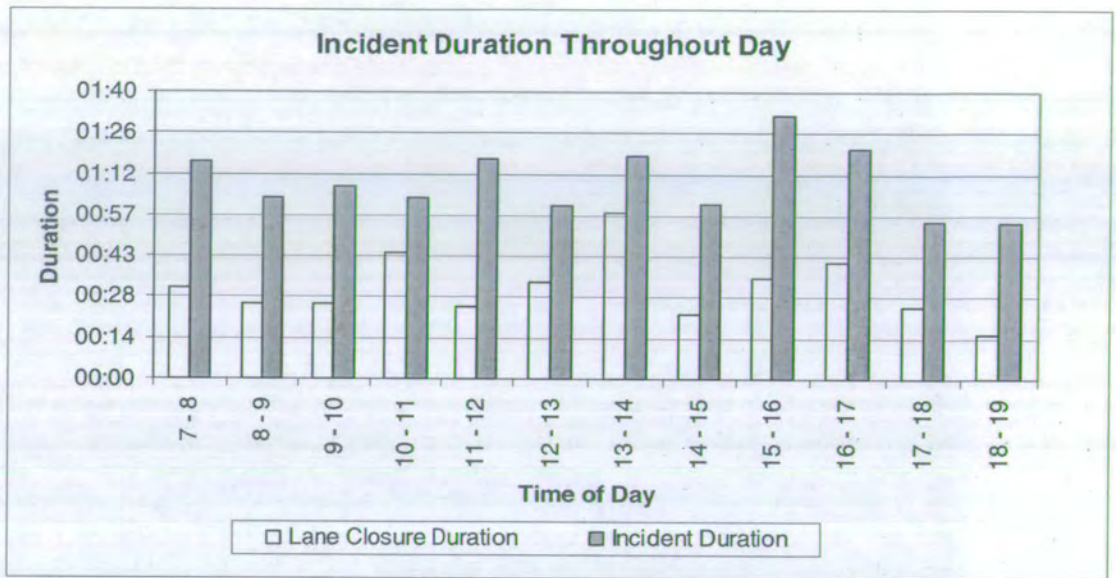


FIGURE 8 Graph of average incident duration and lane closure duration throughout the day.

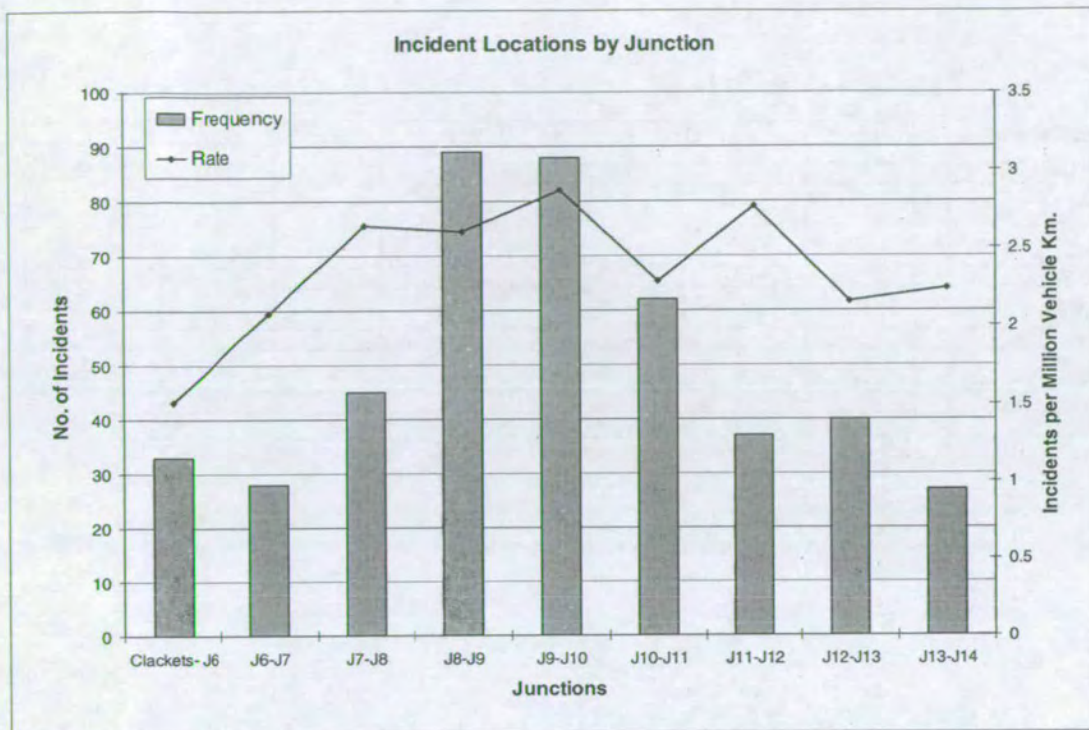


FIGURE 9 Incident locations organized by junctions.

