Monitoring of the M4 Bus Lane:
The First Year

Issue 2

by T R Rees, J K White & J I Quick

Confidential Report
PR/T/125/2000
T801

TRL Limited

PROJECT REPORT PR/T/125/2000

MONITORING OF THE M4 BUS LANE: THE FIRST YEAR ISSUE 2

by T R Rees, J K White & J I Quick (TRL Limited)

Prepared for:	**Project Record:**	**T801 (3/189): Monitoring of M4 Bus Lane**
	Client:	**TSS Division, Highways Agency (Mr S Beale)**

Approvals	
Project Manager	
Quality Reviewed	

This report has been produced by TRL Limited, as part of a Contract placed by the Highways Agency. Any views expressed are not necessarily those of the Highways Agency.

TRL is committed to optimising energy efficiency, reducing waste and promoting recycling and re-use. In support of these environmental goals, this report has been printed on recycled paper, comprising 100% post-consumer waste, manufactured using a TCF (totally chlorine free) process.

Distribution list:

Alan Mellors (30 copies)
Stuart Beale (6 copies)
Paul Harwood (6 copies)
David Pocknall (2 copies)
Roy Brunsden
Paul Ryder
John Poynton
Peter Gray (HETA) (2 copies)
Charles Evans (WSP)
Prof. Mike Macdonald
Prof. Richard Allsop
Prof. Peter Bonsall

CONTENTS

LIST OF FIGURES

MONITORING OF M4 BUS LANE: THE FIRST YEAR

EXECUTIVE SUMMARY

Introduction

The Highways Agency has installed approximately 6km of bus lane on the eastbound M4 between Junctions 3 and 2 into London. This bus lane is reserved exclusively for buses, coaches and taxis, and began operation on 7th June 1999. Its primary aim is to reduce the journey times of buses, coaches and taxis without significantly affecting other vehicles.

The bus lane scheme includes new road layouts at the start and end of the bus lane, and new lower speed limits of 50mph through Junctions 4 and 3, and 40mph approaching the start of the elevated section into London.

In order to assess the effect of the bus lane, traffic data was collected before the bus lane opened (during October and November 1998) and has been collected since the bus lane opened (from 7th June 1999). Data was collected from the M4 between Junctions 4B and 2 and also from the adjoining road network. This report summarises all aspects of the performance of the M4, the bus lane and the adjoining roads during the past year, and compares it to the performance before the bus lane opened, with particular reference to the eight-week period during October and November 1999 when data can be compared against the same period before the bus lane opened.

Principal results

- During peak periods, both buses and cars are benefiting from the bus lane scheme. On average, each bus is saving 3.5 minutes and each car is saving 1 minute during each peak period.

- During off-peak periods, journey times for both buses and cars have increased by 1 minute as a result of the lower speed limits along the section.

- On weekdays, the overall effect of the scheme on travel time is neutral. At weekends, there is less peak period congestion and so the delay caused by the lower speed limits exceeds the time saved during congested conditions, resulting in a calculated increase of 1250 person hours. Over the whole week, there has been an increase of 1.8% in the total time spent travelling on the section of the M4 affected by the bus lane scheme. This is equivalent to an extra 8 seconds on the journey time of each vehicle.

- Journey times for all vehicles have become more reliable following the introduction of the bus lane.

- During uncongested conditions, traffic noise levels and carbon dioxide emissions have been reduced, and fuel consumption has improved. There has been little change during congested conditions.

- Accidents are the subject of a longer-term study, but Police staff have perceived a decrease in the number of accidents attended since the lower speed limits were implemented.

- The flows on the M4 between Junctions 4 and 2, now that the bus lane is open, are similar to those before the bus lane opened. The benefits observed have therefore been achieved with similar flow levels.

- The introduction of the bus lane has changed the general traffic behaviour. Before the bus lane opened, a queue formed where the M4 narrowed from three lanes to two, with drivers queueing for up to ten minutes. Now that the bus lane is open, the queueing behaviour has been replaced by intermittent stop-start driving behaviour (shockwaves), with car drivers typically stopping briefly once or twice as they travel towards the elevated section, but otherwise travelling faster than before. It is this change in behaviour that enables both cars and buses to benefit from the bus lane scheme during peak periods.

- The benefits arising from the installation of the M4 bus lane are specific to this site. Prior to the bus lane scheme opening, there was a bottleneck where three lanes were reduced to two 1.5km before the elevated section, and an upstream junction (Junction 3) where one third of traffic left the motorway. This meant that the installation of the bus lane scheme enabled cars to benefit, as well as buses and taxis, as two lanes of traffic now flow continuously from Junction 3 onto the elevated section. If a similar scheme was installed at another location without these characteristics, it is unlikely that cars would benefit.

- The new road layouts at Junction 3, at the start of the bus lane and at the merge area are all working well. The dedicated exit slip road at Junction 3 has reduced the congestion at that point, and the design of the merge area at the end of the bus lane has smoothed the transition from three lanes to two prior to the elevated section.

- On some days, shockwaves propagate back from the elevated section, and cause congestion to the west of Junction 3. This is a result of only two lanes being available to cars and other vehicles to the east of Junction 3.

- The surrounding roads have not been affected by the bus lane scheme. Quicker journey times on the M4 mean that motorists should not need to divert, and there is no evidence that they are doing so.

- On average, about 3700 vehicles per day use the bus lane: 3100 are taxis, 500 are buses and 100 are minibuses. The number of vehicles using the bus lane has increased during the first year of operation. A typical peak hour flow comprises 250 taxis and 60 buses/minibuses.

- On average, 7% of the vehicles on the M4 into London use the bus lane, but they contain 21% of the people, including drivers.

Conclusions and recommendations

The bus lane scheme has met its primary aim set out before the scheme was installed: the scheme has resulted in time savings during peak periods for all types of vehicles. On average, each bus is saving 3.5 minutes and each car is saving 1 minute during each peak period.

The general public has a perception that not enough vehicles use the bus lane. The reasons for the restriction in numbers could be included in further publicity. The number of vehicles using the bus lane influences the benefits of the bus lane scheme. If too many vehicles were to use the bus lane, a bottleneck might reappear where the three lanes are reduced to two. Therefore, large numbers of other potentially eligible vehicle types should not be allowed to use the bus lane without careful study.

The benefits arising from the installation of the M4 bus lane are specific to this site. The design is specific to this location and cannot easily be transferred to other locations. However, the Highways Agency is gaining valuable operational experience that will be of assistance when considering similar schemes.

GLOSSARY OF TERMS

Accident	An incident resulting in damage or injury.
After	The period after 7th June 1999, when the bus lane was opened. This report covers "after" data collected up to the end of May 2000.
Before	The period from 11th October to 4th December 1998, when data was collected during a pre-bus lane monitoring period.
Bus	Within this report, any reference to buses also includes coaches and minibuses.
Car	Within this report, any reference to journey times for cars also includes other non-priority vehicles.
Congestion	For the purposes of this report, defined as traffic speeds dropping below 25mph for 10 minutes or more.
Demand flow	The number of vehicles that desire to travel on a particular section of road at a particular time.
EMS	Enhanced Message Sign: a sign that displays variable text messages, mounted on a cantilever post or gantry.
GPS	Global Positioning System: a positioning device for vehicles using geographical information from satellites.
Heston	A district near the M4, where one of the Police control centres is situated.
Inter-peak period	The period 09:30 – 17:30.
LAAU	London Accident Analysis Unit
Lane 1	The nearside lane – closest to the hard shoulder.
Lane 2	The middle lane.
Lane 3	The offside lane – closest to the central reservation.
MIDAS	Motorway Incident Detection and Automatic Signalling system, consisting of loop detectors connected to outstations, in turn connected to control centres, one of which is at Heston.
Minibus	A vehicle with ten or more seats, and less than 10m in length.
Motorcycle	A mechanically propelled vehicle with fewer than 4 wheels, of which the weight unladen does not exceed 410kg.

MS2	A type of EMS: a sign that displays variable text messages and advisory speed limits.
MTV	Motorway Traffic Viewer: a suite of graphical analysis programs developed for the Highways Agency by TRL.
Queue	For the purposes of this report, defined as a behavioural characteristic of traffic where traffic moves at below 10mph for at least ten minutes.
Peak period	The time of day for which traffic flow is high: the morning peak period is between 06:30 and 09:30 and the evening peak period is between 17:30 and 20:30.
Person-hour	An economic measure of performance of a section of road. One person-hour is equivalent to a time saving of one minute each for sixty people.
Platoon	A group of vehicles travelling closely together.
Reliability	The reliability of journey times is measured by the variability (standard deviation) of the journey times.
Rogue vehicle	An unauthorised vehicle in the bus lane: not a bus, coach or taxi.
Shockwave	Traffic passing through a shockwave undergoes a sudden drop in speed followed shortly by an increase in speed, so vehicles experience intermittent stop-start conditions. The amount of time for which the speed drops increases as the shockwave spreads upstream through dense traffic.
Stop-start	Driving conditions in which some vehicles temporarily come to a halt or move at a very low speed and then speed up again (eg while passing through a shockwave).
Swooping	A characteristic of driver behaviour where a driver who wants to leave the motorway at the next junction travels in lane 2 until the junction, then moves across lane 1 onto the slip road.
Taxi	A licensed Hackney Carriage.
Throughput	The amount of traffic passing through a given road section in a certain period of time.

MONITORING OF M4 BUS LANE: THE FIRST YEAR

1. INTRODUCTION

The Highways Agency has installed approximately 6km of bus lane on the eastbound M4 between Junctions 3 and 2 into London to encourage the use of public transport. The objectives of the bus lane scheme are:

- to reduce the journey times of buses, coaches and taxis;
- to increase the number of bus and coach seats used, and also the number available to rush hour commuters into London;
- to ensure there is no significant delay for other vehicles;
- to improve safety on the eastbound M4 into London.

To determine whether the objectives have been met and whether any undesirable side effects have been produced, traffic conditions before and after the opening of the bus lane have been compared.

Traffic data, comprising speeds and flows, have been collected from the eastbound M4 into London from west of Junction 4 (the Heathrow junction) to the start of the elevated section (leading to Junction 2). Traffic data from the M4 and the adjoining road network was collected over a period of eight weeks from 11th October 1998 to 4th December 1998. Similar data has also been collected since the bus lane opened on Monday 7th June 1999. This report summarises the performance of the first year of operation of the bus lane, with particular reference to the eight-week period during October and November 1999 when data can be compared against the same period before the bus lane opened.

The performance of the M4 between Junctions 4 and 2 has been measured by examining the traffic behaviour during each peak period, estimating journey times throughout each day, and measuring the flows along the section. The journey times for both buses and cars once the bus lane was operational have been compared against the journey times before the bus lane was open to determine the effect of the scheme on all types of traffic.

The analysis of the effects of the bus lane has been performed in two ways. Typical days (days without incidents) have been compared to determine the effect of the bus lane on an average day. The random effect of incidents is therefore excluded. An analysis of all weekdays has also been carried out to account for the effect of incidents.

Other aspects of traffic behaviour and composition have also been analysed to determine whether the bus lane scheme has been effective. These include compliance with speed limits, an analysis of bus lane usage, and an estimate of the occupancy of coaches, taxis and cars. An assessment of the environmental impact of the bus lane scheme has also been carried out.

Most of this report deals with traffic conditions on weekdays, as these are the days with the highest flows and the worst congestion. Weekends have been analysed separately, as traffic patterns are different to weekdays.

1.1 DOCUMENT OVERVIEW

This report is composed as follows:

- Section 2 presents the bus lane scheme. It describes the original road layout of the M4 and the new road layout to accommodate the bus lane.
- Characteristics of the traffic on the M4 are reported in Section 3, which also considers how traffic behaviour has changed now the bus lane is in operation.
- Section 4 describes the journey times calculated for vehicles using the M4 eastbound between Junctions 4 and 2. The journey times and the reliability of these journey times give a good indication of the performance of the M4.
- Section 5 describes the design of the bus lane and the behaviour of traffic using it. In addition, it describes how the traffic further upstream (to the west of Junction 3) has been affected by the introduction of the bus lane scheme.
- Section 6 describes the number of vehicles using the bus lane, plus the composition of traffic using the bus lane.
- Section 7 describes the traffic flows on the M4, to determine the effect of the bus lane on flow patterns, and to put the performance of the M4 into context.
- The traffic conditions on the adjoining network (A312 and A4) are discussed in Section 8.
- Compliance with the speed limits on the M4, both before and after the bus lane opened, is described in Section 9.
- The number of people in each type of vehicle is analysed in Section 10.
- Feedback on the bus lane scheme, in the form of a publicity review and analysis of a bus and coach company survey is described in Section 11.
- The environmental impact of the bus lane scheme is assessed in Section 12.
- The subject of incidents on the M4 is briefly discussed in Section 13.
- Section 14 presents the conclusions of the report.

- Annex A describes in detail the traffic data used to analyse the performance of the bus lane, and how it was collected.

- Annex B describes the algorithm for calculating journey times through the bus lane section. It also describes the method of validating the results, and discusses the errors involved.

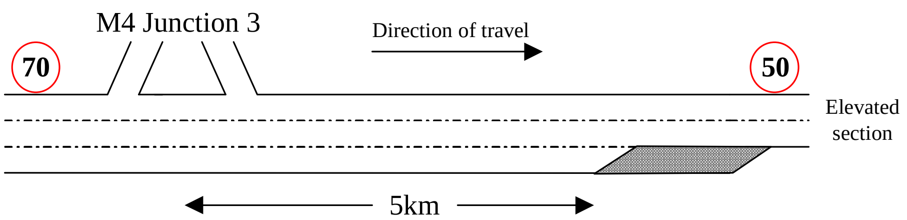
- Annex C describes the method used to calculate person-hours delay, which is used to estimate the benefits arising from changes in journey times.

The tables in this report have been included within the text; most of the illustrative figures have been collated at the end of the text.

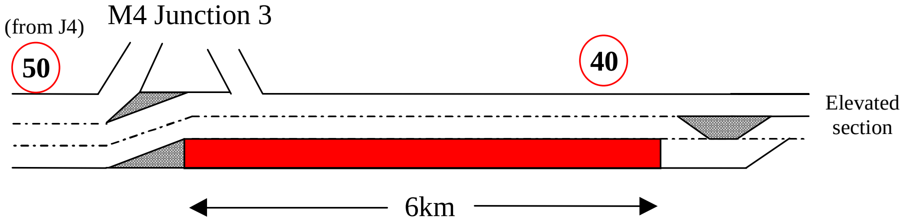
2. DESCRIPTION OF BUS LANE SCHEME

The eastbound M4 between Junctions 3 and 2 originally had three running lanes, reducing to two lanes just before the elevated section into London. The bus lane was realised by converting the offside lane of the 3-lane section into a lane reserved exclusively for buses, coaches and taxis (see Figures 1 and 2 (b)).

Figure 1 – The M4 bus lane



(a) Before the bus lane was installed (speed limits shown)



(b) Bus lane (in red) in operation (speed limits shown)

Figure 2 – The M4 road layout before (a) and after (b) the bus lane was installed

Figure 2(a) shows the M4 road layout before the bus lane was installed. Figures 2(b) and 3 show a schematic representation of the layout of the M4 once the bus lane was opened. Figure 3 (at the back of the report) shows the section of the eastbound M4 from Junction 4B (the junction with the M25) to the start of the elevated section. The original features that were present before the installation of the bus lane were as shown in Figure 2(a):

- There was no dedicated exit lane at Junction 3. There were three lanes of traffic through Junction 3.

- The motorway narrowed from three lanes to two lanes 1.5km before the start of the elevated section, with the offside lane merging into the middle lane.

- The national speed limit applied along the whole section, with a 50mph limit on the elevated section leading to Junction 2.

The bus lane scheme comprises four elements:

- 5.8km of bus lane, with a road surface coloured red and separated from the other two lanes by a solid white line – see the photograph on the previous page (Figure 1).

- A new road layout at Junction 3, before the start of the bus lane. The nearside lane is a dedicated exit slip, and traffic is reduced to two lanes through Junction 3.

- A new road layout at the end of the bus lane, 0.5km before the start of the elevated section. The road has been widened and the middle lane merges with the bus lane using a 200m taper.

- A new lower speed limit imposed for safety reasons. There is a 50mph speed limit from Junction 4 to just before the end of the bus lane, and a 40mph limit at the merge area at the end of the bus lane and onto the elevated section.

In addition, four Enhanced Message Sign (MS2) gantries have been installed by the side of the carriageway between Junction 3 and the start of the elevated section, and an additional CCTV camera has been installed to provide coverage of the whole section.

Within this report, sites along the M4 have been referenced in the text and figures either by marker post locations (eg 15/6 or 15.6, see Figure 3) or by the equivalent carriageway designations (eg 2156B).

3. TRAFFIC BEHAVIOUR

This section describes the general traffic behaviour between Junction 4B and the start of the elevated section, before and after the bus lane opened, and explains the reasons for the change in behaviour. Section 5 provides a more detailed description of the traffic behaviour at various points along the section of the M4 being monitored.

3.1 MTV PLOTS

The daily performance of the eastbound M4 has been graphically represented using the Motorway Traffic Viewer (MTV) suite. The data collected from the M4 (see Annex A) has been processed to create speeds and flows for each minute for each lane. The speed data is shown on Lane Speed plots (see Figures 4 to 7). These plots enable traffic conditions for each day to be viewed along the whole length of the carriageway. The text at the top of each plot specifies the day, plus any conditions which may affect the performance of the motorway (eg accidents, poor weather or bank holidays). The horizontal axis gives time, and the vertical axis is location. The right-hand axis gives the loop numbers (referenced to the nearest marker post) (see Figure 3) and the left-hand axis gives the locations of the diverge and merge for each junction. The direction of vehicle travel is down the page. Lane 3 (the offside lane) is shown at the top of the page and lane 1 (the nearside lane) at the bottom. (Lane 4 at MP 26/4 is not shown.)