TABLE 1 Overall Incident Type Frequency and Locations

Type of Incident	H/S	%	In-Lane	%	Slip Road	%	Unknown	%	Total	%
Breakdowns	247	84.9%	39	13.4%	5	1.7%	0	0.0%	291	64.7%
Accidents	49	53.8%	41	45.1%	1	1.1%	0	0.0%	91	20.2%
Debris	3	7.3%	35	85.4%	1	2.4%	2	4.9%	41	9.1%
Pot Holes	0	0.0%	9	100.0%	0	0.0%	0	0.0%	9	2.0%
Animals	1	20.0%	3	60.0%	0	0.0%	1	20.0%	5	1.1%
Vehicle Fire	2	40.0%	3	60.0%	0	0.0%	0	0.0%	5	1.1%
Medical	3	100.0%	0	0.0%	0	0.0%	0	0.0%	3	0.7%
Pedestrian	2	100.0%	0	0.0%	0	0.0%	0	0.0%	2	0.4%
Abandoned Vehicles	0	0.0%	0	0.0%	1	100.0%	0	0.0%	1	0.2%
Obstruction	0	0.0%	1	100.0%	0	0.0%	0	0.0%	1	0.2%
Suicide	0	0.0%	1	100.0%	0	0.0%	0	0.0%	1	0.2%
Total	307	68.2%	132	29.3%	8	1.8%	3	0.7%	450	100.0%

TABLE 2 Comparison of Study Results

Title of Study (Reference)	London - M25	British Motorways (1)	Los Angeles I-10 (7)	Portland Metropolitan Area (8)
Year of Study	2003	1992/1993	1996	2001
Average Incident Duration (Minutes)	69	46	20.7	33
Incident Rate (Incidents per million vehicle kilometres)	2.32	11.49	92.8	N/A
Percentage In-Lane Incidents (%)	31.1	6	10.7	29.3
Percentage Accidents(%)	20.2	4.7	6.5	15
Percentage Breakdowns (%)	64.7	78.6	86.6	50



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ice

An analysis of road traffic incidents on the M25 motorway, UK

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To date, studies of incidents on British motorways have been very limited. As part of a study into the role of Incident Support Units (ISUs) on the M25, the London orbital motorway, an analysis of road traffic incidents was undertaken. Motorway incident data were collected through closed circuit television (CCTV) observations at Surrey Police's Godstone Motorway Control Room. The collected data covered the Surrey Police section of the M25 motorway between Clacket Lane Services and Junction 14, for a four-week period between 5 November and 11 December 2003. Incident frequency, durations, locations, detection times, notification methods and ISU involvement were examined. It was found that the average incident frequency was 16.1 incidents per day for the study area, and the highest occurrence of incidents was found to be between 11.00 am and 12.00 pm. On average the recorded incidents lasted 1 h 9 min, with those occurring in the evening peak period lasting the longest. The distribution of incidents along the study area showed that the section between Junctions 9 and 10 had the highest rate for the study period. A comparison of incident characteristics between US and UK studies was also conducted. Incident rates between the M25 and the US were found to be substantially different, and incident durations were found to be between double and triple those of the US. Possible reasons for these differences are discussed in the text.

1. INTRODUCTION

Road traffic incidents are an unfortunate part of road travel. Incidents are random events that reduce the capacity of a road, and include accidents, breakdowns, spilled loads and any other event that could cause delay.

It has to be accepted that incidents will happen whatever programmes are introduced to reduce the chance of an incident occurring. With this in mind, the best ways of mitigating the effects of an incident must be discovered and implemented. This study will facilitate a better understanding of where and when incidents happen on the M25.

The M25 motorway is the orbital motorway that encircles London (Fig. 1). It was designed as a bypass for London and the surrounding towns, giving substantial traffic relief for communities, particularly from heavy goods vehicle traffic. It

is approximately 118 miles (190 km) in length, and is dual three-lane carriageway or dual four-lane carriageway in the busier areas. It also has left-lane hard shoulders over the majority of its length. Since its completion in 1986 it has become one of the busiest motorways in Europe, coming under ever-increasing strain. The busiest south-western section of the M25 regularly carries 200 000 vehicles per day. Traffic congestion is a major problem: each year, it leads to millions of hours of vehicle delays, and causes significant losses in productivity, increases in fuel consumption and environmental pollution. Any strategy to reduce congestion could be viewed as part of a sustainability programme.

The rising demand for use of motorway networks has not and cannot be met with corresponding increases in capacity. This has led to an ever-increasing level of daily congestion. Recurring congestion from excess volume of vehicles is expected, but non-recurring or 'incident' congestion is unpredictable. Incidents cause bottlenecks, slowing and frequently stoppages in the flow of vehicles. As the flow of traffic slows following an incident, a queue builds upstream of the incident, and continues until the blockage is cleared and flow restored. Additionally, 'rubbernecking' can reduce the flow in opposing lanes. Owing to the backlog of vehicles it can take a long time after the incident for the accumulated traffic to dissipate. This issue can be compounded by the problem of secondary incidents. Incident management programmes have been developed to mitigate non-recurring congestion from incidents. The purpose of these programmes is to rapidly detect, verify and clear temporary obstructions from roads to restore normal traffic flow as quickly as possible. This non-recurring congestion can be minimised by clearing incidents as quickly as possible or by diverting traffic before vehicles are caught in the traffic backup.

To mitigate non-recurrent congestion, rapid response and clearance are essential. To assist in this, the Highways Agency has deployed a fleet of Incident Support Units (ISUs) on the M25 and other congested roads throughout England.