The plots represent the average speeds for each minute for each lane as coloured blocks, enabling regions of low speed to be easily identified. Slow traffic is shown as red (0-10mph), orange (10-20mph) and yellow (20-30mph). Uncongested free-flowing conditions are shown as blue (60mph+). Any missing data or periods when there was no traffic in the lane during the minute are shown as grey.

3.2 TYPICAL TRAFFIC BEHAVIOUR BEFORE THE BUS LANE OPENED

Figures 4 and 5 show 4-hour plots for typical morning and evening periods respectively during 1998. These periods have been selected so that all regular congestion is included on the plots. The morning period is from 6:00 to 10:00; the evening period is from 17:00 to 21:00.

These plots show that in congested conditions, the speeds in each lane were similar. Between Junction 3 and the start of the 2-lane section, there were generally two traffic states: traffic either travelled at over 50mph or at under 20mph, with the changeover between the states occurring within 5 minutes. Within the area of slow-moving traffic, there were some areas of queueing resulting in shockwaves that propagate upstream. However, the shockwaves were not as pronounced as those observed on other motorways (especially the M25). The bottleneck created by the reduction of three lanes to two caused a well-defined area of congestion.

There was queueing back from site 17/2, where the 3-lane section merges into two. The section between site 17/2 and the elevated section, although slow moving (less than 40mph), did not suffer queueing. (No data is shown for lane 3 after 17/2, as this was a 2-

lane section.) On the elevated section (site 15/6), where there was a 50mph speed limit, traffic speeds were below 50mph throughout the day. In both the morning and the afternoon, slow moving traffic reached as far upstream as site 19/7 (a queue of 2.5km).

There were separate areas of congestion caused by the merges and diverges at the junctions further upstream. The congestion caused by the diverge at Junction 3 was generally in lane 1, where queueing back from the roundabout and "swooping" caused slow moving traffic between Junctions 4 and 3 (at sites 22/7 and 23/2). Lanes 2 and 3 were less affected as they were being used by through traffic. In the evening peak period (see Figure 5), the congestion was worst at Junction 4.

During most peak periods, a queue formed in all three lanes at the bottleneck where three lanes reduced to two (at site 17/2), and tailed back upstream towards Junction 3. In the morning, a queue formed on around 90% of peak periods, and did not often tail back beyond site 20/5 (a queue of 3.3km). In the evening, a queue formed on around 80% of peak periods, and did not often tail back beyond site 19/3 (a queue of 2km). The queue reached Junction 3 on one evening only (and no mornings) during the eight weeks of the "before" period.

3.3 TYPICAL TRAFFIC BEHAVIOUR AFTER THE BUS LANE OPENED

Figures 6 and 7 show the speeds in each lane for a typical morning and evening peak period after the opening of the bus lane. The queueing behaviour in the two lanes available for use by any vehicle (lanes 1 and 2) is different to that observed during the "before" period (see Figures 4 and 5). The solid area of congestion has been replaced by shockwaves of slow moving traffic, indicated by areas of red, orange and yellow moving from bottom left to top right. These shockwaves propagate back from the merge area at the end of the bus lane (between sites 16/2 and 15/6). The shockwaves extend back to Junction 3, and occasionally extend back to join a separate area of congestion at the Junction 4 merge. The time between shockwaves is irregular, but is on average 15 minutes.

From a car driver's perspective, 3km of queueing has been replaced by 6km of intermittent stop-start driving. Speeds vary from 0mph to 50mph during the stop-start conditions, with drivers typically stopping briefly once or twice as they pass through the section being monitored. The times of congestion during the peak periods are similar before and after the bus lane opened.

Figure 8 shows car speeds (see Annex B) for two typical journeys along the M4 between Junction 4 and the start of the elevated section, starting at 7:00 on a November weekday. One journey is from 1998 (before the bus lane opened), the other is from 1999 (with the bus lane open). The speeds are the average speeds of the car for each minute; at low speeds, it is likely that the car comes to a halt for a short period. (This is not shown due to the coarseness of the data.) There are differences in the journeys:

- Before the bus lane opened, the car travelled at over 50mph until it reached the back of the queue, just after Heston Services. It then stayed in the queue, travelling at below 20mph onto the elevated section.

- With the bus lane open, the car travelled more slowly until Junction 3, where it encountered the first shockwave. Once the car passed through the shockwave, it then proceeded onto the elevated section without any further serious delays.

- Each car slows down earlier now that the bus lane is open, creating the impression that the bus lane scheme has made the congestion worse. However, the fact that there is no longer a queue where the three lanes reduced to two means that cars are benefiting during congestion as a result of the scheme. In Figure 8, the journey after the bus lane opened was 47 seconds quicker than the "before" journey.

Traffic in the bus lane is always free-flowing, unless there is a major incident between Junction 3 and the start of the elevated section. The only congestion experienced by buses is between Junctions 4B and 3, prior to the bus lane.

Because there is no longer queueing behaviour, a direct comparison of queue lengths with the "before" period is not possible. Instead, a comparison of speeds at two locations has been carried out.

Figures 9 and 10 show the speed profiles of traffic at two locations, at Junction 3 and halfway between Junction 3 and Junction 2 on the M4. This data is shown for the first Monday in November for 1998 and 1999, for lane 1. The speeds shown in Figure 9 are for all vehicle types; Figure 10 shows the speeds for all vehicles during the pre-bus lane monitoring period, and for cars and HGVs for the period since the bus lane opened.

These speed profiles are for the same days shown in Figures 4 to 7. During the pre-bus lane monitoring period (Figures 4 and 5), a queue formed where three lanes reduced to two lanes. This queue extended back for 2.5km but did not go as far as Junction 3. Therefore, traffic travelling through Junction 3 did not encounter any congestion so its speed remained approximately constant (see Figure 9). However, the traffic experienced a sharp fall in speed during both the morning and evening peak periods further downstream (see Figure 10). During the peak periods, the speed fluctuated by small amounts, demonstrating queueing behaviour.

After the bus lane opened (Figures 6 and 7), shockwaves occurred affecting traffic at both locations. The traffic speeds show different behaviour to those during the pre-bus lane monitoring period, with the speed dropping sharply for short periods during the morning peaks at both locations as the traffic encountered the shockwaves. The speeds remain higher than those observed in the queues during the "before" period. The fluctuations in the speeds are larger as a result of the shockwaves.

During off-peak periods, the speeds were lower in 1999 than they were in 1998, as a result of the new 50mph speed limits in place at both locations.

3.4 REASONS FOR CHANGE IN BEHAVIOUR

Before the bus lane opened, three lanes were available to traffic until 1.5km before the elevated section. There was a bottleneck where the M4 narrowed from three lanes to two, frequently causing long queues of slow moving traffic. Approximately one third of traffic left at Junction 3, leaving lane 1 under-utilised through Junction 3. Because lane 1 contained very few vehicles, the traffic was effectively in two lanes at that point. Relatively few vehicles (14%) joined at Junction 3. The bus lane scheme removes the bottleneck because it causes the majority of traffic passing through Junction 3 to stay in two lanes up to and over the elevated section. The loss of one lane through Junction 3 has not caused any severe additional queueing.

Following the elimination of the bottleneck, the main causes of congestion on the eastbound M4 are shockwaves of slow moving traffic propagating back from the elevated section. When traffic slows down on the elevated section for any reason during a period of high flow, a shockwave is started. These shockwaves were also present before the bus lane opened, but were absorbed in the general queueing at the bottleneck.

4. JOURNEY TIMES

Journey times are an important indicator of the performance of the M4, as they measure what drivers experience as they drive through the section, and they contribute to an estimate of the economic effect of the bus lane scheme. Benefits can be achieved by a reduction in the journey time, and also by making the journey time more reliable, so that drivers can better predict how long their journeys will take.

Journey times have been calculated for the section of carriageway between Junction 4 and the start of the elevated section (a distance of 8.4 km) by tracking the progress of typical vehicles through the section. The journey time reliability has also been analysed. Annex B describes the algorithm for calculating journey times. It also describes the method of validating the results, and discusses the errors involved.

Before the bus lane was opened, journey times for typical vehicles were calculated by averaging the journey times in each of the lanes. All vehicle types (eg cars and buses) had similar journey times in congested conditions. After the bus lane was opened, journey times for priority vehicles (buses and taxis) and non-priority vehicles (eg cars) were calculated separately. Buses were assumed to travel in the bus lane. Journey times for cars were calculated by averaging the journey times in each of the available lanes. Taxis were assumed to travel at the quicker of the car and bus journey times: within this report, all references to bus journey times during congested conditions also apply to taxis.

This section describes the journey times for all vehicles during the "before" period, and for cars and buses since the bus lane has opened, with particular reference to October and November 1999, which is the corresponding time of year to the "before" period.

The journey time analysis has been divided into peak and off-peak periods. The peak periods have been selected to be the periods with the greatest congestion. To try to ensure that all regular congestion is included, and that the analysis of peak periods only covers times when congestion is likely to be present, each of the peak periods is three hours long. The morning peak period is from 6:30 to 9:30; the evening peak period is from 17:30 to 20:30.

4.1 THE EFFECT OF INCIDENTS ON JOURNEY TIMES

The success of the bus lane scheme is determined by comparing the performance of the M4 before and after the bus lane opened. When an incident occurs, it can cause a random variation in the normal traffic behaviour and, in particular, it can cause a large increase in journey times. Incidents can be assumed to occur randomly.

The performance comparisons can cover all days (ie including incidents), or they can only deal with typical days (ie excluding incidents). Both methods of comparison have been used to monitor the M4, and the particular method used at each stage has been made clear in this report.

Most of the journey time comparisons deal with typical days (ie excluding incidents). The most appropriate method to use varies according to the information required and the time period over which the data is being analysed:

- When dealing with short time periods (eg one week), typical days (excluding incidents) are used for comparison. This is because the inclusion of any days on which there was an incident would have an undue effect and would distort the results.

- To identify small differences in the traffic behaviour, typical days are analysed because the inclusion of incidents in the analysis would swamp the small differences. This also applies to the analysis of journey time reliability.

An analysis of all days (including incidents) is performed for two scenarios:

- By analysing all days, the effect of incidents can be included. It is possible that the installation of the bus lane has caused the overall incident rate to change (eg by making the road safer/more dangerous) or affected the traffic delay due to the severity of accidents. Including all days enables any effect to be included in the analysis.

- When comparing long periods (eg the 8-week "before" and "after" periods), the effect of individual incidents will not be as great as for short periods, and the distribution of incidents is likely to be similar. Therefore, for long periods of comparison, all days (including incidents) are used.

4.2 JOURNEY TIME PROFILES

Figure 11 shows the average journey times throughout each day of the week before the bus lane was opened (excluding days with incidents). This shows that:

- The average journey time during free-flow conditions (eg at midnight) was 4.7 minutes, representing an average speed of 67mph.

- The congestion started at the same time (about 6:30) every weekday morning, as indicated by journey times rising from 5 minutes to 15 minutes (17 minutes on a Monday morning).

- The congestion generally cleared by 9:15 (9:45 on a Monday morning).

- During the midday inter-peak period, the journey time varied between 5 and 7 minutes.

- Congestion during the evening generally lasted from 17:30 until 20:15, with journey times again rising to 15 minutes.

- On Friday evenings, the congestion built up quicker and the maximum journey times were greater.

- On Sunday evenings, the congested period was longer, but the journey times were lower.

Figures 12 and 13 show the average journey times for the corresponding period during 1999, after the bus lane was opened. Figure 12 shows the journey times for cars; Figure 13 shows the journey times for buses (and taxis). These show the following results (with the differences from the "before" period in brackets):

- The average journey time during free-flow conditions is now 5.6 minutes (an increase of 0.9 minutes), representing an average speed of 56mph (a drop of 11mph). This is a consequence of the lower speed limits along the section.

- The congestion during the morning peak period starts at the same time and clears slightly later. The time that the congestion clears is more variable than during 1998; on some days, the congestion does not clear until after 10:00 (45 minutes later). The congestion during the evening peak period starts and finishes at similar times to 1998.

- The maximum journey times for cars are lower: about 14 minutes during the morning (a drop of 1 minute) and 13 minutes during the evening (a drop of 2 minutes).

- Buses suffer little congestion, with maximum journey times of under 10 minutes (a drop of 5 minutes). There is no congestion on the bus lane itself; buses are, however, delayed by congestion before the start of the bus lane (see Section 5.4).

- Before the bus lane was installed, there was congestion during Sunday lunchtimes. This congestion does not generally occur now that the bus lane is open.

Figure 14 shows a summary profile for typical weekdays (excluding incidents), comparing the "before" period against the corresponding period during 1999. Figure 15 shows a similar profile, but including weekdays with incidents. These show that:

- During the morning peak period, cars are saving up to 4 minutes and buses are saving up to 8 minutes.

- During the evening peak period, there are also savings, but they are smaller, with cars saving up to 1 minute and buses saving up to 5 minutes.

- Journey times for cars are longer on some days between 9:00 and 11:00. Congestion in the morning often takes longer to clear now that the bus lane is open. When the bus lane opened, the traffic behaviour changed from queueing to shockwaves, and this has made the traffic more susceptible to poor weather. Rain causes traffic within shockwaves to leave larger headways, which results in the congestion lasting longer. The effect of rain on queueing traffic is not as great.

- There is no major difference in the results between comparing typical days and days with incidents over a long period.

4.3 COMPARISON OF JOURNEY TIMES

Table 1 compares typical weekday journey times during October and November 1998 (before the bus lane opened) with the average journey times for cars and buses, both for the summer of 1999 (just after the bus lane opened) and for the corresponding 8-week period during October and November 1999. Days with incidents have been excluded from this table. Values in green indicate that the performance is better now that the bus lane is open, and values in red show that the performance is worse than before.

Table 1 – Typical journey times (excluding incidents)

Time of day (weekday)	Percentage of daily flow	Journey time (minutes)				
		"Before"	"After"			
		Average for Oct/Nov 1998	Average for June-September 1999		Average for October-November 1999	
		Car & Bus	Car	Bus	Car	Bus
0630-0930	19%	10.1	8.1	6.8	9.4	7.2
0930-1730	45%	5.1	5.9	6.1	6.1	6.1
1730-2030	19%	9.9	7.5	6.7	9.2	7.2
2030-0630	17%	4.7	5.7	5.9	5.8	5.9

During the peak periods (when 38% of the traffic travels), both cars and buses are saving time now that the bus lane is open. During off-peak periods, vehicles are taking longer due to the introduction of the new speed limits.

Comparing the before and after average journey times for October and November, buses are reaching the elevated section 2.9 minutes quicker than before during the morning peak period, and 2.7 minutes quicker during the evening peak period. Cars are saving 0.7 minutes during the both the morning and evening peak periods. Journey times during the summer months of 1999 were lower than during October/November 1999, due to a variety of reasons; for example, better weather and lighting conditions and peak spreading effects. A direct estimate of the savings is not possible, as there is no data for the summer of 1998.

Table 2 compares the average weekday journey times for all days (including those with incidents).

Table 2 – Average journey times (including incidents)

Time of day (weekday)	Percentage of daily flow	Journey time (minutes)				
		"Before"	"After"			
		Average for Oct/Nov 1998	Average for June-September 1999		Average for October-November 1999	
		Car & Bus	Car	Bus	Car	Bus
0630-0930	19%	11.5	9.0	7.0	10.2	7.4
0930-1730	45%	5.4	6.2	6.1	6.4	6.1
1730-2030	19%	10.2	8.6	7.0	9.6	7.3
2030-0630	17%	4.7	6.1	6.1	5.9	5.9

The time savings are broadly comparable with those in Table 1. During October and November, buses are reaching the elevated section 4.1 minutes quicker on average than before, during the morning peak period, and 2.9 minutes quicker during the evening peak period. These savings are greater than those for typical days because the buses obtain an additional benefit from the bus lane when an incident occurs, as they can avoid the congestion between Junction 3 and the start of the elevated section.

Cars are saving on average 1.3 minutes in the morning peak and 0.6 minutes in the evening peak. Journey times for both cars and buses during the summer months of 1999 were again lower than during October/November 1999.

4.4 JOURNEY TIME BY JUNCTION-TO-JUNCTION SECTION

Sections 4.2 and 4.3 describe journey times for through traffic, ie traffic travelling from Junction 4 onto the elevated section and into Central London. To fully examine the effect of the bus lane scheme on journey times, the journey times of traffic leaving and joining the M4 at Junction 3 have been calculated.

Journey times to the west of Junction 3 have been analysed where possible. Between Junctions 4B and 4, there is only one loop site (at site 26/4) measuring the average speed across all lanes over 5-minute periods. Because of this, sensible estimates of journey times cannot be calculated west of Junction 4.

Figure 16 shows a comparison of the average weekday journey times from Junction 4 to Junction 3 for all vehicles, for the week beginning 31st October 1998 (during the pre-bus lane monitoring period) and the week beginning 1st November 1999 (since the bus lane opened).

The journey times between Junction 4 and Junction 3 are worse now that the bus lane has opened. During the morning and evening peak periods, shockwaves propagate back from the elevated section/merge area, causing increases in journey times and also a greater variability.