This investigation of incidents on the M25 has been undertaken as part of a study into the role of ISUs on the road network. It is the intention to study the frequency, duration and location of incidents, with the aim of ultimately reducing the traffic impacts of incidents through the allocation of equipment and personnel.



Fig. 1. Map of roads within M25 Sphere

2. BACKGROUND

There is limited literature on incident analysis on motorways in Britain, with the exception of Roberts *et al.*¹ Their study for the then UK Department of Transport, in 1992 and 1993, provided a review of incidents on British motorways. They assessed incidents at 10 motorway control rooms, to establish incident rates and durations on motorway links. Multi-channel time-lapse video from CCTV cameras and historical police records were used.

There is more information available on US freeway incident characteristics.²⁻⁸ Other studies for major cities in the US have been useful sources of information, as reported traffic conditions are similar to those of the M25. However, many were carried out in the 1960s and 1970s,³ when drivers and vehicles were very different. More recent studies into the characteristics of incidents were undertaken in Seattle,⁵ Portland⁶ and Los Angeles.^{3,4,6,7} These studies used archived incident records as data, with Skabardonis *et al.*^{3,7} collecting comprehensive field data, using probe vehicles, to determine incident and accident patterns. These data will be referred to in more detail within the analysis and comparison.

3. DATA DESCRIPTION

The data for this paper were collected through observations, using closed-circuit television (CCTV), at Surrey Police's Godstone Motorway Control Room. A total of four weeks (28 days) of incident data were collected between 5 November and 11 December 2003. Every day, incident information was collected for a 12 h period between 7 am and 7 pm. This time period was chosen as it covered the majority of the morning and evening travel peaks.

Godstone Motorway Control Room manages Surrey Police's strategic roads, which include the M25, M23, M3 and other

major trunk roads. This paper is concerned only with incidents that occurred on their section of the M25, which is between Clacket Lane Motorway Services (marker post 4335) and Junction 14 (marker post 4919) and is approximately 58.4 km (36.3 miles) long. The annual average daily traffic over the study area ranged from 140 000 to 200 000 vehicles per day.

The complete survey area is covered by an extensive network of CCTV cameras, emergency roadside telephones (ERT), gantry matrix signals for speed and lane controls, and variable message signs (VMS). The matrix signals are used by the Motorway Incident Detection and Automatic Signalling (MIDAS) system. The MIDAS system covers the area between Junction 6 and Junction 16, and uses information on flows, speed and occupancy from a large number of loop detectors, spaced at approximately 300 and 500 m, to trigger and impose speed limits on that section through the overhead gantry matrix signals and VMS. This is known as the variable speed limit zone; it attempts to 'smooth out' the traffic flow, thereby reducing the stop-start and wave effect brought on by heavy traffic flow. In theory, this should create a more efficient network, keep congestion at a minimum, and improve safety. The data recorded from loop detectors used by the MIDAS system have also been collected.

When an incident was notified to the control room, the following information was recorded on incident characteristics

- (a) time of notification
- (b) type of incident (breakdown, accident, debris, vehicle fire, animal, etc.)
- (c) time travel lanes were cleared
- (d) time incident was cleared
- (e) day of week
- (f) method of notification
- (g) location (marker post, direction, junctions, lane)
- (h) number of lanes blocked
- (i) weather conditions
- (j) light conditions
- (k) road conditions
- (l) length of queue (if available)
- (m) occurrence of secondary accidents
- (n) whether an ISU was required
- (o) time of ISU request and arrival
- (p) type and number of vehicles involved
- (q) any other relevant details (times of matrix signal activations and settings, VMS messages and timings, type, number and timings of emergency and recovery vehicles at incident scene, etc.).

A total of 450 incidents were recorded for the study area throughout the study period.

4. INCIDENT SUPPORT UNITS

With sections of the M25 carrying an average of 200 000 vehicles a day, even a minor incident can bring traffic to a halt very quickly. To help mitigate the impact of incidents on the road users of the M25, a new joint initiative by the Highways Agency, Mouchel Parkman and Carillion plc has been implemented. A fleet of 16 ISUs are on standby 24 h a day, 365 days a year, to solve problems on the M25 and adjoining roads (known as the M25 Sphere). These vehicles are dedicated

maintenance vehicles that do minor maintenance activities on the network, but are available whenever an incident occurs or their presence is requested by the emergency services. The ISUs are placed at strategic locations around the road network and are monitored by GPS, allowing the nearest vehicle to be dispatched. They are manned by specialist two-man crews, equipped with cones, warning signs, environmental protection packs and suitable equipment to deal with most situations and carry out emergency maintenance and repairs. They are neither allowed nor responsible for removing vehicles from travel lanes, but do provide emergency traffic management to protect incident scenes.

The aim of this service is to provide assistance to the emergency services and reduce the impact of an incident on the road network. The role of Carillion's Incident Support Units is to

- (a) provide immediate response to incidents on the network
- (b) provide emergency, short-term lane closures
- (c) deal immediately with minor, incident-related debris.

5. INCIDENT DATA ANALYSIS

The data collected and described above can be investigated and analysed to provide greater insight into the occurrence of incidents on the M25. These data can be investigated in four separate areas

- (a) incident frequency
- (b) incident durations
- (c) incident locations
- (d) Incident Support Unit involvement.

Each of these four areas will be discussed below, with conclusions where applicable.