During the morning peak period, the average journey time between Junction 4 and Junction 3 has increased from 0.9 minute before the bus lane opened, to 1.3 minutes since the bus lane opened. During the evening peak period, journey times between Junction 4 and Junction 3 have risen from 1.4 minutes to 1.5 minutes.

Although all vehicles are losing time between Junctions 4 and 3, cars are saving time in each peak period over the whole section between Junctions 4 and 2. Therefore, the benefit from the bus lane scheme for cars joining at Junction 3 is correspondingly greater (by 0.4 minute during the morning peak, and by 0.1 minute during the evening peak).

Due to the 50mph speed limit imposed now that the bus lane is in operation, journey times between Junctions 4 and 3 during off-peak periods are 0.1 minute longer than during the pre-bus lane monitoring period.

4.5 JOURNEY TIME RELIABILITY

Reliability of journey times is important as it enables drivers and passengers to predict their arrival times. This is especially important for bus companies, who are running scheduled services to a timetable. The main measure of reliability is the day to day reliability, which shows how well drivers will be able to predict their arrival times if they leave at the same time each day.

4.5.1 Day to day reliability

Figure 17 shows the variability (ie standard deviation) of the journey times for typical weekdays (excluding incidents), comparing the "before" period against the corresponding period during 1999. Figure 18 shows a similar profile, but including weekdays with incidents. A low variability indicates greater reliability. These show that:

- The journey time reliability for buses has improved throughout the day since the bus lane opened.
- The journey times for all vehicles are very reliable before 7:00, as suggested in Figures 11 to 13. Drivers arriving at the same time each day should be able to predict their journey time over this stretch of road to within a minute (provided there are no incidents).
- The journey time reliability for cars is unchanged between 7:00 and 9:00.
- The reliability for cars has become worse between 9:00 and 12:00, as the time that the congestion clears is now more variable.
- The poor reliability in the evenings before the bus lane opened indicates that, although the congestion was less than in the mornings, it was less predictable. Once the bus lane opened, the reliability improved, indicating that car journey times during the evening peak are more predictable than they used to be.
- The inclusion of incidents results in a large increase in variability (see Figure 18), as journey times can be very large if an incident occurs, and the extent of the delay depends on the details of the incident. However, now that the bus lane is open, bus journey times are reliable even when an incident occurs.

4.5.2 Within day reliability

Another measure of journey time reliability is the reliability within a day. This shows how well drivers will be able to predict their journey time if they vary their departure time by up to an hour on a particular day. Table 3 shows the variability (one standard deviation) of these journey times for typical weekdays. Values in green indicate that the variability is smaller now that the bus lane is open and values in yellow show that there has been little or no change (0.1 minute or less).

Table 3 – Journey time reliability by time period (typical weekdays)

Time period (weekday)	Percentage of daily flow	Variability (minutes)		
		"Before"	"After"	
		Car & Bus	Car	Bus
0630-0730	7%	3.4	2.5	1.2
0730-0830	6%	2.2	1.5	0.7
0830-0930	6%	1.7	1.2	0.4
0930-1630	38%	0.6	0.7	0.4
1630-1730	6%	0.6	0.5	0.3
1730-1830	7%	1.9	1.4	0.7
1830-1930	7%	2.0	1.8	0.9
1930-2030	6%	2.2	1.2	0.5
2030-0630	17%	0.3	0.3	0.4

Table 3 shows how much the congestion varied within each time period:

- The reliability for cars has improved throughout each peak period since the bus lane opened. The intermittent stop-start traffic behaviour results in a more reliable journey time than the queueing behaviour, as each driver stops once or twice within the section, instead of joining the back of a queue of varying length.

- The reliability for buses has improved throughout the day since the bus lane opened.

4.6 JOURNEY TIME TRENDS

To compare journey times, the weekly trends have been examined. This enabled seasonal trends to be identified, and allowed a year-to-year comparison.

Figure 19 shows the average weekly journey times for days without incidents for cars and buses, comparing the data obtained for each of the weeks since the bus lane opened to that obtained during the pre-bus lane monitoring period, October 1998 to November 1998. The journey times shown are the averages of the journey times during the morning and evening peak periods for each week. Journey times since the bus lane opened are shown as blue and red lines for cars and buses respectively. The green lines represent the journey times during the pre-bus lane monitoring period.

Bus journey times are now consistently lower and more reliable than they were for the corresponding weeks in 1998. In general, cars are also benefiting during peak periods.

Figure 19 also shows the seasonal variation in journey times. The congestion is lower during August then becomes steadily worse leading up to Christmas. The level of congestion is more consistent between January and June. A similar seasonal pattern of congestion has been observed on other motorways (eg the M25).

Table 4 shows the average journey time in each peak period, by the day of the week, for days without incidents (as shown in Figures 11 to 13). Values in green indicate that journey times are lower now that the bus lane is open and values in red indicate that journey times are worse. Before the bus lane opened, there was a consistent trend throughout the week. In the mornings, Mondays had the worst congestion and Fridays had the least. In the evenings, Mondays were the least congested and congestion on Fridays was much worse than other peak periods.

Now that the bus lane is open, the daily trend is less pronounced. In the mornings, the journey times are similar on all weekdays except for Friday mornings, where journey times are lower. In the evenings, all journey times are similar. The biggest percentage improvement in journey times, for both cars and buses, occurs for Friday evenings (23% and 42% improvement respectively).

Table 4 – Journey times by day of week

Day of week	Average journey time (AM peak) (min)			Average journey time (PM peak) (min)		
	"Before"	"After"		"Before"	"After"	
	Car & Bus	Car	Bus	Car & Bus	Car	Bus
Sunday	4.7	5.6	5.9	8.3	8.8	6.9
Monday	11.8	10.1	7.4	7.5	8.0	6.8
Tuesday	10.2	9.9	7.4	8.2	9.2	7.3
Wednesday	10.4	10.2	7.5	10.7	10.0	7.6
Thursday	9.9	10.0	7.4	10.5	8.9	7.0
Friday	8.3	7.2	6.5	12.8	9.9	7.4

The introduction of the bus lane has had the greatest beneficial effect during the busiest peak periods, ie Monday mornings and Friday evenings. These peak periods now have the same pattern of congestion as other days. The journey times during some of the quieter peak periods (Thursday morning and Sunday to Tuesday evenings) have become slightly worse, as the effect of the lower speed limits is greater when there is less congestion.

Before the bus lane was installed, there was congestion during Saturday and Sunday lunchtimes. This congestion has been reduced now that the bus lane is open; weekend lunchtimes are now generally uncongested.

4.7 PERSON-HOURS DELAY

An estimate of the time savings per week as a result of the bus lane scheme has been made (Annex C describes the calculation of person-hours delay). On weekdays, around 540 person-hours are saved during the morning peak period and 300 person-hours are saved during the evening peak period. Therefore, the bus lane scheme results in 840 hours being saved every weekday. The introduction of the 50mph/40mph speed limits has resulted in an extra 560 hours of delay during the midday inter-peak period, and an extra 270 hours of delay during the late evening and early morning. The benefits and disbenefits cancel each other out, so that the overall effect of the scheme on weekdays is neutral.

On Sundays, there is less congestion than on weekdays, so the delay caused by the lower speed limits exceeds the time saved during congested conditions. Overall, there is a disbenefit of 600 person-hours each Sunday as a result of the bus lane scheme.

The effect of the scheme on Saturdays has been estimated using data from Traffic*master* infrared sensors, which provide information on slow speeds at various locations. There was midday congestion at the bottleneck on four of the eight Saturdays during October/November 1998, before the bus lane opened. During October/November 1999, with the bus lane operational, there was no Saturday congestion. As on Sundays, the delay caused by the lower speed limits exceeds the time saved during congested conditions. Overall, there is an estimated disbenefit of 660 person-hours each Saturday as a result of the bus lane scheme.

Therefore, there is an increase in delay of 1250 person-hours per week as a result of the bus lane scheme. This is an increase of 1.8% on the total time spent travelling on the section of the M4 affected by the scheme, and is equivalent to an extra 8 seconds on the journey time of each vehicle.

4.8 CONCLUSIONS

Congestion occurs on the eastbound M4 into London during the morning and evening peak periods. There is little congestion outside these times. The journey time profiles for cars before and after the bus lane opened are similar, although the traffic is now behaving differently.

Both cars and buses are saving time during peak periods (when 39% of the traffic travels) as a result of the bus lane scheme. During off-peak periods, journey times have increased as a result of the lower speed limits installed as part of the scheme.

Bus journey times are more reliable throughout the day since the bus lane opened. Car journey times are more reliable during the evening peak period, and have become slightly worse during the end of the morning peak period, as the congestion takes longer to clear on some days. The journey times during each peak period have become more consistent, as each driver is affected by one or two shockwaves, rather than joining the tail of a queue of varying length which builds up and dissipates during the peak period.

The bus lane scheme has improved conditions on days that previously had the worst congestion. Before the bus lane opened, Monday mornings and Friday evenings had significantly worse congestion than other days. Now the bus lane is open, the congestion is similar to other peak periods.

The bus lane scheme has resulted in time savings during peak periods for both cars and buses. A direct comparison of journey times during October/November 1998 and October/November 1999 (before and after the bus lane opened) has shown that buses are saving on average 4.1 minutes during the morning peak period, and 2.9 minutes during the evening peak period. Cars are saving on average 1.3 minutes in the morning peak and 0.6 minutes in the evening peak. On average, each bus is saving 3.5 minutes and each car is saving 1 minute during peak periods.

These savings include the effect of incidents. During incidents, buses achieve the greatest savings, as they are able to reach the start of the elevated section without queueing.

Journey times for both buses and cars during off-peak periods have increased, as a result of the lower speed limits along the section. In free-flow conditions, typical journey times have increased on average from 4.7 minutes to 5.6 minutes.

Journey times for vehicles leaving the M4 at Junction 3 have increased now that the bus lane has opened. During the morning and evening peak periods, shockwaves propagate back from the elevated section/merge area, causing increases in journey times and also a greater variability.

Overall, the effect of the scheme on weekday travel time is neutral. At weekends, there is less peak period congestion and so the delay caused by the lower speed limits exceeds the time saved during congested conditions, resulting in a calculated increase of 1250 person hours. Over the whole week, there has been an increase of 1.8% in the total time spent travelling on the section of the M4 affected by the bus lane scheme. This is equivalent to an extra 8 seconds on the journey time of each vehicle.

5. BUS LANE DESIGN AND OPERATION

To assess the design of the bus lane, video and manual observations have been made on a number of occasions at several points along the bus lane: at the end of the bus lane near the merge area, near the middle, and at the start. Of particular interest is how the design of the merge area affects traffic merging and how vehicles join and leave the bus lane. The design of the bus lane is shown in Figures 2 and 3. The following sections describe the design and performance of each area of interest, starting from the merge area and progressing upstream.

5.1 TRAFFIC BEHAVIOUR AT THE MERGE AREA OF THE BUS LANE JUST BEFORE THE ELEVATED SECTION

This section describes traffic behaviour at the merge area near the elevated section (see Figure 20) to assess its performance. It is believed that the merge area has had an effect on the extent of the congestion on the M4 between Junctions 4 and the elevated section, now that the bus lane is operational. Furthermore, the Highways Agency have asked for an opinion about improvements to the merge design based on the performance of the traffic at this location.

Figure 20 - The merge area of the bus lane with the middle lane

The merge area is designed so that traffic in the middle lane merges with traffic in the bus lane, traffic in the bus lane having priority. The design is similar to a normal motorway entry slip road. A hatched area bordered by solid white lines (ghost island) separates the traffic in the nearside lane from the other two lanes. The designer of the merge area incorporated the ghost island since it was crucial in smoothing the traffic flow.

Videos have been made of the behaviour of the traffic at the merge area. The traffic behaviour observed can be separated into several types dependent on traffic conditions and individual driver behaviour. Throughout the morning peak period, traffic was seen to be queueing back from the elevated section at regular intervals. Figure 20 shows an example of this behaviour.

Data from a Traffic*master* infrared sensor has been used to provide information on the speed of traffic on the elevated section, as loops do not work on the elevated section due to the materials used in its construction. The Traffic*master* sensor is located near to Junction 2.

The traffic behaviour varied according to the amount of traffic at the merge area and the amount of congestion on the elevated section. In traffic that was moving freely, the following observations were made:

- When there is nothing on the bus lane, traffic joins at the start of the merge.

- When there are single vehicles on the bus lane, traffic still joins at the start of the merge.

- When more than one vehicle is on the bus lane, traffic either waits for them to pass, or merges in between at the start of the merge, or moves to some point along the merge and then merges when it is feasible to do so.

- Some drivers appear to take risks and pull out at whichever point of the merge they have reached in front of vehicles from the bus lane. Occasionally some drivers will wait until the end of the merge area to try and merge. This is made more difficult if drivers behind have already merged and overtake the vehicle in the merge area.

- Sometimes several vehicles merge at once from different points along the merge.

When traffic was queueing back from the elevated section, two types of queueing behaviour were observed (Figure 20 shows a combination of the two types of behaviour):

- Traffic queues back from the offside lane of the elevated section to the middle lane so that vehicles queue in single file through the merge area. This occurs when there is little traffic from the bus lane and the queue from the offside lane of the elevated section grows very quickly.

- Traffic queues back from the offside lane of the elevated section and queues in both the offside lane and the middle lane in the merge area. This is caused by vehicles in the merge area being unable to merge with traffic from the bus lane. As a result, there are effectively three lanes of traffic queueing for approximately 200 metres and a small bottleneck forms at the end of the merge area.

Other behaviour observed during queueing is:

- When traffic can move onto the elevated section, vehicles in the merge section mix with others wherever they can; often two vehicles end up side by side travelling onto the offside lane of the elevated section.

- When there are three lanes of queueing traffic, on occasions some vehicles will cross the hatching and move from the middle lane into the nearside lane. Vehicles will also cross from the offside lane, right across to the nearside lane.

- Vehicles occasionally stop in the merge area, even when there is space ahead in the area into which to move. They then wait until there is a suitable gap to merge with traffic in the offside lane.

Figure 6 shows the speeds of traffic at various locations on the M4 between 06:00 and 10:00 on Monday 1st November 1999. Red sections show periods of very slow moving traffic. The diagonal bands of red from bottom left to top right of each plot are shockwaves; vehicles travelling from top left to bottom right pass through these shockwaves and undergo stop-start behaviour.

The traffic behaviour seen on this morning shows this stop-start traffic beginning at 07:20 and ending just before 09:00. In general, shockwaves occurring before 07:00 are not caused by traffic on the elevated section since the traffic is not slow moving at this time. One likely explanation is that these shockwaves are due to the sheer weight of traffic at the merge area at that time. The first shockwave typically occurs at 6:45, as can be seen in Figure 6. Otherwise, when shockwave behaviour is observed, slow moving traffic on the elevated section is usually responsible. The cause and dissipation of the shockwaves is attributable to several factors including weight of traffic, traffic behaviour on the elevated section and in the merge area.

In conclusion, the design of the merge area is working well. In terms of improving the design of the merge, given the previous description, the authors believe that any changes (eg to the length of the taper) are unlikely to be beneficial. If the taper were made shorter, vehicles in the middle lane may have less opportunity to merge smoothly with the traffic from the bus lane, and the merge area might be less safe. If the taper were made longer, there may be more queueing in the merge area, creating a larger bottleneck.

5.2 TRAFFIC BEHAVIOUR ON THE MID-SECTION OF THE BUS LANE

Figure 21 shows the daily flow in the bus lane at each of the monitoring sites during the week beginning 18th October 1999. Traffic joins the bus lane at various points along it, not just at the start. Site 21/6 is located near the start of the bus lane and hence the daily flows here are lower due to not all the eligible traffic joining the bus lane at this point. The length figures used to analyse bus lane use are obtained from site 19/7 (2km after the start of the bus lane). The daily flow at the end of the bus lane is approximately 800 vehicles greater than at the start. The increase in bus lane flow along the section is consistent from day to day.

This behaviour does not adversely affect the performance of the bus lane, as the vehicles joining the bus lane after the start do so without affecting the traffic already in the lane. There are possible safety implications in this behaviour (eg crossing a slippery white line, and joining the bus lane at a slower speed than the vehicles already in the lane).

During free-flow conditions, traffic in the bus lane is generally travelling about 5mph slower than traffic in the middle lane. Therefore, there is often nearside passing. Occasionally, taxis move out of the bus lane to undertake a slower bus in front, then move back into the bus lane. This manoeuvre is illegal, and may compromise safety.

For each accident between Junction 3 and the start of the elevated section during the first year of operation, the cause of the accident has been determined from Police incident logs. There have been no accidents caused by vehicles entering or leaving the mid-section of the bus lane, so there do not appear to be any safety implications with nearside passing or undertaking.

5.3 TRAFFIC BEHAVIOUR AT THE START OF THE BUS LANE

All through traffic is constrained to the inside two lanes as it passes through Junction 3 prior to the start of the bus lane, because of the lane drop at the Junction 3 diverge (see Figures 2 and 3). Buses and taxis can then join the bus lane at any point after it starts in the offside lane.

Traffic behaviour at the start of the bus lane has been observed covertly from an overbridge on the M4. From this bridge, both the entry slip road at Junction 3 and the start of the bus lane could be viewed.

In general, vehicles joined the bus lane at the start. However, when traffic was heavy, it was not always possible for vehicles to move straight into the bus lane. This was also affected by the lane in which they were travelling – for example, buses in the nearside lane have to cross the middle lane in order to get into the bus lane.