5.1. Incident frequency

The incident records were analysed to derive the incident type proportions, and summary statistics are shown in Table 1 and Fig. 2.

Figure 2 shows the breakdown of incident types. For the study period there were 291 breakdowns, which accounted for

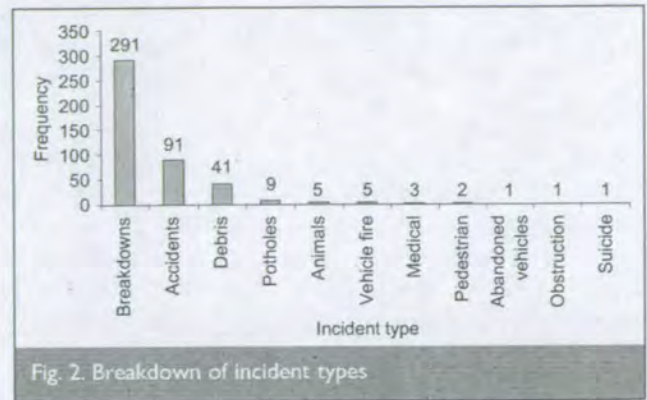


Fig. 2. Breakdown of incident types

approximately 64.7% of all incidents and were followed by accidents at 20.2% and debris with 9.1% of the total 450 incidents. The estimated incident rate for the study area was 2.32 incidents per million vehicle km (3.74 incidents per million vehicle miles). In comparison, in the US, Bertini *et al.*⁸ found that breakdowns accounted for 50% and accidents for 15% of all incidents, and Skabardonis *et al.*⁷ found that 86.6% of incidents were breakdowns and 6.5% were accidents. As Skabardonis *et al.*⁷ used probe vehicles, patrolling the highway looking for incidents, instead of CCTV for data capture, they will have witnessed more breakdowns than this study. On the M25 only breakdowns notified to the control room were logged: hence the smaller number of breakdowns. This highlights a difference in the recording of the incident data.

Table 1 illustrates the type and the lateral locations of incidents on the carriageway. The locations are classified as where the incident was first observed, so it may have occurred in the live lanes but by the time it was detected and verified the incident may have cleared to the shoulder. It can be seen that the predominant incident type recorded was breakdowns on the hard shoulder: approximately 55% of all incidents. In-lane accidents accounted for 45.1% of all accidents and 9.1% of all incidents. Approximately 29.3% of all recorded incidents occurred in-lane and had the potential to cause delay to motorists. The majority of accidents, 61.6%, involved only one or two vehicles, and 80.2% of accidents involved three or fewer vehicles. A total of 50.5% of accidents involved a large goods vehicle (LGV), and 34% of all accidents included a foreign

Type of incident	H/S		In-lane		Slip road		Unknown		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Breakdowns	247	84.9	39	13.4	5	1.7	0	0.0	291	64.7
Accidents	49	53.8	41	45.1	1	1.1	0	0.0	91	20.2
Debris	3	7.3	35	85.4	1	2.4	2	4.9	41	9.1
Potholes	0	0.0	9	100.0	0	0.0	0	0.0	9	2.0
Animals	1	20.0	3	60.0	0	0.0	1	20.0	5	1.1
Vehicle fire	2	40.0	3	60.0	0	0.0	0	0.0	5	1.1
Medical	3	100.0	0	0.0	0	0.0	0	0.0	3	0.7
Pedestrian	2	100.0	0	0.0	0	0.0	0	0.0	2	0.4
Abandoned vehicles	0	0.0	0	0.0	1	100.0	0	0.0	1	0.2
Obstruction	0	0.0	1	100.0	0	0.0	0	0.0	1	0.2
Suicide	0	0.0	1	100.0	0	0.0	0	0.0	1	0.2
Total	307	68.2	132	29.3	8	1.8	3	0.7	450	100.0

Table 1. Overall incident type frequency and locations

LGV, which is very concerning as they constitute less than 10% of the LGV traffic. Foreign LGVs, however, accounted for only 1.37% of all breakdowns, with all LGVs accounting for 5.84%.

In contrast, in the US, Skabardonis *et al.*⁷ observed that the proportion of in-lane incidents was approximately 10.7% on I-10; Skabardonis *et al.*³ on I-880 showed that 4.6% occurred in-lane, and the FHWA⁹ also presented values of approximately 4%. Bertini *et al.*,⁸ however, observed 29.3% in-lane incidents using historical data from the Portland area. Roberts *et al.*¹ estimated that 6% of incidents occurring on the motorway network had the potential to interfere with free-flowing traffic in the running lanes. Skabardonis *et al.*³ do admit that if CCTV had been used to observe incidents, rather than probe vehicles, the number of in-lane incidents would have been higher.

Shown in Fig. 3 are the percentage breakdowns of lanes blocked by noted incidents. As shown, 69% of incidents blocked only the hard shoulder, and only 7.6% of lane-blocking incidents blocked two or more lanes. Less than 1% of incidents blocked three or more lanes, which is much lower than Bertini *et al.*,⁸ who reported that 3% of incidents blocked all lanes.

An average of 16.1 incidents/day was observed during the study period, within the study area, with an average of 10.39 breakdowns and 3.25 accidents per day. For each collection day there were on average 2.32 incidents per million vehicle-km (3.73 incidents per million vehicle-miles). The number of incidents was approximately the same for each direction of the study area, with only 3.5% difference between the clockwise and anti-clockwise carriageways.

Figure 4 shows the variability of recorded accidents by days of the week. The plot of data shows, for weekdays, that a large number of incidents occur on Fridays, with 74 incidents or 16.4% of all incidents in the study period. This is expected, as more vehicles use the M25 on a Friday than on any other day, and gives an incident rate of 2.41 incidents per million vehicle-km (3.88 incidents per million vehicle-miles). It can also be seen from Fig. 4, however, that, unexpectedly, there is an

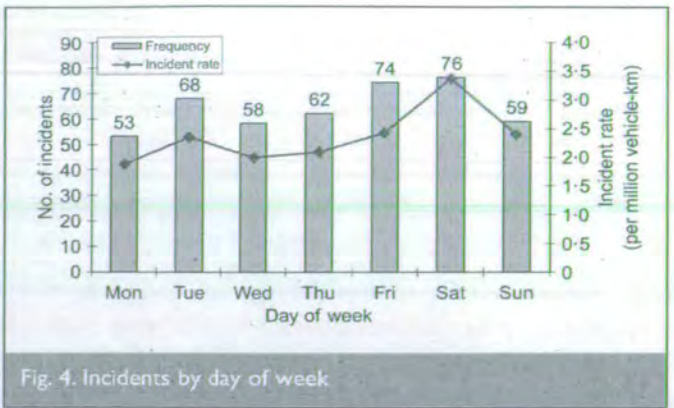
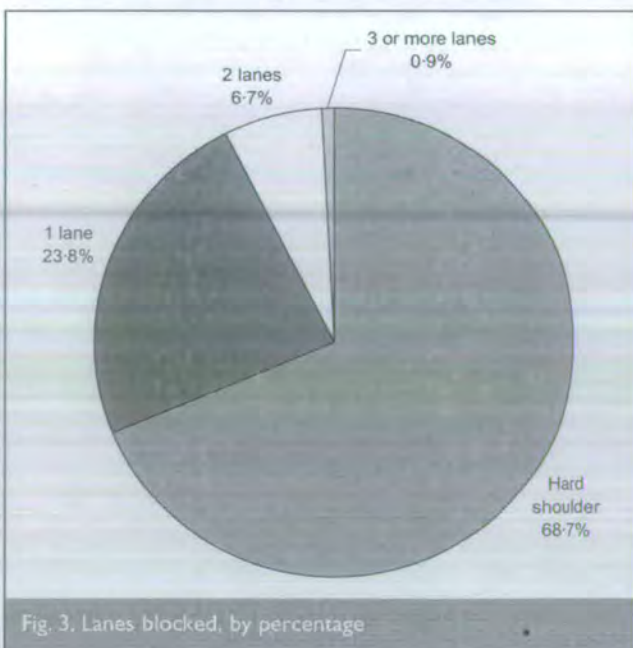


Fig. 4. Incidents by day of week

increase of incidents on a Tuesday. This requires further investigation with a larger data set to fully understand the influence of days of the week on the frequency of incidents.

Also unexpectedly there are more incidents on Saturdays than any other day of the week, giving an incident rate of 3.36 incidents per million vehicle-km (5.42 incidents per million vehicle-miles). With Sunday also very high compared with weekdays, this may be due to the fact that motorists using the M25 at the weekend may be less prepared for or experienced in driving on an extremely busy motorway, compared with weekday commuters. It should also be noted that the majority of incidents at weekends were breakdowns, 72% of all incidents compared with an average of 61.5% on weekdays. Even though there were more incidents at weekends, fewer of them occurred in-lane: on average 21.8% of incidents in-lane compared with 35.4% on weekdays. Vehicle fires also occurred more often at weekends than on weekdays, possibly confirming that less well maintained vehicles were being used at the weekend.

The rate of incident occurrence changes throughout the day and generally corresponds to the number of vehicles on the road, with the majority of all incidents occurring when the road network is near or exceeding capacity, as shown graphically in Fig. 5. There are, however, two exceptions to this, between 11:00 and 12:00 and between 14:00 and 15:00, when the incident rates are higher than expected. Further work has to be done on the timings of incident occurrence, as the discrepancies occur in uncongested low-flow periods. The temporal variation in the occurrence of incidents can be used to enhance the ISU programme by optimising staffing shift patterns.

Figure 6 illustrates the different ways in which incidents were notified to the motorway control room. As can be seen, emergency roadside telephones (ERT) are the most frequent method of notification, with 236 uses or 52.4%. This is then followed by 999 (British emergency number) emergency calls, with 25.1%, and then police patrols with 5.8%. The remainder of incidents were either observed by CCTV from the control room or reported by the Highways Agency, including ISUs, other emergency services or various breakdown agencies.