Almost all of the vehicles joining at Junction 3 that are eligible to join the bus lane are taxis (only one bus per hour was observed). Observations of the bus lane past Junction 3 showed a variety of joining behaviours. 70% of the taxis joined the bus lane very soon after joining the M4 at Junction 3. A few taxis took longer and were observed joining the bus lane approximately 700 metres after Junction 3. The remainder of the taxis had not joined the bus lane by the time they were out of sight of the overbridge.

In conclusion, the design of the start of the bus lane is working well. There have been no accidents at the start of the bus lane during the first year of operation. It is safer for all traffic to be constrained in two lanes through Junction 3, then for buses and taxis to join the bus lane, than it would be to allow vehicles to join the bus lane at the start of the hatched area. One possible improvement would be to remove the solid white line at the start of the bus lane, so vehicles do not have to cross a potentially slippery line to join the lane.

5.4 PERFORMANCE TO THE WEST OF JUNCTION 3

One of the possible adverse effects of the bus lane scheme is extra congestion on the M4 between Junctions 4B and 2. In particular, some drivers have complained that congestion has increased to the west of Junction 3.

To assess congestion to the west of Junction 3, traffic speeds at the Junction 4B merge, Junction 4 diverge, Junction 4 merge and Junction 3 diverge areas have been analysed for November 1998 (before the bus lane opened) and November 1999 (bus lane in operation). Of particular interest is whether any of the congestion to the west of Junction 3 is attributable to the bus lane scheme.

An important issue in this analysis is the nature of the data to the west of Junction 3. Between the Junction 3 diverge and Junction 3 merge, one-minute average speeds and flows have been collected for each lane at two loop sites (sites 22/1 and 21/6). This provides good quality data from which to calculate journey times and to assess causes of congestion.

To the west of the Junction 3 diverge, there is only one site collecting one-minute average speeds (site 23/2), and four sites collecting five-minute average speeds and flows averaged across lanes. These four sites are located at the Junction 4 merge (site 23/9), between the Junction 4 diverge and merge (sites 24/5 and 25/2) and between Junctions 4B and 4 (site 26/4). Where speeds are averaged across lanes, as at these sites, it is not possible to distinguish congestion in any particular lane (eg the slip road lanes).

Traffic data is currently being collected which will distinguish between speeds in individual lanes, for all sites between Junction 4B and the start of the elevated section. This will be used to determine the current traffic conditions on the slip roads, although there will be no “before” data to compare it against.

5.4.1 Analysis of traffic speeds to the west of Junction 3

Traffic speeds to the west of Junction 3 have been analysed to establish where congestion occurred during the pre-bus lane monitoring period (November 1998) and the equivalent month since the bus lane has opened (November 1999). The initial cause of the congestion (ie where the congestion first started) has also been determined by examination of the MTV plots. For the purposes of this report, congestion is defined as traffic speeds dropping below 25mph for a period of at least ten minutes.

Due to the location of the monitoring sites, it is not possible to distinguish whether congestion between Junctions 4B and 4 is caused by Junction 4B merge, Junction 4 diverge, or a combination of the two. However, it is possible to determine which of the sites is congested.

Figure 22 shows, for each location to the west of Junction 3, the percentage of peak periods for which that location was congested, and the causes of that congestion. The height of each column shows the amount of congestion, and the colours show the initial downstream cause of the congestion.

There are two main causes of congestion at a particular location:

- the location itself is causing the congestion, or

- the location is congested as a result of congestion tailing back from further downstream.

The number of times that each location causes congestion gives a measure of how well the road layout at that location is performing.

Comparing the height of the columns for the months before and after the bus lane opened shows that, overall, the M4 is now more congested to the west of Junction 3 than it was before the bus lane opened. Some of this congestion is due to the bus lane scheme as a result of the shockwave behaviour propagating back through Junction 3 and causing congestion further upstream.

5.4.2 Congestion at the Junction 3 diverge

The Junction 3 diverge area (see Figure 23) is now more congested than it was during the pre-bus lane monitoring period.

Before the bus lane opened, all of the congestion was due to the Junction 3 diverge itself. This congestion was caused by drivers weaving or swooping to get into the slip lane to leave the M4, and by queueing on the slip road.

Figure 23 - M4 Junction 3 diverge area

Now the bus lane is open, the nearside lane approaching Junction 3 is a dedicated slip lane. This has reduced the amount of congestion originating at the Junction 3 diverge during peak periods. The majority of the congestion is caused by shockwaves propagating back from the elevated section/bus lane merge area, mostly affecting the offside and middle lanes at the Junction 3 diverge area.

5.4.3 Congestion at the Junction 4 merge

Merge areas in general can cause congestion especially when there is a large amount of traffic already on the motorway and a large amount of traffic wishing to join. Traffic in the nearside lane of the main carriageway may try to move into the middle lane just before the merge area in order to create space for vehicles to join from the slip road. Also, the roundabout at Junction 4 is controlled by traffic lights, so traffic joining at Junction 4 will tend to do so in platoons.

During the pre-bus lane monitoring period, the Junction 4 merge area was congested on 50% of peak periods: most of the congestion on those peak periods was caused by the Junction 4 merge itself. Since the bus lane opened, the Junction 4 merge area was congested on 68% of peak periods. For 10% of the peak periods (ie one day in 10), this congestion was caused by the elevated section/bus lane merge area, again as a result of shockwaves propagating back.

Since the bus lane has opened, the Junction 4 merge is performing slightly better than during the pre-bus lane monitoring period (shown by the reduced number of times for which the Junction 4 merge caused congestion at that location). This may be a result of better lane use on the approach to Junction 3.

Before the bus lane opened, traffic joining the motorway at Junction 4 could stay in the nearside lane up to and through Junction 3. The Junction 3 diverge now has a dedicated exit slip road, which means that through traffic must move out of the nearside lane earlier than before. This increases the number of weaving movements near to the Junction 4 merge area, resulting in increased congestion attributable to the Junction 3 diverge.

5.4.4 Congestion at the Junction 4 diverge

Congestion at the Junction 4 diverge has increased since the bus lane opened, when compared to the pre-bus lane monitoring period. Since there is no monitoring site close enough upstream to the Junction 4 diverge, it is not possible to assess whether this location is the cause of any of the congestion. Furthermore, since the data is averaged across all lanes, the monitoring cannot identify any changes in problems on the slip road.

However, both before and after the bus lane opened, the majority of the congestion on the main carriageway at the Junction 4 diverge was caused by the Junction 4 merge area. The elevated section/bus lane merge area caused congestion at the Junction 4 diverge on 6% of peak periods (ie one day in 16), due to shockwaves propagating back from the elevated section/bus lane merge.

5.4.5 Congestion between Junction 4B and Junction 4

Because the traffic speed data are averaged across all lanes, it is not possible to identify how the slip roads are performing. The road is assumed to be congested if the average speed across all lanes is low, in which case it is likely that all lanes are experiencing similar congestion. There is anecdotal evidence that the nearside lane between Junction 4B merge and Junction 4 diverge is often congested during peak periods, with the other lanes containing free-flowing traffic.

During the pre-bus lane monitoring period, the section between Junction 4B merge and Junction 4 diverge was congested on 12% of peak periods (see Figure 22). On two thirds of these, the congestion originated between Junctions 4B and 4.

Since the bus lane opened, the section between the Junction 4B merge and the Junction 4 diverge was congested during 45% of the peak periods, although this location was the cause of the congestion during only 10% of the peak periods. The increase in the number of peak periods for which this location was congested was mainly due to congestion tailing back from the Junction 4 merge.

Congestion can be caused by drivers weaving to get into the required lane. This has an increased effect where two junctions are close together, such as the Junction 4B merge and Junction 4 diverge. The drivers joining at Junction 4B conflict with other drivers wanting to leave at Junction 4.

Overall, since the bus lane opened, the section between the Junction 4B merge and the Junction 4 diverge is performing slightly worse than it was during the pre-bus lane monitoring period. There is also more congestion caused by traffic tailing back from further downstream.

None of the congestion between Junctions 4B and 4 is caused by the elevated section/bus lane merge area. However, once the area is congested, any shockwaves propagating back from downstream will make the congestion worse.

5.4.6 Summary

To the west of Junction 3, congestion is worse overall now that the bus lane is open. This is due to shockwaves propagating back from the elevated section, which makes the existing congestion at each slip road location worse. This congestion continues to propagate further upstream. However, congestion between Junctions 4B and 4 does not appear to be caused by the bus lane scheme.

The new design of the Junction 3 diverge area has reduced congestion originating at that location.

Traffic data is currently being collected which will distinguish between speeds in individual lanes, for all sites between Junction 4B and the start of the elevated section. This will be used to determine the current traffic conditions on the slip roads.

5.5 PERFORMANCE OF BUS LANE SURFACE

Since the bus lane was installed, the red surface and white lining have not deteriorated. Concerns were raised by the Highways Agency that the white lining might be a problem for motorcyclists who may slip as they cross it. No accidents of this type have been reported by the Police. No adverse comments regarding the bus lane operation or the materials used in its construction have been received from the public.

5.6 CONCLUSIONS

The design of the bus lane scheme is working well. In particular, the merge area is not causing serious problems, and any changes are unlikely to be beneficial. At the start of the bus lane, some vehicles are not able to join the bus lane as they are in the nearside lane. Additional signing to the west of Junction 3 may improve this behaviour, although most drivers are familiar with the scheme by now and would not be affected by such signing.

The congestion to the west of Junction 3 has increased as a result of the bus lane opening. The additional congestion is caused by shockwaves propagating back from the elevated section, and is a result of only two lanes being available to cars after Junction 3. The new layout of the Junction 3 exit slip has not contributed to the additional congestion.

During peak periods, traffic leaving the M4 at Junction 4 or 3 has often been delayed by the additional congestion to the west of Junction 3, compared to the situation before the bus lane opened. The journey times for through traffic were quicker than before, and traffic joining at Junction 3 gained the greatest benefit from the introduction of the bus lane scheme.

6. USE OF BUS LANE

Three main classes of vehicle are allowed to use the M4 bus lane: buses/coaches, minibuses and taxis. Vehicle length data has been collected from loops to analyse bus lane usage in terms of each of these vehicle classes. Taxis are defined as having vehicle length between 3 metres and 5.5 metres. The categories of minibuses and buses/coaches from the length data have been calibrated using observations of vehicles in the bus lane obtained from video footage.

Figure 24 shows the typical daily profile of vehicles using the bus lane. The profile for taxis is slightly different to that for minibuses and buses/coaches. Taxi use of the bus lane is highest in the morning and evening peak period, with the peak flow occurring at approximately 7:00. There are more minibuses and buses/coaches in the bus lane during the morning.

Figure 25 shows the average number of vehicles using the bus lane each weekday since it opened in June 1999. The plot also shows the daily total of taxis, minibuses and buses/coaches. Data is not available on several occasions during the monitoring period since the bus lane opened due to data collection problems (see Annex A).

The number of minibuses and buses/coaches that use the bus lane has remained constant throughout: approximately 100 minibuses and 500 buses/coaches use the bus lane daily each week. There has been no increase detected in the number of buses using the M4 following the opening of the bus lane.

On average, 3700 vehicles per day use the bus lane, which is 7% of the total traffic on the eastbound M4. The daily total using the bus lane has varied between 3000 and 4750 and is greatly affected by the number of taxis using the bus lane: between 2400 and 4100 per day. A typical peak hour flow comprises 250 taxis and 60 buses/minibuses.

Video recordings have been used to analyse the percentage take up of the vehicles eligible to use the bus lane. In the peak periods, the percentage take up is almost 100% of all eligible vehicles (apart from minibuses). During off-peak periods, the percentage take up is approximately 70% for taxis, 90% for buses and coaches, and 50% for minibuses. It is likely that the reason that minibuses are not using the bus lane is that their drivers are not sure whether they are permitted to use it.

It may be useful for infrequent users to have more information about using the bus lane. One option would be to increase the signing before the start of the bus lane, but this would have safety implications. A better option would be to have further publicity about how to use the bus lane, perhaps included with the next release of results from the bus lane monitoring.

6.1 TRENDS IN BUS LANE USE

Figure 25 shows the seasonal variation in the bus lane use. In general, the number of vehicles using the bus lane has been rising since the bus lane was installed, with peak usage occurring during May 2000. The number of taxis using the bus lane was lowest during August 1999, when there was little congestion. During free-flow conditions, taxis do not gain any advantage by using the bus lane and hence fewer taxis choose to use the bus lane. There was also a drop in use of the bus lane during January 2000 – this was a result of the overall traffic flow on the M4 being lower than in other months.

The decrease in taxi (and hence bus lane) use during the week beginning 21st November 1999 is a result of the overnight closure of the M4 for roadworks on four nights. The decrease in bus lane use during the week beginning 16th April 2000 is likely to be due to the beginning of the school Easter holidays.

6.2 ROGUE VEHICLES IN THE BUS LANE

Identification of rogue vehicles using the bus lane is not possible from the length data: it is not possible to positively distinguish a car from a taxi or an HGV from a coach, and motorcycles often do not ride directly over the loops. Video data has been obtained on several occasions during the morning peak periods and during one afternoon. During a typical 3-hour morning peak period, one car was observed to be using the bus lane. Most often, motorcycles are observed using the bus lane: during the period 06:45 to 09:45 up to 25 motorcycles have been observed using the bus lane.

The presence of motorcycles in the bus lane does not cause any problems, so it is currently not practical to stop them using the lane. However, the white line separating the bus lane from the other lanes may be come slippery when wet, so there may be safety implications in allowing motorcycles to use the bus lane. However, no accidents of this type have been reported during the first year of operation.

7. TRAFFIC FLOWS

Traffic flows have been monitored for two reasons:

- To determine the effect of the bus lane on flow patterns.

- To determine if flow levels have changed, so that any change in performance following the introduction of the bus lane could be put into context.

The daily traffic flows along the main carriageway have been measured at each site, and slip road flows have been derived from the mainline flows. The flow information has been used to calculate the demand flows for each link, including slip roads. The flows in November 1998 (before the bus lane opened) have been compared against the flows after the bus lane is operational to determine any changes in flow levels and patterns.

7.1 FLOW PATTERNS

Figure 26 shows the average flows along each link for weekdays during a typical week during November 1998. In summary,

- The largest flow of 83,600 vehicles per day (over all lanes) was achieved between Junctions 4B and 4, a 4-lane section of motorway. For comparison, the weekday flows on the 4-lane sections of the M25 vary between 83,000 (near Junction 10) and 98,000 (between Junctions 13 and 14).

- Between Junctions 4 and 3 (a 3-lane section), the flow was 74,200, an average of 24,700 vehicles per lane per day.

- Between Junctions 3 and 2, the flow was 52,800, giving an average of 17,600 and 26,400 vehicles per lane per day for the 3-lane and 2-lane sections respectively.

- 31% of the main carriageway flow joined at Junction 4 and 37% left at Junction 3. Therefore, a lot of lane changing occurs along this section, as vehicles joining at Junction 4 move out to join the main carriageway and vehicles leaving at Junction 3 move onto the slip road.

- Relatively little traffic (14% of the traffic arriving at the elevated section) joined at Junction 3.

- A comparatively low proportion of traffic (7%) left at the Heston services. However not all traffic rejoined; about 1500 vehicles per day left the services via the service road and joined either the M4 westbound or the local road network.

Figure 27 shows the average flows along each link for weekdays during the corresponding week during November 1999. The flow between Heston Services and the elevated section has risen slightly; the flows between Junction 4B and Heston have dropped slightly. However, the slip road percentage flows are similar to those during

November 1998 for each of the slip roads, so there is no evidence that traffic patterns have changed as a result of the bus lane scheme.

7.2 FLOW LEVELS

Figure 28 shows the average weekday flows between Junctions 3 and 2, for each week since the bus lane opened in June 1999, and also for the period from October 1998 to March 1999, before the bus lane opened. The missing data is for weeks where the eastbound M4 was closed for roadworks during the night, so daily flow data is not typical and has been omitted.

The seasonal variation in flows is similar to that observed on other motorways (eg the M25). The lowest flows are during the Christmas period. The flows rise to a peak during the summer months, and then drop off towards the end of the year. There is a small drop in flow during August, likely to be due to the holiday period. The flows for October 1999 were higher than for October 1998, whereas the flows for November were slightly lower in 1999.

Table 5 shows the daily mainline traffic flows for the weeks beginning Sunday 8th November 1998 (highlighted with a grey background) and Sunday 7th November 1999. Figures in bold italic indicate that the flows for the week beginning 7th November 1999 are higher than those for the week beginning 8th November 1998.

Table 5 – Daily traffic flows for the weeks beginning 8th November 1998 and 7th November 1999

Day	Junction 4 to 3		Through Junction 3		Junction 3 to 2	
	W/B 8/11/98	W/B 7/11/99	W/B 8/11/98	W/B 7/11/99	W/B 8/11/98	W/B 7/11/99
Sunday	64300	***66300***	44300	***45700***	49700	***51100***
Monday	72500	71600	45500	***45700***	51400	***52200***
Tuesday	74000	72200	46400	45900	52400	***52800***
Wednesday	74500	73800	46200	***46800***	52600	***53800***
Thursday	75700	74100	47400	46400	53700	53400
Friday	76700	73000	48200	46400	54400	53300

The flows generally increase towards the end of the week. This pattern has been maintained from 1998 to 1999.

The maximum flow onto the elevated section during November 1998 and November 1999 was about 3800 veh/hr. Therefore, the introduction of the bus lane has not affected the maximum flow onto the elevated section. During July 1999, just after the bus lane opened, the maximum flow was 4000 veh/hr. This increase may be as a result of a variety of factors, for example, better weather and lighting conditions during Summer, compared to Autumn/Winter.

The flows onto the elevated section during peak periods were similar during November 1998 and November 1999:

- The average flow during the morning peak hour (6:30-7:30) rose from 3490 in the before period to 3520 in the after period.

- The average flow over the 3-hour morning peak (6:30-9:30) dropped from 9630 (3210 veh/hr) in the before period to 9520 (3170 veh/hr) in the after period.

- The flows during evening peaks were slightly lower than during the morning. The average flow during the evening peak hour (17:30-18:30) rose from 3450 in the before period to 3480 in the after period. The average flow over the 3-hour evening peak (17:30-20:30) dropped from 3190 veh/hr in the before period to 3160 veh/hr in the after period.

7.3 CONCLUSIONS

There has been no significant change in traffic flows or in flow patterns as a result of the bus lane opening. The flows now that the bus lane is open are similar to those before the bus lane opened, therefore any benefits observed have been achieved with similar flow levels. There is no evidence that traffic is diverting onto the adjacent network as a result of the bus lane scheme.

The flows during the summer of 1999 were higher than during the October/November comparison period; this is because of seasonal variations. The traffic patterns remain the same during the summer.

There is now a dedicated exit lane at Junction 3, and two lanes through Junction 3. Just over one third (37%) of traffic leaves at Junction 3, so that traffic approaching Junction 3 will be spread evenly between the three lanes.

When there is severe congestion on the M4 following an accident, traffic flows drop but slip road percentages remain the same. Therefore, traffic does not divert onto the surrounding network; the implication is that the “missing” traffic used the M25 as part of an alternative route, or that some of the journeys were cancelled.

8. TRAFFIC CONDITIONS ON ADJOINING NETWORK

One of the possible undesirable effects of the introduction of the bus lane scheme was that, traffic might divert away from the M4 and onto the A4 and other local roads. To assess if the bus lane scheme has had any effect on the adjoining road network, the following were investigated:

- The amount of congestion on the M4 Junction 3 roundabout.

- The journey times into London along the primary alternative route.

Traffic flows and speeds on the adjoining road network have been monitored since the bus lane opened on 7th June 1999 and were also collected during the pre-bus lane monitoring period (October and November 1998). Data from October and November 1999 has been compared to the equivalent weeks in 1998 to investigate if the bus lane scheme has had any effect on the adjoining network.

The alternative routes into London were assessed before the bus lane was opened. The route to the north of the M4, through Southall and Ealing, was felt to be too congested to be a viable diversion route. The route to the south of the M4 was a more likely diversion route, although the journey times along this route were typically over twice as long as along the M4. Strategic diversions, such as along the M3 or the M40, were outside the scope of the monitoring. Any significant diverting of traffic away from the M4 would be detected by monitoring the mainline and slip road flows on the M4. In addition, the police (with whom the Highways Agency are in close liaison) would be observing the performance of the adjoining network, and would detect any major problems as a result of the bus lane scheme.

The data used to assess the impact of the bus lane scheme on the adjoining network has been obtained from two sources. Traffic flows and speeds from loops were collected on the northbound approach to Junction 3; this is to assess congestion at the Junction 3 roundabout. A car fitted with a Global Positioning System (GPS) receiver was driven along a standard route during one morning peak period per week during the “before” and “after” periods. The standard route is south along the A312 past Junction 3, and east along the A4 (south of the M4) as far as Junction 1 at Chiswick. This route is shown in Figure 29, which shows the locations of the car along the standard route, overlaid onto a map of the area. Each car position logged is shown as a circle, with the colour representing the speed of the car - those shown as red are where the car travelled slowly or stopped during its journey. During a typical morning peak period the car was driven along the route four times. Typical queues approaching the M4 are on Hyde Road waiting to join the A312 and at the traffic lights at Junction 3. The GPS data is used to obtain information about journey times to London as well as information about queueing at the Junction 3 roundabout.

8.1 CONGESTION AT THE JUNCTION 3 ROUNDABOUT

The flows and speeds on the A312 on the northbound approach to Junction 3 of the M4 have been monitored, both during the “before” and “after” periods, to assess the performance of the roundabout at Junction 3. Figures 30 and 31 show the average hourly speeds and flows on the northbound approach to Junction 3 on the A312 for a typical week “before” and “after” the bus lane opened, respectively. The height of the bars on each graph show the amount of flow and the size of the different coloured blocks in each bar shows how many vehicles are travelling at a particular speed. Figure 31 shows that the flows on the A312 are similar to those during the pre-bus lane monitoring period. The speed data provide a measure of queueing. The measuring site is approximately 200 metres south of the roundabout, so traffic with a speed below 11mph indicates a queue of at least 200 metres. During the “after” period, the speeds are above 11mph in the morning peak period, indicating that the queue does not go beyond 200 metres. During the evening peak period there is more queueing. However, the queueing behaviour does not show any great change when compared to the “before” data.

When congestion is present on the M4 at Junction 3, information from the A312 may indicate whether traffic on the roundabout is being affected by this congestion. For example, during one morning when there was severe congestion on the M4, comparison of speeds of vehicles on the A312 at this time showed that there was not a large amount of queueing on the A312. This suggests that the behaviour of traffic on the M4 is not affecting traffic on the A312.

The GPS data has been used to calculate the length of time spent in queues throughout the morning peak period. Figures 32 and 33 show the length of time spent queueing while approaching Junction 3 on the A312 in each direction for each journey for the “before” and “after” periods respectively. During the morning peak, most of the queueing is from the north of Junction 3, with the queueing time varying from just under 2 minutes at the edges of the peak period to around 12 minutes at 8:00. The queueing times are similar before and after the bus lane opened; the queues at Junction 3 are no worse in the “after” period.

The queueing time from the south is generally never more than 2 minutes, showing the same pattern as during the “before” period. This can be compared with Figure 31; this shows that there is never more than 200 metres of queueing on the A312 during the morning peak period.

8.2 JOURNEY TIMES INTO LONDON ALONG THE PRIMARY ALTERNATIVE ROUTE

The GPS data has been used to calculate the journey times into London along the alternative A4 route shown in Figure 29. Table 6 shows the minimum and maximum recorded journey times between Junctions 3 and 2 of the M4 via the A4. In the morning peak, journey times are the highest between 8:00 and 9:00. Journey times between Junctions 3 and 2 on the adjoining network for the morning peak period are lower since the bus lane opened than during the “before” period.

Table 6 – Minimum and maximum journey times to travel between Junctions 3 and 2 of the M4 via the A4

	Journey time between M4 J3 and M4 J2 via the A4 during morning peak period	
	Minimum journey time	Maximum journey time
11th Oct 1998 – 4th Dec 1998 (during pre-bus lane monitoring period)	13 minutes	31 minutes
26th Oct 1999 – 27th Nov 1999 (bus lane in operation)	13 minutes	30 minutes

A typical journey time on the M4 between Junctions 3 and 2 in the morning peak period is now 6-9 minutes for a car and approximately 6 minutes for a bus. On the adjoining network, the journey time between Junctions 3 and 2 for this same period varies between 13 minutes and 30 minutes.

8.3 CONCLUSIONS

Overall, these results suggest that traffic on the adjoining network is not being affected by the M4 bus lane scheme. Queues at the Junction 3 roundabout are no worse than they were before the bus lane opened and journey times along the alternative A4 route are slightly quicker than during the "before" period. It is still over twice as quick to travel on the M4 between Junction 3 and Junction 2 than it is on the adjoining network. There is no incentive for traffic to divert, nor is there any evidence that it is doing so. Furthermore, any congestion on the M4 is not affecting the performance of the adjacent network.

9. SPEED COMPLIANCE

Along the M4 there are new speed limits of 50mph just before Junction 4 and 40mph just before the merge area at the end of the bus lane. Compliance with these speed limits has been directly measured by analysing the speed of each vehicle at the four sites described in Table 7. Before the bus lane opened, the national speed limit covered the eastbound M4 until the elevated section, and there was a 50mph limit from the start of the elevated section. A speed limit of 50mph now covers the first two locations, whilst there is a speed limit of 40mph near the merge area of the bus lane and at the start of the elevated section. For the pre-bus lane monitoring period, site 16/2 was after the bottleneck where three lanes reduced to two. Following the road redesign, this site is just before the merge area; there are three lanes of traffic, including the bus lane.

Table 7 – Sites chosen for speed investigation

Site	Speed limit before	Speed limit after
23/2 (between J4 and J3)	70	50
18/7 (middle of bus lane)	70	50
16/2 (near merge)	70	40
15/6 (before elevated section)	50	40

Traffic speeds have been monitored for five time periods: the early morning, the morning peak, the midday period, the evening peak and the late evening. To assess speed compliance, free flow traffic data from 20:00 to 06:00 has been analysed, so that traffic is not constrained at a particular speed.

9.1 RESULTS FOR PRE-BUS LANE MONITORING PERIOD

Figure 34 shows the speed distribution of traffic at each of the four sites during free flow conditions during the pre-bus lane monitoring period. At the start of the elevated section (site 15/6) there was little variation in speed, with most of the traffic travelling between 40mph and 50mph. There was more variation at the other three sites. For site 16/2, most traffic travelled below 70mph, whilst for the other two sites (18/7 and 23/2), most traffic travelled below 75mph. Table 8 shows the 85th percentile speed[1] and the average (mean) speed for the four sites during the pre-bus lane monitoring period. In addition, the table shows the percentage of traffic exceeding a threshold speed of (110% * speed limit + 2)[2].

[1] 85% of traffic travels at or below this speed. This is the standard measurement used by traffic engineers with regards to speed limits.

[2] This threshold speed is the speed limit, plus a tolerance. It is likely that drivers exceeding this speed are consciously exceeding the speed limit.

Table 8 – Speeds under free-flow conditions: pre-bus lane monitoring period

Site	Speed limit	85^{th} percentile speed	Average speed	Percentage exceeding threshold
23/2 (J4-3)	70mph	78mph	66mph	11%
18/7 (J3-2)	70mph	78mph	68mph	10%
16/2 (near elevated section)	70mph	70mph	62mph	2%
15/6 (elevated section)	50mph	50mph	45mph	4%

During the pre-bus lane monitoring period, 42% of vehicles exceeded the national speed limit at site 18/7 and only 17% exceeded the speed limit at the elevated section (where there was an operational speed camera). The average speeds at site 16/2 were lower than at the sites further upstream, because drivers were slowing down in preparation for the 50mph limit at the start of the elevated section.

9.2 RESULTS ONE MONTH AFTER BUS LANE OPENED

Figure 35 shows the speed distribution of traffic at each of the four sites during free flow conditions, one month after the bus lane opened. At the start of the elevated section (site 15/6) there was little variation in speed, with most of the traffic travelling between 35mph and 45mph. There was more variation at the other three sites. For site 16/2, most traffic was travelling below 55mph, whilst for the other two sites (18/7 and 23/2), most traffic was travelling below 65mph and 60mph respectively.

Table 9 shows the 85^{th} percentile and average (mean) speeds under free-flow conditions one month after the bus lane opened, and the percentage of traffic exceeding a threshold speed of (110% * speed limit + 2).

Table 9 – Speeds under free-flow conditions one month after the bus lane opened

Site	Speed limit	85^{th} percentile speed	Average speed	Percentage exceeding threshold
23/2 (J4-3)	50mph	65mph	57mph	41%
18/7 (J3-2)	50mph	64mph	58mph	48%
16/2 (near elevated section)	40mph	57mph	50mph	73%
15/6 (elevated section)	40mph	46mph	41mph	14%

The compliance at site 16/2 is now worse than at other sites, because drivers have just entered a 40mph limit, and have not slowed by 10mph. The better compliance at site 15/6 is likely to be due to the presence of a speed camera.

Just under half of the drivers in the 50mph speed limit area are exceeding the threshold speed. This figure rises to 73% in the 40mph speed limit area, but drops to 14% where there is an operational speed camera.

9.3 RESULTS SIX MONTHS AFTER BUS LANE OPENED

Figure 36 shows the speed distribution of traffic at each of the four sites during free flow conditions, six months after the bus lane opened. The distributions are very similar to those one month after the bus lane opened.

Table 10 shows the 85th percentile and average (mean) speeds under free-flow conditions six months after the bus lane opened, and the percentage of traffic exceeding a threshold speed of (110% * speed limit + 2).

Table 10 – Speeds under free-flow conditions six months after the bus lane opened

Site	Speed limit	85th percentile speed	Average speed	Percentage exceeding threshold
23/2 (J4-3)	50mph	64mph	56mph	35%
18/7 (J3-2)	50mph	63mph	57mph	41%
16/2 (near elevated section)	40mph	55mph	48mph	55%
15/6 (elevated section)	40mph	45mph	40mph	12%

The compliance six months after the bus lane opened is better than it was one month after the bus lane opened, possibly due to the poorer weather and lighting conditions during November. At all sites, the percentage of vehicles exceeding the speed limit has fallen, although it is above 70% at all the sites apart from site 15/6, where it is 47%.

9.4 RESULTS ONE YEAR AFTER BUS LANE OPENED

Figure 37 shows the speed distribution of traffic at each of the four sites and Table 11 shows the 85th percentile and average (mean) speeds, during free flow conditions one year after the bus lane opened, and the percentage of traffic exceeding a threshold speed of (110% * speed limit + 2).

Table 11 – Speeds under free-flow conditions one year after the bus lane opened

Site	Speed limit	85th percentile speed	Average speed	Percentage exceeding threshold
23/2 (J4-3)	50mph	64mph	56mph	37%
18/7 (J3-2)	50mph	68mph	61mph	73%
16/2 (near elevated section)	40mph	57mph	49mph	62%
15/6 (elevated section)	40mph	47mph	41mph	16%

At sites 23/2, 16/2 and 15/6, the speed distributions and compliance are similar to one month after the bus lane opened. At site 18/7, traffic speeds have increased during the year and are now about 3mph faster than during July 1999.

Figure 38 shows the compliance with the 50mph speed limit between Junction 4 and Junction 3 and Figures 39 and 40 show the compliance with the 40mph speed limit near the bus lane merge and the elevated section respectively. These Figures show compliance at all times of the day. During peak periods, compliance is better as many vehicles do not have the opportunity to exceed the speed limit because of the congested conditions. The compliance with the 40mph limit is better near the elevated section, probably due to the presence of a speed camera at the start of the elevated section.

9.5 CONCLUSIONS

Speed compliance has been measured with the 70mph and 50mph limits in place before the bus lane opened, and with the new 50mph and 40mph limits. The number of vehicles exceeding the speed limit rose following the introduction of the new lower speed limits. The number of vehicles exceeding the new 50mph speed limit is double the number that exceeded the national speed limit before the bus lane scheme was installed. This is likely to be because the drivers do not feel that a fixed 50mph limit is appropriate. Drivers tend to have less respect for fixed speed limits – there is better compliance with the variable speed limits on the M25, as the drivers know that the limits have been set for a reason. There is also greater enforcement on the M25.

The compliance during the winter is better than during the summer, possibly due to poorer weather and lighting conditions.

During off-peak periods six months after the bus lane opened, over 70% of vehicles exceed the speed limit between Junction 4 and the elevated section and nearly 50% exceed the 40mph speed limit at the start of the elevated section despite the presence of a speed camera.

Speed cameras were installed on the M4 between Junctions 4 and 2, but they were not operational and did not flash. The only site where compliance with the speed limit is good is just before the start of the elevated section, where there is an operational speed camera. A study of speeds on the M25 has shown that neither the introduction of camera signs nor the presence of speed cameras has a great effect on speed compliance. It is necessary for the cameras to flash before drivers obey the speed limits.

10. OCCUPANCY OF VEHICLES

To analyse the cost benefits of the bus lane scheme, the change in delay to people using the M4 once the bus lane is opened must be assessed. Vehicle occupancy figures are used in this assessment. To estimate the number of people using the M4, average occupancy figures for coaches, taxis and cars have been surveyed during the morning peak period. Additionally, manual counts have been conducted during the morning peak period to ascertain the number of coaches and taxis that are empty.

Video data of the traffic using the M4 between Junction 3 and the elevated section has been collected on a number of occasions since the bus lane opened. This video data has been analysed to assess vehicle occupancy.

The results of this analysis showed that the average car occupancy during the morning peak period was 1.2 persons. This means that, on average, 80% of cars entering London via the M4 contain only the driver.

A subsequent study of car occupancy on the eastbound M4 has shown that on weekdays, there is little change in occupancy levels during the day. The occupancies varied between 1.1 at the height of the morning peak period to 1.3 during the inter-peak period. On Sunday evenings, car occupancies were higher, averaging 1.6 persons per car.

From the data collected during the morning peak period, taxis had an occupancy of 2.5, and coaches had an occupancy of 15. Both of these figures include the driver. Approximately 25% of taxis and 33% of buses/coaches using the bus lane during the morning peak did not contain any passengers. It has not been possible to detect any change in vehicle occupancies following the introduction of the bus lane.

Combining the average occupancy figures with the number of vehicles using the bus lane (see Section 6) shows that 21% of people using the M4 into London use the bus lane (but in only 7% of the vehicles).

11. FEEDBACK

Both before and since the bus lane opened, there has been much discussion about the performance of the scheme. Since the bus lane is an innovative high-profile traffic scheme, there has inevitably been a lot of media attention. This is discussed in the review of the publicity that the scheme has received since it opened.

In addition, to obtain information from users of the bus lane, bus and coach companies and their drivers were asked to complete a questionnaire about the bus lane design and performance.

The Highways Agency run an Information Line for the public to ring in with questions and comments. A common comment about the bus lane scheme is that the callers cannot see how losing a lane for cars can make all traffic (including cars) reach their destinations quicker.