For the entire study period there were only four secondary accidents, and all were very minor, damage-only accidents. Other incident types, however, had even fewer secondary effects, with only two incidents of debris being struck before clearance. This may be a result of the MIDAS system quickly

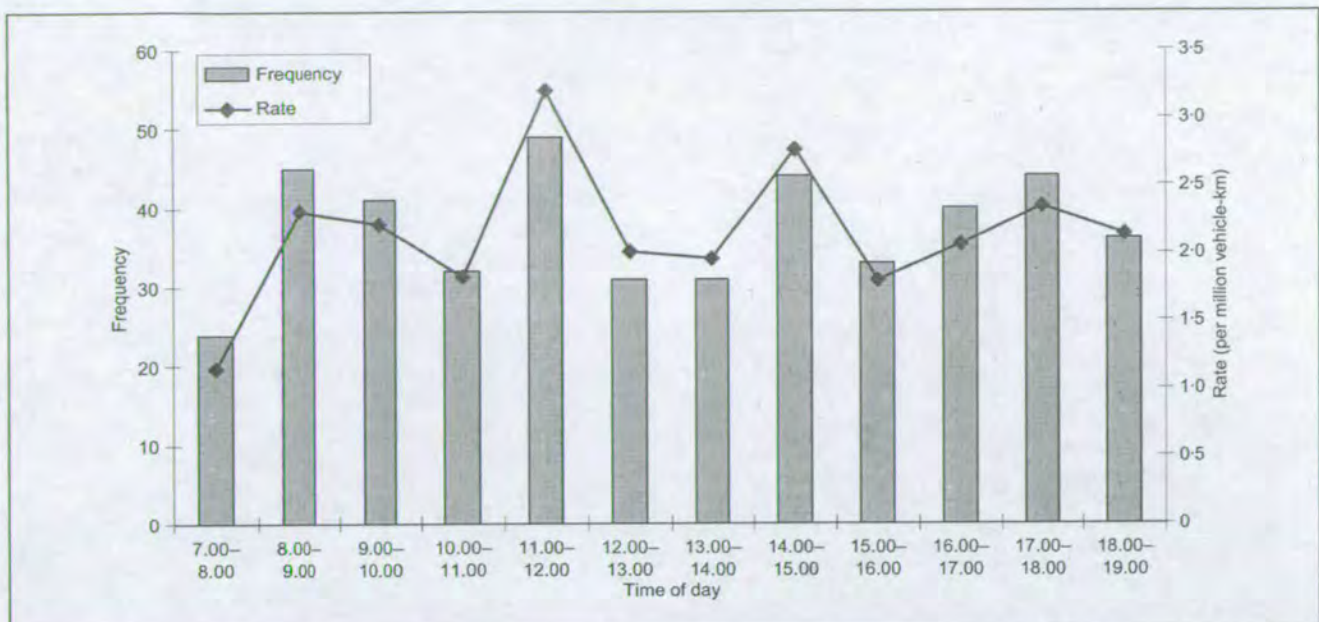


Fig. 5. Incidents by time of day

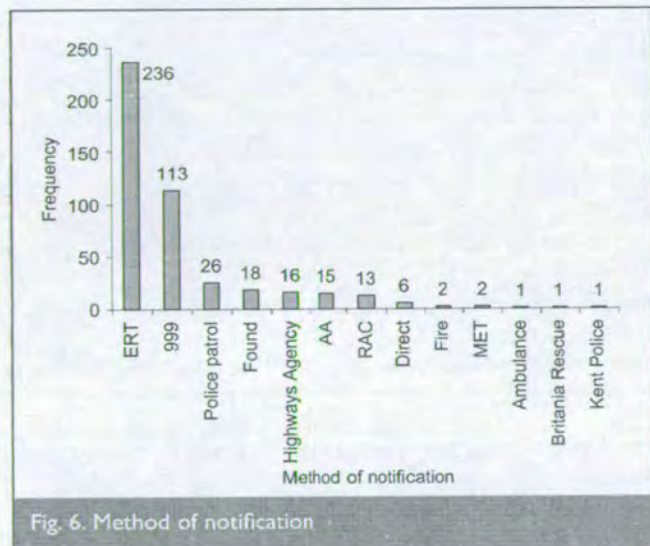


Fig. 6. Method of notification

reducing speed limits following incidents, and preventing other vehicles from meeting stationary queues at high speed.

5.2. Incident durations

For the 450 incidents observed, the total accident duration was calculated as the difference in the time from when the incident was first observed until all lanes, including the hard shoulder, were cleared. The average duration of all incidents was 1 h 9 min. This duration is approximately three times that of Skabardonis *et al.*'s⁷ incident duration of 20.7 min, and double the duration of Bertini *et al.*'s⁸ study in Portland at 33 min. The British study by Roberts *et al.*¹ found an average incident duration of 46 min for several UK motorways. This longer duration may be due to many locations on the M25 being rural and having longer distances between junctions compared with other study areas, as emergency and recovery vehicles have to travel further to an incident scene. The average duration of a travel lane being blocked was 32 min. The longest observed incident duration, and travel lane blockage duration, was 6 h

40 min, and involved extensive infrastructure damage that had to be repaired immediately for safety reasons. Accidents had the longest durations of all incidents, at 81 min, approximately 6 min longer than breakdowns, at 75 min. Debris incidents in general lasted 19 min, and all other incidents, including vehicle fires, animals and pedestrians, lasted approximately 49 min on average.

Figure 7 shows the distribution of durations for all incidents. The distribution shows that approximately 50% of all incidents last less than 60 min, 75% of all incidents last less than 90 min, and 90% of all incidents last less than 140 min.