11.1 REVIEW OF PUBLICITY

The amount of publicity the bus lane scheme has received since it opened has varied over the weeks. When it first opened there was a lot of publicity describing the scheme and most of the journalists were extremely sceptical. On two occasions, Highways Agency press releases provided information detailing the first two weeks of operation of the bus lane and a leaflet describing the first three months of operation. As a result of this, there was a large amount of positive publicity about the bus lane during the beginning of November 1999.

Initially, however, publicity about the bus lane was adverse. The day after the bus lane opened, congestion on the M4 tailed back to the M25 and was reported in the papers. This was not caused by the bus lane but by a problem on the elevated section. During the third week of operation, most of the daily newspapers reported the story about the Prime Minister being caught in congestion on the M4 and having to use the bus lane. The Daily Telegraph reported that the AA had claimed that traffic was diverting to other routes to avoid the extra congestion caused by the bus lane. Other areas of complaint voiced in the newspapers at this time were:

- The bus lane was causing longer daily journeys
- There were 6-mile tailbacks in the morning rush hour
- Lanes 1 and 2 were nose to tail and journey time for a 3-mile section was one hour
- Few buses were using the lane and car drivers were stuck in traffic jams.

A Highways Agency press release containing the main results of the first two weeks of monitoring was issued on 28th June 1999 and reported in both the Financial Times and The Daily Telegraph. The main reported result was that peak journey times for both cars and buses had been cut.

The Daily Telegraph on 15th July 1999 reported that four times as many taxis as buses use the bus lane. This caused some concern amongst members of a transport committee and one commented that "a bus lane should have buses in it".

The Sunday Times on 25th July 1999 published an article entitled "Lost on Prescott's road to nowhere". The article contained several criticisms of the bus lane. The AA claimed that motorists were using alternative routes to avoid the added congestion on the M4. This was supported by comments from a resident living near the A4. The article described heavy queueing on the morning of Friday 23rd July, claiming that this behaviour was normal. However, it failed to mention that this was as the result of an incident between Junctions 3 and 2.

The Times on 27th July 1999 reported that the Metropolitan Police have hailed the bus lane as a success due to the reduced accident rates that have been reported.

Leaflets entitled "M4 Bus Lane: The First Three Months", summarising the performance of the bus lane during the first three months of operation, were produced by the Highways Agency. These were distributed at the London Motor Show, which was held during October 1999. The leaflets were also distributed to the media at the launch of the Highways Agency's Toolkit during October.

As a result of the leaflets, there was a large amount of publicity about the bus lane. On 5th November 1999, Meridian News ran an item describing the performance of the first three months of the bus lane. This included interviews with Alan Mellors from the Highways Agency and a spokesman from the AA. The AA's comment was that they would like to see variable speed limits on that section of the M4 and that they were also interested in how many drivers have diverted off the M4 and how many passengers the buses are carrying. The RAC made similar remarks including suggesting that the bus lane be operated at peak times only.

On 7th November 1999, the BBC ran an Internet article about the bus lane describing how journey times have been reduced. BBC Radio 4 also discussed the bus lane on 8th November. Articles about the bus lane were also carried in The Times and The Guardian on 8th November. Overall, the general tone of the articles was favourable towards the bus lane.

On 13th March 2000, the Highways Agency issued a press release confirming that that bus lane was a success. This was in response to an announcement that Reading Buses were suspending their service into London due to falling demand. There was no comment in the media following the press release.

The Surveyor on 23rd March 2000 reported comments by Alan Mellors on safety aspects of the bus lane, that the bus lane was a success, and that the Highways Agency could have publicised the positive results more quickly.

On 13th May 2000, the Daily Telegraph motoring section contained an article entitled "Punishment, not a panacea", concluding that bus lanes hindered traffic flow rather than helped it. Although there was a large picture of the M4 bus lane accompanying the article, the article was mainly about urban bus lanes, in particular in Aberdeen and

Brighton. Although the article did not mention the effect of the M4 scheme on traffic, there was an implication that it was the same as for urban bus lanes. The article was repeated four weeks later, this time entitled “Bus lanes are a waste of space”.

11.2 BUS COMPANY QUESTIONNAIRE

Twenty bus and coach companies were sent copies of a two-part questionnaire to obtain information from the companies themselves and their drivers.

The company questionnaire required information about the number of services (vehicles) run on the M4 per day and the number of passengers using each vehicle.

The driver questionnaire asked for information on what drivers thought about using the M4 between Junction 4B and Junction 2 before and after the bus lane opened. They were also asked about the bus lane itself, including whether it had improved their journey times, whether the road layout was an improvement and whether the speed limits were appropriate.

Both questionnaires asked for general opinions about the bus lane scheme, in particular whether it was a good idea and whether opinions had changed now that the bus lane was in operation.

Seven companies replied to the questionnaire and 90 drivers answered the driver questionnaire. Most of the companies ran express coaches and single and double deckers. The average number of customers per service was 25 and only one company had reduced the number of services due to a falling number of customers. The general opinion expressed by the companies was that the bus lane was a very good idea.

95% of the drivers who responded used the bus lane all the time; 40% said that it had made their journeys quicker, and 45% said that it had made their journeys smoother as well as quicker. In general, drivers did not have any problems joining the bus lane but approximately 5% of them said that they did experience problems driving behind taxis that moved in and out of the bus lane. 15% of the drivers said that they had problems at the bus lane merge due to the following reasons:

- vehicles from the middle lane did not always give way
- vehicles pushed in
- vehicles from the middle lane merged in too fast and then braked hard.

Drivers were asked about the road layout at the merge. Approximately 60% said that they thought that the traffic flow was safer and two thirds of those said that traffic flowed better. In general, 60% of the drivers said that the 50mph and the 40mph speed limits were “about right” and 40% said that they were too slow. 37% said that Variable Speed Limits would be a good idea. About 80% of drivers said that they thought their journey times had improved as a result of the bus lane.

Figure 41 shows the response when drivers were asked which other vehicles they would approve of using the bus lane; this included taxis, which are already eligible. 46% of drivers said they were happy with taxis using the bus lane and 26% said they would be happy for motorcycles to use the lane. 11% of drivers said that no other vehicles should use the bus lane.

The main locations of congestion, as experienced by the bus and coach drivers, were ascertained. The results are shown in Figure 42. In summary, bus and coach drivers think that congestion has reduced to the west of Junction 3 since the bus lane has opened and has increased very slightly on the elevated section. (The congestion to the west of Junction 3 has actually increased since the bus lane opened; the drivers' response probably reflects their general satisfaction with the eastbound M4.)

11.3 CONCLUSIONS

When the bus lane first opened, there was a large amount of adverse publicity in the media. However, when monitoring results were published by the Highways Agency, publicity for the bus lane improved and in general, media comment after six months was favourable. During the last six months, there has been little media attention on the bus lane.

Comments from both the bus and coach companies, and their drivers, have been favourable towards the bus lane. All the companies who responded said that they thought the bus lane was a very good idea. The majority of drivers said that their journey times are improving and that they think the road layout at the merge has made the traffic flow better and safer. The overall opinion expressed by bus and coach drivers was that more schemes like this should be installed.

12. ENVIRONMENTAL IMPACT

To fully evaluate the bus lane scheme, the environmental impact of the scheme has been calculated. The main environmental effects are the levels of noise and vehicle emissions. The effect of the scheme on noise levels and carbon dioxide emissions is described below.

12.1 TRAFFIC NOISE MODEL

In terms of public perception, noise from road traffic is the most pervasive form of environmental impact from transport. In assessing the impact of traffic noise on the environment, an index for describing traffic noise levels has been developed which have been found to correlate measurably well with people's dissatisfaction with road traffic noise experienced in their homes. The noise index, $L_{Aeq,T}$, enables traffic noise levels to be calculated by aggregating the emission levels from individual vehicles in the traffic stream[1]. This model is therefore sensitive to changes in the distribution of vehicles across the carriageway, as have occurred as a result of the bus lane scheme.

In general, traffic noise at a given location is the combined noise from all the individual time varying noise sources, ie the vehicles in the traffic stream. The sources of noise on a vehicle can be separated into two components. The first is generated by the engine, exhaust system and transmission and is the dominant noise source in slow-moving traffic. The second noise component is generated from the interaction of the tyres with the road surface and is the dominant noise source under free-flow conditions at moderate to high road speeds. Noise levels vary depending on vehicle speed, the road surface and whether the road is wet or dry.

12.2 NOISE ANALYSIS AND RESULTS

Traffic data including traffic flow, average traffic speed and composition for each lane of the carriageway was collected at two sites where the bus lane scheme has been introduced on the M4. Site 17/2 is near the bottleneck: prolonged periods of congestion were experienced prior to the introduction of the scheme. Site 20/5 is closer to Junction 3: the traffic was more freely flowing. Now that the bus lane is open, both sites experience shockwaves.

The model predicts the hourly traffic noise levels, $L_{Aeq,1h}$ dB(A), at a distance of 50m from the road. Figure 43 shows the variation in the hourly traffic noise levels for each site. Figure 43(a) shows the values for site 17/2 where prior to the scheme, there was congestion at the bottleneck during peak periods. Generally, traffic noise levels are lower after the scheme was introduced, except during the morning and to a lesser extent the evening peak periods, where traffic noise levels have increased. Figure 43(b) shows

[1] $L_{Aeq,T}$ provides a continuous equivalent noise level measured on the scale of dB(A). It is defined as the noise level which if maintained constant over the time period *T* would contain the same acoustic energy as the actual time varying sound. The index was developed by the Noise Advisory Council in 1978 and is widely used in Europe and the USA.

the corresponding values for site 20/5 where the traffic was less congested during the "before" period. Throughout the daytime period, hourly traffic noise levels are lower after the scheme was introduced.

These results show that the dominant noise component is from tyres, where noise levels increase as speeds increase. The lower speed limits introduced as part of the bus lane scheme have slowed the traffic, and consequently reduced the noise. Where there was a bottleneck prior to the introduction of the scheme, speeds have now increased during the peak periods, resulting in a slight increase in noise during these periods. However, the noise during peak periods is lower than during free-flow conditions.

Near the bottleneck, the average daytime reduction in hourly traffic noise levels, $L_{Aeq,1h}$, was 0.6dB(A) at 50m from the road. A similar result is shown near Junction 3, where the average daytime reduction in hourly traffic noise levels, $L_{Aeq,1h}$, was 1.3dB(A) at 50m from the road.

There have been several studies carried out to establish the relationship between changes in traffic noise levels and the change in the percentage of people annoyed living alongside roads. The results from these surveys have provided input to DETR's methodology for assessing the environmental impact of new roads. The method allows the change in the percentage of people bothered very much or quite a lot to be determined for a given change in the average daytime noise level. Applying the method to the change in noise levels determined at the two sites indicates that a reduction of 0.6dB(A) would reduce the percentage of people bothered very much or quite a lot by about 18%. Similarly, a reduction of 1.3dB(A) would reduce the percentage of people bothered very much or quite a lot by about 22%.

These estimates are based on a methodology which has been derived from surveys where the response to changes in traffic noise may have been influenced by additional changes to the environment, eg alterations in road layout. Introducing a bus lane scheme may not elicit such a reduction in annoyance as indicated above. It would therefore be reasonable to regard these estimates as an upper limit with respect to the acoustic benefits from introducing such schemes until further research is carried out.

Determining any cost benefits in reducing road traffic noise is complex and is site dependent, particular where reducing the noise at source obviates the need for expensive mitigation measures such as constructing noise barriers. However, there are other costs associated with the environmental impact of traffic noise that need to be evaluated. Although there are several valuation methods, the majority of studies use hedonic pricing, where noise differences reflected in the market value of housing are analysed after taking into account other variables. A recent literature review indicates that on average, property prices reduce by about 0.9% for each 1dB increase in noise. This relationship is assumed independent from the initial noise level. If the reverse relationship holds when noise levels are reduced, then house values may increase by between 0.5 to 1.2% when noise levels are reduced by between 0.6 to 1.3dB(A).

12.3 VEHICLE EMISSIONS

The change in the levels of carbon dioxide emissions following the introduction of the bus lane scheme has been estimated. During off-peak periods, the average speed of traffic before the bus lane opened was 67mph. Following the introduction of the lower speed limits, this speed dropped to 56mph. For these average speeds, the level of carbon dioxide emissions for a typical vehicle fleet will drop by 16%.

The level of carbon dioxide emissions is linked to fuel consumption. The drop in speeds when the bus lane scheme was installed will lead to typical fuel consumption for a vehicle using this section of the M4 improving from 37 miles per gallon to 43mpg.

These benefits occur during off-peak periods, when traffic speeds are slower than before the bus lane opened. There has been little change in emissions or fuel consumption during peak periods.

12.4 CONCLUSIONS

Traffic noise levels have been assessed at two sites within 50m of the motorway, providing the following conclusions:

- The dominant noise component on the M4 bus lane section is from tyres, where noise levels increase as speeds increase. The lower speed limits introduced as part of the bus lane scheme have slowed the traffic, and consequently reduced the noise. Where there was a bottleneck prior to the introduction of the scheme, speeds have now increased during the peak periods, resulting in a slight increase in noise during these periods.

- The re-distribution of traffic over the carriageway after the scheme was introduced has had little effect on noise levels.

- Estimated daytime traffic noise levels have on average been reduced by between 0.6 and 1.3 decibels.

- The reduction in the percentage of people bothered very much or quite a lot has been estimated to be between 18 to 22%. This estimate is an upper limit to the acoustic benefits of introducing such a scheme.

- Using hedonic pricing on property values, the reductions in noise levels may lead to property values increasing by between 0.5 to 1.2%.

It is estimated that during off-peak periods, carbon dioxide emissions have been reduced by 16%, and fuel consumption has improved by 16%. There has been little change during peak periods.

13. INCIDENTS

A detailed analysis of the effect of the bus lane scheme on the number of incidents on and around the M4 is outside the scope of this report, which is only looking to detect large changes in the number of incidents. A study of the number of damage only accidents reported to the Heston Control Centre has not shown any large change in the number of accidents on the M4 before and after the bus lane opened compared to the number of accidents on the M25 during the same periods. The number of personal injury accidents is being studied by the London Accident Analysis Unit (LAAU).

Each incident has a different effect on the road network, depending on the location, time of day, severity of the incident etc. It is not possible to quantify the effects of incidents, so a direct comparison between the periods before and after the bus lane opened cannot be carried out. Some general observations are:

- When an incident occurs on the elevated section or near the end of the bus lane, congestion builds up quicker now that the bus lane is open than it did before, as there are only two lanes available for traffic to queue in, rather than three. Therefore, the congestion extends back to Junction 3 more often than it did before the bus lane was opened.

- The performance of the bus lane itself is not affected by incidents, with buses and taxis able to reach the start of the elevated section without queueing. Indeed, it is during severe congestion following an accident that buses save most time (up to an hour in one instance). The new EMS signs have been used to inform drivers of congestion resulting from incidents.

The Metropolitan Police has made the following statement about incidents:

"Before the bus lane was constructed, the M4 eastbound went from three lanes to two lanes just prior to the elevated section. This caused queueing and a resulting higher than average accident rate for a motorway.

The Highways Agency consulted the Police on the construction of the bus lane and as a result of those discussions made several improvements, not only to the bus lane part, but to the complete section of motorway between Junction 4 and Junction 1. This included lowering the speed limit with camera enforcement, better CCTV coverage, including a multiplex recording system, better lane marking and signing and a comprehensive VMS/Matrix signalling system.

From Heston Police Motorway Centre situated next to the bus lane, both control room staff and patrolling officers feel that the alterations have improved the service to the motoring public. Although the statistics for accidents have not been fully examined at this time, Police staff perceive a decrease in accidents attended. Traffic flow has appeared to have improved during the peak hours and with the additional camera coverage, our response to incidents has improved with the knock on effect of being able to remove obstructions more quickly. Enhanced VMS/Matrix signalling has enabled us to control events more effectively and has improved the safety of both the motoring public and police officers dealing with incidents on the carriageway."

14. CONCLUSIONS

This report has examined the performance of the eastbound M4 between Junctions 4B and 2, both during a pre-bus lane monitoring period (October and November 1998) and for the first year since the bus lane opened, from 7th June 1999 until the end of May 2000. The performance of the adjoining road network has also been examined.

Traffic behaviour

Before the bus lane opened, three lanes were available to traffic until 1.5km before the elevated section. Allowing the traffic to continue in three lanes created a bottleneck where the M4 narrowed from three lanes to two, frequently causing long queues of slow moving traffic. Approximately one third of traffic left at Junction 3, leaving the nearside lane under-utilised through Junction 3. The traffic was effectively in two lanes at that point. The bus lane scheme removes the bottleneck because it causes the majority of traffic passing through Junction 3 to stay in two lanes up to and over the elevated section. The loss of one lane through Junction 3 has not caused any severe additional queueing in normal conditions.

One of the main effects of the bus lane scheme has been to change traffic behaviour on the eastbound M4. Following the elimination of the bottleneck, the main causes of congestion are shockwaves of slow moving traffic propagating back from the elevated section. When traffic slows down on the elevated section for any reason during a period of high flow, a shockwave is started, resulting in following traffic stopping briefly once or twice between Junction 3 and the start of the elevated section. These shockwaves were also present before the bus lane opened, but were absorbed in the general queueing at the bottleneck.