During a day the average duration of incidents varies by as much as 37 min, as shown in Fig. 8. Also shown in Fig. 8 are lane closure durations throughout the day, with the period between 13:00 and 14:00 hours having the greatest average duration of 58 min. The duration of an accident was affected by the number of lanes blocked (severity), with one-lane accidents having an average duration of 85 min and lane closure duration of 29 min. Two-lane accidents had an average duration of 92 min and lane closure duration of 39 min. Accidents affecting three lanes or more had an average duration of 283 min and lane closure duration of 209 min, though the sample size was very small for more severe accidents.

As this study was constantly observing traffic flows, using CCTV, several incidents were actually observed before the control room had been notified. This enabled approximate detection times to be established. For the incidents that were discovered there was on average 5 min between the incidents occurring and the control room being notified.

5.3. Incident locations

The location of each incident was recorded to the nearest marker post. These are spaced at 100 m intervals along the full length of the study area. The spatial distribution of incidents, organised by junctions, is shown in Fig. 9.

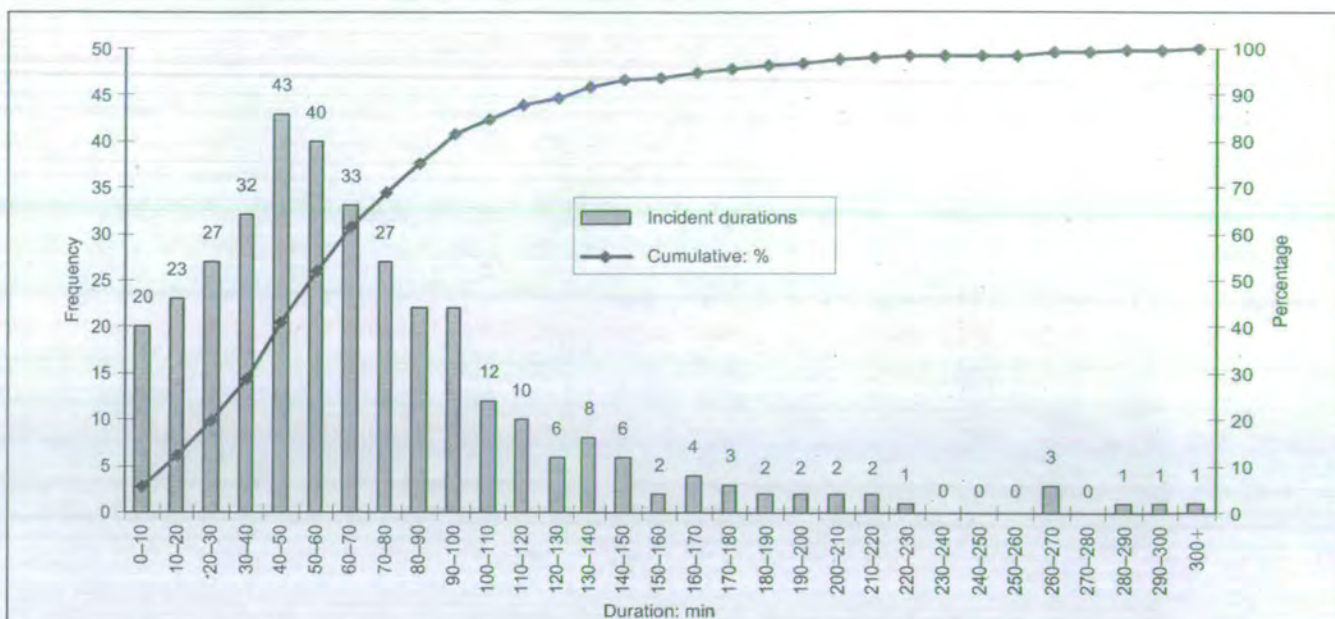


Fig. 7. Distribution of durations for all incidents

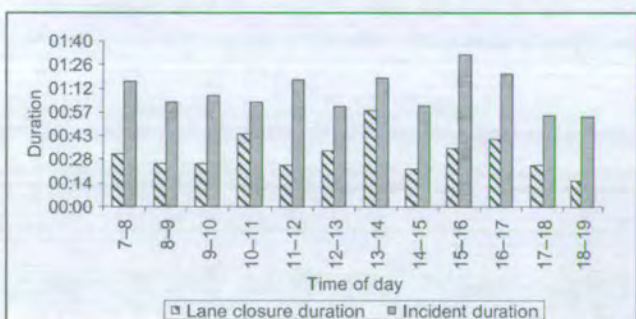


Fig. 8. Graph of average incident duration and lane closure duration throughout the day

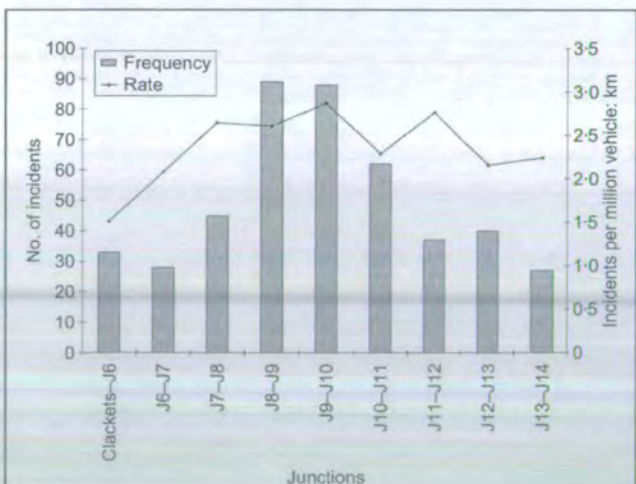


Fig. 9. Incident locations organised by junction

It can be seen that, for a straight count of incidents, the section between Junctions 8 and 9 has the highest occurrence of incidents. However, when incident rates are considered, the section between Junctions 9 and 10 has the highest rate of

incidents, at 2.87 incidents per million vehicle-km (4.63 incidents per million vehicle-miles). This information can be used to enhance the ISU programme, as the standby locations can be altered in relation to the spatial locations of incidents.

5.4. Incident Support Unit involvement

Incident support units were requested to attend 21.33% of all incidents during the study period. They attended 44% of all accidents, 5% of breakdowns and 63.41% of debris incidents. After being requested, the ISUs had an average response time of 12 min over 96 incidents. Further research will have to be conducted to fully understand the influence of ISUs on the M25 road network.

6. COMPARISON BETWEEN UK AND US INCIDENT DATA

Table 2 shows a comparison between this study's findings regarding incident characteristics and three other studies.^{1,7,8} It can be seen that there are few similarities between the studies.

Average incident duration varies by as much as 28 min between the M25 and Interstate 10. Durations in the UK are between double and triple those of the US. Does this imply that US incident management practices are better than UK practices?

Incident rates between Britain and the US are vastly different, with an average incident rate of 6.91 incidents per million vehicle-km from Britain compared with 92.8 in the US. This may be due to different driving styles, vehicles, vehicle regulations, driving distances, weather and many other factors such as incident recording. The difference between percentages of in-lane incidents appears to increase with more recent studies. Very minor incidents may not have been captured in this study, thus increasing the in-lane percentage. The percentages in this study and the Portland study⁸ are, however, both greater than in the two older studies in the comparison. The differences could be due to different traffic densities. The percentage of accidents could also be due to the age of the study—again, the two more recent studies have greater

Title of study	London M25	British motorways ¹	Los Angeles I-10 ⁷	Portland Metropolitan Area ⁸
Year of study	2003	1992/1993	1996	2001
Average incident duration: min	69	46	20.7	33
Incident rate: incidents per million vehicle-km	2.32	11.49	92.8	N/A
Percentage in-lane incidents: %	31.1	6	10.7	29.3
Percentage accidents: %	20.2	4.7	6.5	15
Percentage breakdowns: %	64.7	78.6	86.6	50

Table 2. Comparison of study results

percentages of accidents occurring. The lower accident percentages may also be due to the total number of incidents, as the studies with the higher incident rates have lower percentages. Again, the age of the studies may be the cause of the differences between studies, as more modern vehicles are less prone to breaking down. The differences between studies may also have been due to the method of detection of the incidents. This study recorded incidents reported to the police control room and through observations on CCTV, whereas Skabardonis *et al.*^{3,7} used probe vehicles, and Pal *et al.*,² Giuliano *et al.*,⁴ Jones *et al.*,⁵ Golob *et al.*⁶ and Bertini *et al.*⁸ used historical operational data.

7. APPLICATION OF FINDINGS AND FUTURE WORK

The results from this study will enable incident management programmes currently in operation on the M25 to be re-evaluated. In addition, there is now a base case for current operations, which will allow future improvements to be quantified.

The findings of this study will be used to investigate the impact of incidents on traffic flow and the associated delays. As accurate incident locations and on-scene activities have now been recorded they can be matched to archived traffic flow data. The effectiveness of motorway matrix lane control signals can also be evaluated. This study will also allow a better understanding of the influence of incident management strategies on the M25 to be achieved. In the short term, ISU staffing and vehicle standby locations can be optimised in order to increase the impact and influence of their service.

8. CONCLUSIONS

This paper has provided an overview of the characteristics of incidents on the south-western part of the M25 London orbital motorway for the period between 5 November and 11 December 2003. Incident frequency, durations and locations were examined, from which the following observations were made.

- (a) A total of 450 incidents were observed, giving an average frequency of 16.1 incidents per day or 2.32 incidents per million vehicle-km (3.74 incidents per million vehicle-miles) for the study area. The majority of recorded incidents, 64.7%, were breakdowns.
- (b) 69% of incidents blocked just the hard shoulder, and only 7.6% blocked two or more lanes.

- (c) Saturday had both a higher incident frequency and a higher incident rate than any other day of the week.
- (d) The highest occurrence of incidents and highest rate during the day were found to be between 11:00 and 12:00.
- (e) Emergency roadside telephones were the most frequent method of incident notification.
- (f) The average incident duration for the study period was found to be 1 h 9 min.
- (g) Approximately 50% of incidents lasted less than 60 min, and the average travel lane blockage was 32 min. The longest incident durations were recorded between 15:00 and 16:00, and the longest lane closure durations were between 13:00 and 14:00.
- (h) The majority of incidents occurred between Junctions 8 and 9, but the highest incident rate was between Junctions 9 and 10.
- (i) Incident Support Units attended 21.33% of all incidents and had an average response time of 12 min.
- (j) Incident characteristics between US and UK studies were compared and found to be different.

9. ACKNOWLEDGEMENTS

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