Traffic behaviour to the west of Junction 3 has been affected by the bus lane scheme. Before the bus lane opened, the traffic queues at the bottleneck did not generally affect Junction 3 or the London-bound motorway upstream of Junction 3, as three lanes were available for queueing traffic. Separate areas of congestion were present at the merge and diverge areas west of Junction 3 on many occasions. Now that the bus lane is open, on some days the shockwaves extend back through Junction 3 and cause congestion, with the overall congestion west of Junction 3 being worse than it was before the bus lane opened. The new design of the Junction 3 exit slip has reduced the congestion for traffic leaving at that junction.

Bus lane use

Since the bus lane opened, the number of vehicles using the bus lane each weekday has varied between 3000 and 4750. The number of vehicles using the bus lane rose throughout the first year of operation and usage peaked during May 2000. On average 3700 vehicles per day use the bus lane: 3100 are taxis, 500 are buses and 100 are minibuses. The greatest variation is in the number of taxis using the bus lane: between 2400 and 4100 per day. The number of buses/coaches and minibuses using the bus lane each day has remained quite consistent since the bus lane opened; there has been no increase detected in the number of buses using the M4 following the opening of the bus lane.

During peak periods, almost 100% of eligible vehicles use the bus lane. A typical peak hour flow comprises 250 taxis and 60 buses/minibuses. During off-peak periods, the percentage take up is approximately 70% for taxis, 90% for buses and coaches and 50% for minibuses. There are very few rogue vehicles using the bus lane (less than one car per hour).

On average, 7% of the vehicles on the M4 into London use the bus lane, but they contain 21% of the people, including drivers.

Journey times

Congestion occurs on the eastbound M4 into London during the morning and evening peak periods. There is little congestion outside these times. The pattern of journey times for cars before and after the bus lane opened is similar, although the traffic behaviour is now different.

The bus lane scheme has resulted in journey time savings during peak periods (during which 39% of traffic travels) for all vehicles. A direct comparison of journey times during October and November 1998 and the same period in 1999, before and after the bus lane opened, has shown that both cars and buses are saving time. Buses are saving on average 4.1 minutes during the morning peak period of 6:30 to 9:30, and 2.9 minutes during the evening peak period of 17:30 to 20:30. Cars are saving on average 1.3 minutes in the morning peak and 0.6 minutes in the evening peak.

During off-peak periods, journey times for both buses and cars have increased as a result of the lower speed limits along the section. Typical car journey times in uncongested conditions have increased from 4.7 minutes to 5.6 minutes.

There has been a small increase in journey times at the end of the morning peak period, as the congestion takes longer to clear. The change in traffic behaviour when the bus lane opened from queueing to shockwaves has made the traffic more susceptible to poor weather.

The journey time reliability for buses has improved throughout the day since the bus lane opened. The journey time reliability for cars has improved during the evening peak period, and has become slightly worse during the end of the morning peak period, as the congestion takes longer to clear on some days. The journey times during each peak period have become more consistent, as each driver is affected by one or two shockwaves, rather than joining the tail of a queue which builds up and dissipates during the peak period.

Traffic flows

There has been no major change in traffic flows as a result of the bus lane opening. The flows now that the bus lane is open are similar to those before the bus lane opened, therefore the benefits observed have been achieved with similar flow levels. The flows vary according to the time of year, with flows during the summer being higher than during the winter.

Effects of the bus lane

The number of people in each vehicle using the M4 has been estimated by observation. On weekdays, this figure is 1.2 for cars, 2.5 for taxis and 15 for buses. Combining these occupancy figures with flows and changes in journey times provides an estimate of the change in travel time on the M4 as a result of the bus lane scheme.

On weekdays, the overall effect of the scheme on travel time is neutral. There is a benefit of 840 person-hours per day due to a reduction in delay during peak periods, during which 39% of the traffic travels. This is offset by a disbenefit of 840 person-hours per day during off-peak periods due to the lower speed limits. At weekends, the delay caused by the lower speed limits exceeds the time saved during congested conditions: there is an increase in delay of 650 person-hours on Saturdays and 600 person-hours on Sundays as a result of the bus lane scheme. Therefore, there is an increase in delay of 1250 person-hours per week as a result of the bus lane scheme. This is an increase of 1.8% on the total time spent travelling on the section of the M4 affected by the scheme, and is equivalent to an extra 8 seconds on the journey time of each vehicle.

It is estimated that during off-peak periods, traffic noise levels have been reduced by about 1 decibel, carbon dioxide emissions have been reduced by 16%, and fuel consumption has improved by 16%. There has been little change during peak periods.

Accidents are the subject of a longer-term study, but Police staff have perceived a decrease in the number of accidents attended since the lower speed limits were implemented.

Speed compliance

The number of vehicles exceeding the speed limit rose following the introduction of the new lower speed limits. The number of vehicles exceeding the new 50mph speed limit is double the number that exceeded the national speed limit before the bus lane scheme was installed. The compliance during the winter is better than during the summer, possibly due to poorer weather and lighting conditions.

Traffic on the adjoining network

Traffic on the adjoining network has not been adversely affected by the bus lane scheme. Queues at the Junction 3 roundabout are no worse than they were before the bus lane opened and journey times along the alternative A4 route are slightly shorter than during the "before" period. It is still over twice as fast to travel on the M4 between Junction 3 and Junction 2 than it is on the adjoining network. There is no incentive for traffic to divert, nor is there any evidence that it is doing so. Any congestion on the M4 has not affected the performance of the adjacent network.

Road layout

The new road layouts at Junction 3, at the start of the bus lane and at the merge area are all working well. The dedicated exit slip road at Junction 3 has reduced the congestion at that point, and the design of the merge area at the end of the bus lane has smoothed the transition from three lanes to two prior to the elevated section.

Feedback

Feedback has been obtained via comments in the media and a bus/coach company survey. When the bus lane first opened, there was a large amount of adverse publicity in the media. However, when monitoring results were published by the Highways Agency, publicity for the bus lane improved and in general, recent media comments about the bus lane have been favourable. Bus and coach companies, and their drivers, all said they thought the bus lane was a very good idea, because their journey times had improved as a result of the bus lane scheme.

Summary and recommendations

The bus lane scheme has met most of the objectives set out before the scheme was installed. The scheme has resulted in time savings during peak periods for all types of vehicles. On average, each bus is saving 3.5 minutes and each car is saving 1 minute during each peak period.

The general public has a perception that not enough vehicles use the bus lane. The reasons for the restriction in numbers could be included in further publicity. The number of vehicles using the bus lane influences the benefits of the bus lane scheme. If too many vehicles were to use the bus lane, a bottleneck might reappear where the three lanes are reduced to two. Therefore, large numbers of other potentially eligible vehicle types should not be allowed to use the bus lane without careful study.

The lower speed limits were installed for safety reasons. However, the Highways Agency could consider the installation of Variable Speed Limits. It may be possible during off-peak periods for the 50mph limit to be increased to 60mph without compromising safety. This would reduce journey times during off-peak periods, and would increase the cost benefit of the scheme. The 40mph limit at the merge area and on the elevated section should remain, as these are the areas that have the greatest risk of accidents.

The benefits arising from the installation of the M4 bus lane are mostly site specific, with the following characteristics present prior to the bus lane scheme:

- There was a bottleneck where three lanes were reduced to two just before the elevated section,

- An upstream junction where one third of traffic left the motorway.

This meant that the installation of the bus lane scheme enabled cars to benefit, as well as buses and taxis, as two lanes of traffic now flow continuously from Junction 3 onto the elevated section.

The design is specific to this location and cannot easily be transferred to other locations. A similar scheme installed at another location without the characteristics above, may not show benefits for cars. However, the Highways Agency is gaining valuable operational experience that will be of assistance when considering similar schemes.

ANNEX A
DESCRIPTION OF TRAFFIC DATA COLLECTED

There were two phases of data collection, a "before" phase prior to construction of the bus lane, and an "after" phase once the bus lane was operational. The "before" phase was from 11th October 1998 to 4th December 1998, a period of eight weeks. The "after" phase began on 7th June 1999, when the bus lane was opened. The period between 10th October 1999 and 3rd December 1999 provides a direct comparison of the effect of the bus lane scheme, as the seasonal effects are eliminated.

Traffic speeds and flows were collected for each week at 20 existing MIDAS loop sites on the eastbound M4 from west of Junction 4 to the start of the elevated section, located approximately every 500 metres along this section (see Figure 3). Traffic data is available from sites between marker post (MP) 26/4 and 15/6, a distance of 10.8km. Data on individual vehicles has been collected from the sites between Junction 4 and the start of the elevated section (MPs 23/2 to 15/6) so that accurate journey times can be calculated. Data in 5-minute blocks has been collected from the sites between Junctions 4B and 4 (MPs 26/4 to 23/9) so that queue lengths can be monitored. Vehicle length data has been collected from one site between Junctions 3 and 2.

The traffic data was collected by attaching counting equipment to each of the existing MIDAS loops on the eastbound carriageway. The counting equipment is manufactured by Counters & Accessories Ltd; similar equipment has been used to collect data for other HA projects. Each counter is battery powered (with a backup internal battery) and stores a speed, time and lane number for each vehicle that passes over the loop. Each counter can hold data for up to 420,000 vehicles.

Traffic data was collected from Sunday to Friday of each week. The data from each site was downloaded from the equipment during each Saturday, and the equipment was set up to restart at midnight on Saturday. This had the following advantages:

- The downloading was carried out during periods of low flow, reducing the danger resulting from a vehicle parked on the hard shoulder.

- Between Junctions 4 and 3, the weekly flows are approximately 470,000 vehicles. Starting the data collection at midnight on Saturday meant that the equipment collected data for the six busiest days of the week before it filled up. There is relatively little congestion during Saturdays, so the missing data did not cause significant problems.

Saturday data was collected for a six-week period beginning on 6th May 2000. This data has been used to obtain traffic patterns for Saturdays; there is no "before" data to compare it against.

During the "before" period, most of the loops were operational (see Figures 4 and 5). The only loop which was permanently faulty was lane 2 at site 22/7; some other sites had intermittent faults which were all repaired by the end of the "before" period.

During the construction of the bus lane, roadside cabinets were installed to contain MIDAS equipment. The installation of these cabinets resulted in some faulty loop connections during the “after” period (see Figures 6 and 7). The availability of each loop has remained constant throughout the “after” period.

Data has been collected continuously since the bus lane opened on 7th June 1999, apart from two periods:

- Between 27th September 1999 and 17th October 1999, an attempt was made to send the MIDAS data directly to the Heston Control Centre. As a result, the counting equipment was disconnected. Because the connection to Heston did not work properly, data was lost during this period. The counting equipment was reinstalled on 17th October 1999, and data was collected normally from that date onwards.

- Between 10th February 2000 and 11th March 2000, the roadside cabinets were rewired. As a result, data was lost for many of the sites between Junctions 3 and 2 during some or all of this period.

In addition, traffic was observed covertly from overbridges on several occasions. From these observations, traffic behaviour could be analysed, the number of occupants of vehicles determined and the number of rogue vehicles using the bus lane estimated. Video footage of the traffic was also taken.

Traffic data was also collected from the adjoining road network, using two methods:

- Traffic flows and speeds from loops were collected on the northbound approach to Junction 3.

- A car fitted with a Global Positioning System (GPS) receiver was driven along a standard route during one morning peak period per week during the “before” and “after” periods.

ANNEX B
DESCRIPTION OF JOURNEY TIME ALGORITHM

TRL has developed a method of calculating journey times along lengths of motorway using speed data obtained from loops in the road. This method has been used to calculate journey times between Junction 4 and the start of the elevated section.

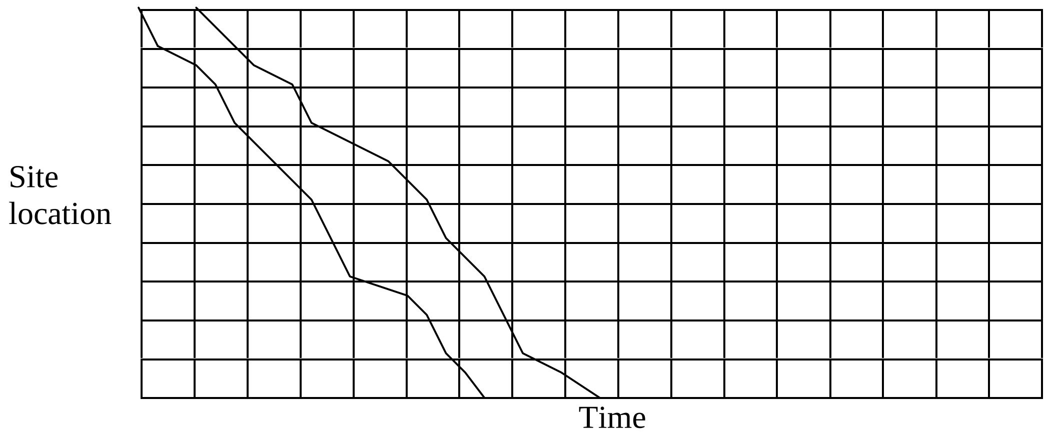
The loops are generally spaced at 500m intervals, and the speed data is available as 1-minute average speeds at each loop site.

<u>Methodology</u>

The journey times are calculated by modelling the progress of a virtual vehicle along the motorway every minute. The motorway is divided into sections, each section being from the midpoint of one pair of loops to the midpoint of the next pair. The speed at each loop site is assumed to apply for the whole of the section for the whole minute.

A vehicle is assumed to arrive at the start of the motorway section at the start of a minute. Its progress is then modelled using the 1-minute speed for the first loop. Whenever the vehicle reaches the midpoint of a pair of loops, or the end of a minute is reached, a new speed is used. The total time for the vehicle to reach the end of the motorway section is calculated. A new vehicle is then modelled, arriving one minute after the first vehicle, and so on.

If a grid of site locations against time is drawn, the paths of the vehicles can be shown as follows:



It should be noted that as each vehicle is assumed to travel at the average traffic speed, a vehicle cannot overtake the one in front. A vehicle's journey time can never be more than one minute quicker than the previous vehicle's journey time.

<u>Vehicle types</u>

Each lane speed is treated separately so that journey times in individual lanes can be calculated. Before the bus lane opened, journey times for typical vehicles were calculated by averaging the journey times in each of the lanes, weighted according to the flow in the lane. Once the bus lane was operational, journey times for priority vehicles (buses and taxis) and non-priority vehicles (eg cars) were calculated separately. Buses were assumed to travel in the bus lane. Journey times for cars were obtained by calculating the weighted average of the journey times in each of the available lanes (ie all lanes up to the start of the bus lane, then lanes 1 and 2 only).

<u>Mean speeds</u>

Mean speeds can be calculated in two ways. The time-mean speed is the arithmetic mean of the individual vehicle speeds, whereas the space-mean speed is the harmonic mean. The space-mean speed is the more accurate measure of the average traffic speed; using the time-mean speed will result in an underestimation of the journey times.

For the M4 bus lane project, individual vehicle speeds are collected and a space-mean speed is calculated. The space-mean method is reasonably accurate as long as the traffic continues to move. When the traffic comes to a halt for part of a minute, the space-mean speed will overestimate the average speed, as stationary traffic is not detected by the loops. For example, if the traffic were stationary for 30 seconds and then moved at 10mph for the remainder of the minute, the space-mean speed would be calculated as 10mph, whereas the real traffic speed is 5mph.

When the traffic comes to a halt for the whole of a minute, different problems apply – see below.

<u>Missing data</u>

It is possible for a speed to be missing, either because there has been no traffic during a minute, or because there has been a loop fault. For the journey time algorithm to work, it is necessary to fill in all the gaps before the journey times are calculated.

When a gap is found, the algorithm first looks for speeds at the same loop for adjacent minutes. If these are found, the speed for the missing minute is assumed to be the average of the speeds for the adjacent minutes (or, if necessary, two minutes away). If there are no adjacent speeds, ie data is missing for at least 5 consecutive minutes, then the gap is filled using the average of the speeds at the two adjacent loops for that minute. If there are no speeds for adjacent loops, ie data is missing for at least three consecutive loops, then the algorithm returns a null value, as it cannot estimate the journey times accurately.

Because the algorithm replaces all zero speeds, it will replace a “real” zero speed, ie a minute in which no traffic passes over a loop because the traffic is stationary in a queue. The loops cannot distinguish between zero speed and flow because of congestion, zero speed and flow because of zero demand, and zero speed and flow because of a loop or transponder fault.

<u>Validation</u>

Actual journey times have been measured on the M4 during two peak periods by videoing traffic at two points and matching specific vehicles at each site. The actual journey times have been compared with the journey times calculated by the algorithm. At high speeds, the results match well. During peak periods, there are two types of congestion. During the “before” period, high-speed traffic was followed by queueing at a bottleneck. During the “after” period, there are shockwave conditions.

For each of these types of congestion, the journey time algorithm underestimated the journey times by about 30 seconds (over a total journey time of 10 to 20 minutes – a minimum average speed of 20mph). The variability was similar for each of the congestion types.

Summary

Journey times have been calculated for sections of motorway using speed data obtained from loops in the road. The loops are spaced every 500m and data is available for each minute. The same counting equipment has been used to collect data from each loop both before and after the bus lane opened.

With this amount of data, the journey time algorithm is reasonably accurate, underestimating the journey times by about 30 seconds out of a total journey time of 20 minutes (an average speed of 20mph). The change in traffic behaviour following the installation of the bus lane has not affected the accuracy of the journey time algorithm.

ANNEX C
CALCULATION OF PERSON-HOURS DELAY

This Annex describes the method for calculating person-hours delay. The bus lane scheme comprises two main elements: a new road layout incorporating the bus lane on the eastbound M4 between Junctions 3 and 2 and new, lower, speed limits between Junctions 4 and 2. Traffic data from the "before" period (October/November 1998) has been compared with the corresponding period after the bus lane opened (October/ November 1999).

Methodology

Person-hour savings have been calculated for all days (including incidents). Weekdays, Saturdays and Sundays have been treated separately. To calculate person-hour savings per day, let

$m_v(t) :=$ The number of minutes saved by vehicle type *v* during time period *t*,

$o_v(t) :=$ The occupancy of vehicle type *v* during time period *t*.

$n_v(t) :=$ The number of vehicles of type *v* on the M4 during time period *t*.

For weekdays, four time periods are considered:

1. Morning peak period: 06:30 – 09:30
2. Inter-peak period: 09:30 – 17:30
3. Evening peak period: 17:30 – 20:30
4. Night-time period: 20:30 – 06:30.

Journey times have been calculated throughout each day. An average journey time has been calculated for the morning and evening peak periods, the inter-peak period and the night-time period.

The quantity $m_v(t)$ is calculated as the difference between the journey time in 1998 for vehicle type *v* during time period *t*, $\tau_{v,1998}(t)$, and the respective value during 1999 (the journey times are calculated as described in Annex B):

$$m_v(t) = \tau_{v,1998}(t) - \tau_{v,1999}(t) .$$

A positive value represents a saving, whilst a negative value represents a disbenefit. The occupancy is an observed quantity, obtained from manual observations from an overbridge on the M4. The number of vehicles on the M4 is obtained from loop data.

The number of person-hours saved (PHS) per day is

$$PHS = \sum_{v,t} m_v(t) o_v(t) n_v(t) / 60 .$$

This calculation of person-hours is carried out for all of the traffic affected by the bus lane scheme. Three types of journey have been considered:

1. Through traffic (ie journeys between Junction 4 and Junction 2)
2. Traffic joining at Junction 3 (ie journeys between Junction 3 and Junction 2)
3. Traffic leaving at Junction 3 (ie journeys between Junction 4 and Junction 3).

Assumptions

- Average occupancy per vehicle type has been observed. The occupancy of cars is assumed to vary according to the time of day, in line with HETA's national statistics. The occupancy of taxis and buses is assumed to be constant throughout the day for both weekdays and weekends ($o_v(t) = o_v$). Table C1 gives the average occupancy for each vehicle type: this is the average number of people (including the driver) in each vehicle, and includes taxis and buses that are empty (ie containing only the driver).

Table C1 – Vehicle occupancy

Time of day	Car	Taxi	Bus
0630-0930 (weekday)	1.21	2.5	15
0930-1730 (weekday)	1.32	2.5	15
1730-2030 (weekday)	1.24	2.5	15
2030-0630 (weekday)	1.26	2.5	15
weekend	1.47	2.5	15

- The occupancies are assumed to be the same for each journey type.

- The number of vehicles of each type is assumed to be constant from weekday to weekday, and from year to year. Tables C2 to C4 give the number of vehicle of each type during each weekday time period, for each of the three types of journey. There are very few buses joining or leaving the M4 at Junction 3.

Table C2 – Average weekday flows (through traffic between Junction 4 and Junction 2)

Time of day (weekday)	Flow per period			
	Car	Taxi	Bus	TOTAL
0630-0930	8,150	700	175	9,025
0930-1730	17,950	1,050	275	19,275
1730-2030	8,450	675	125	9,250
2030-0630	7,300	525	75	7,900
TOTAL	41,850	2,950	650	45,450

Table C3 – Average weekday flows (traffic joining at Junction 3)

Time of day (weekday)	Flow per period			
	Car	Taxi	Bus	TOTAL
0630-0930	1,350	125	0	1,475
0930-1730	2,975	150	0	3,125
1730-2030	1,400	100	0	1,500
2030-0630	1,200	75	0	1,275
TOTAL	6,925	450	0	7,375

Table C4 – Average weekday flows (traffic leaving at Junction 3)

Time of day (weekday)	Flow per period			
	Car	Taxi	Bus	TOTAL
0630-0930	5,125	175	0	5,300
0930-1730	11,025	275	0	11,300
1730-2030	5,250	175	0	5,425
2030-0630	4,475	150	0	4,625
TOTAL	25,875	775	0	26,650

- All types of vehicle leaving at Junction 3 are assumed to have the same journey times.

- The distribution of incidents during the “before” and “after” periods is assumed to be typical, so that any changes in journey times are directly a result of the bus lane scheme.

- Taxis are assumed to travel at the quicker of the car and bus journey times (for both before and after periods).

Confounding

In order to assess the true economic benefit of the bus lane scheme, the separate effect of the new speed limits should be eliminated from the data. This would only be possible by comparing data from the eastbound M4 between Junctions 3 and 2 for “before” and “after” periods for the same time of year and with the same speed limits in operation. Due to the time constraints of the implementation of the system, this was not feasible.

RESULTS

Weekdays

Tables C5 to C7 show the changes in journey times for each type of vehicle as a result of the bus lane scheme. The changes have been calculated for all weekdays (including incidents), for each of the three journey types. A positive change represents a quicker journey time. Because very few buses join or leave at Junction 3, no changes have been measured for buses for these journey types.

Table C5 – Changes in average journey times (through traffic)

Time of day (weekday)	Change in journey time from "before" to "after" (minutes)		
	Car	Taxi	Bus
0630-0930	1.3	4.1	4.1
0930-1730	-1.0	-0.7	-0.7
1730-2030	0.6	2.9	2.9
2030-0630	-1.2	-1.2	-1.2

Table C6 – Changes in average journey times (traffic joining at Junction 3)

Time of day (weekday)	Change in journey time from "before" to "after" (minutes)	
	Car	Taxi
0630-0930	1.7	4.5
0930-1730	-0.9	-0.6
1730-2030	0.7	3.0
2030-0630	-1.1	-1.1

Table C7 – Changes in average journey times (traffic leaving at Junction 3)

Time of day (weekday)	Change in journey time from "before" to "after" (minutes)	
	Car	Taxi
0630-0930	-0.4	-0.4
0930-1730	-0.1	-0.1
1730-2030	-0.1	-0.1
2030-0630	-0.1	-0.1

Combining Table C1 with the corresponding pairs of tables (C2 and C5, C3 and C6, C4 and C7) gives the total person-hours saved or lost during each period for each type of journey. The results are summarised in Tables C8 to C10. A positive value indicates a saving; a negative value represents a disbenefit.

Table C8 – Person-hour savings per weekday (through traffic between Junction 4 and Junction 2)

Time of day (weekday)	Savings per period (person-hours)			
	Car	Taxi	Bus	TOTAL
0630-0930	213	120	179	512
0930-1730	-394	-31	-48	-473
1730-2030	105	81	91	277
2030-0630	-183	-26	-23	-232
TOTAL	-259	144	199	84

Table C9 – Person-hour savings per weekday (traffic joining at Junction 3)

Time of day (weekday)	Savings per period (person-hours)			
	Car	Taxi	Bus	TOTAL
0630-0930	47	23	0	70
0930-1730	-59	-4	0	-63
1730-2030	20	13	0	33
2030-0630	-28	-3	0	-31
TOTAL	-20	29	0	9

Table C10 – Person-hour savings per weekday (traffic leaving at Junction 3)

Time of day (weekday)	Savings per period (person-hours)			
	Car	Taxi	Bus	TOTAL
0630-0930	-41	-3	0	-44
0930-1730	-24	-1	0	-25
1730-2030	-11	-1	0	-12
2030-0630	-9	-1	0	-10
TOTAL	-85	-6	0	-91

Combining Tables C8 to C10 gives the total person-hours saved or lost during each period. The results are summarised in Table C11. A positive value indicates a saving; a negative value represents a disbenefit.

Table C11–Person-hour savings per weekday (all journeys)

Time of day (weekday)	Savings per period (person-hours)			
	Car	Taxi	Bus	TOTAL
0630-0930	219	140	179	538
0930-1730	-477	-36	-48	-561
1730-2030	114	93	91	298
2030-0630	-220	-30	-23	-273
TOTAL	-364	167	199	2

The savings of 836 person-hours during the peak periods are due to the improved road layout. The disbenefits of 834 person-hours during the off-peak periods are due to the lower speed limits. Overall, the effect of the bus lane scheme on weekdays is neutral.

Weekends

A similar method of calculation to that described above has been used for Sundays. Sunday lunchtimes and evenings are congested; the remainder of Sunday is free-flowing. The flow and journey time data for Sundays are summarised in Tables C12 to C17. Positive values indicate savings; negative values represent disbenefits.

Table C12 – Average Sunday flows (through traffic between Junction 4 and Junction 2)

Time of day (Sunday)	Flow per period			
	Car	Taxi	Bus	TOTAL
0000-1200	11,575	775	250	12,600
1200-2200	23,600	1,625	500	25,725
2200-0000	2,725	225	50	3,000
TOTAL	37,900	2,625	800	41,325

Table C13 – Average Sunday flows (traffic joining at Junction 3)

Time of day (Sunday)	Flow per period			
	Car	Taxi	Bus	TOTAL
0000-1200	1,925	125	0	2,050
1200-2200	3,900	275	0	4,175
2200-0000	475	25	0	500
TOTAL	6,300	425	0	6,725

Table C14 – Average Sunday flows (traffic leaving at Junction 3)

Time of day (Sunday)	Flow per period			
	Car	Taxi	Bus	TOTAL
0000-1200	7,175	225	0	7,400
1200-2200	14,600	500	0	15,100
2200-0000	1,700	75	0	1,775
TOTAL	23,475	800	0	24,275

Table C15 – Changes in average journey times (through traffic)

Time of day (Sunday)	Change in journey time from "before" to "after" (minutes)		
	Car	Taxi	Bus
0000-1200	-0.9	-0.9	-1.2
1200-2200	-0.5	1.4	1.4
2200-0000	-0.9	-0.9	-1.2

Table C16 – Changes in average journey times (traffic joining at Junction 3)

Time of day (Sunday)	Change in journey time from "before" to "after" (minutes)	
	Car	Taxi
0000-1200	-0.8	-0.8
1200-2200	-0.4	1.5
2200-0000	-0.8	-0.8

Table C17 – Changes in average journey times (traffic leaving at Junction 3)

Time of day (Sunday)	Change in journey time from "before" to "after" (minutes)	
	Car	Taxi
0000-1200	-0.1	-0.1
1200-2200	-0.1	-0.1
2200-0000	-0.1	-0.1

Table C18 summarises the overall person-hours saved or lost during each period on a Sunday. A positive value indicates a saving; a negative value represents a disbenefit.

Table C18 – Person-hour savings per Sunday (all journeys)

Time of day (Sunday)	Savings per period (person-hours)			
	Car	Taxi	Bus	TOTAL
0000-1200	-312	-34	-75	-421
1200-2200	-364	110	175	-79
2200-0000	-73	-9	-15	-97
TOTAL	-749	67	85	-597

Because there is less congestion on Sundays compared to weekdays, there is less benefit from the bus lane itself, and more disbenefit from the lower speed limits. Overall, there is a disbenefit to the bus lane scheme of 597 person-hours every Sunday.

No traffic data is available for Saturdays, so the effect of the scheme on Saturdays has been estimated using data from Traffic*master* infrared sensors, which provide information on slow speeds at various locations. There was midday congestion at the bottleneck on four of the eight Saturdays during October/November 1998, before the bus lane opened. During October/November 1999, with the bus lane operational, there was no Saturday congestion.

The length of the queue has been estimated at either one or three miles, depending on the number of consecutive Traffic*master* sensors logging slow speeds. The average speed in the queue has been assumed to be 20mph. These assumptions result in an average delay per vehicle of either 3 or 9 minutes, depending on the length of the queue. Tables C19 to C21 summarise the averaged Saturday data.

Table C19–Saturday estimates (through traffic between Junction 4 and Junction 2)

Time of day (Saturday)	Change in journey time (min)	Flow (veh)	Savings (person-hours)
1100-1200	0	3,100	0
1200-1400	1.3	5,250	168
1400-1000	-0.9	31,650	-700
TOTAL		40,000	-532

Table C20 – Saturday estimates (traffic joining at Junction 3)

Time of day (Saturday)	Change in journey time (min)	Flow (veh)	Savings (person-hours)
1100-1200	0.1	500	1
1200-1400	1.4	850	29
1400-1000	-0.8	5,150	-101
TOTAL		6,500	-71

Table C21 – Saturday estimates (traffic leaving at Junction 3)

Time of day (Saturday)	Change in journey time (min)	Flow (veh)	Savings (person-hours)
1100-1200	-0.1	1,825	-4
1200-1400	-0.1	3,075	-8
1400-1000	-0.1	18,575	-46
TOTAL		23,475	-58

Because there is less congestion on Saturdays compared to weekdays (and Sundays), there is less benefit from the bus lane itself, and more disbenefit from the lower speed limits. Overall, there is a disbenefit to the bus lane scheme of 661 person-hours every Saturday.

Summary

The main points that can be noted are:

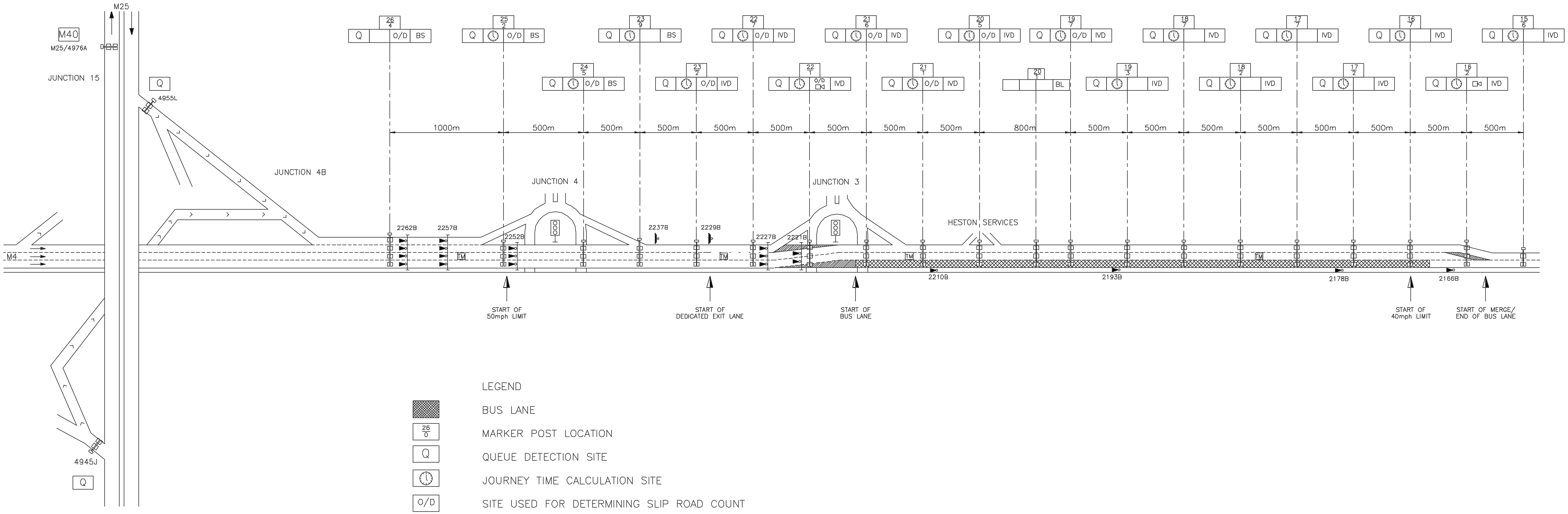
- During free flow conditions, all vehicles suffer a disbenefit as a result of the lower speed limits.

- During congested conditions, there is an overall benefit for both cars and buses. Cars benefit as a result of the improved road layout. Taxis and buses benefit from the bus lane itself, since it allows them to pass the congestion, but at a lower speed than they would have been able were the speed limits not to have been lowered.

- The overall effect of the bus lane scheme on weekdays is neutral. There is a benefit of 836 person-hours per weekday due to a reduction in delay during peak periods, which is offset by a disbenefit of 834 hours per weekday due to the lower speed limits.

- There is a disbenefit of 660 person-hours each Saturday, and a disbenefit of 600 person-hours each Sunday.

- There is therefore an overall disbenefit of 1250 person-hours per week as a result of the bus lane scheme.



LEGEND

	BUS LANE
26/0	MARKER POST LOCATION
Q	QUEUE DETECTION SITE
	JOURNEY TIME CALCULATION SITE
O/D	SITE USED FOR DETERMINING SLIP ROAD COUNT
M40	SITE USED AS A GUIDE TO DETERMINING No. OF VEHICLES DIVERTING TO M40
	CAMERA CALIBRATION SITE
500m	DISTANCE BETWEEN LOOP SITES
2275B	POST 75 MOUNTED SIGNAL SITE
	GANTRY MOUNTED SIGNAL SITE
	MIDAS LOOP SITE
2273B	ENHANCED MESSAGE SIGN SITE
	SIGNAL CONTROLLED ROUNDABOUT
BS	'BINNED' SPEED COUNTER SITE
BL	'BINNED' LENGTH COUNTER SITE
IVD	INDIVIDUAL VEHICLE DATA SITE
TM	TRAFFIC MASTER SITE
	TRAFFIC DIRECTION

A	INITIAL ISSUE	SB 7.10.98
ISSUE	AMENDMENTS	APPD/DATE

HIGHWAYS AGENCY
TRAFFIC SYSTEMS & SIGNING
TOLLGATE HOUSE
HOULTON STREET
BRISTOL BS2 9DJ

DETR Environment Transport Regions

This drawing was generated on computer and must not be manually updated

TITLE

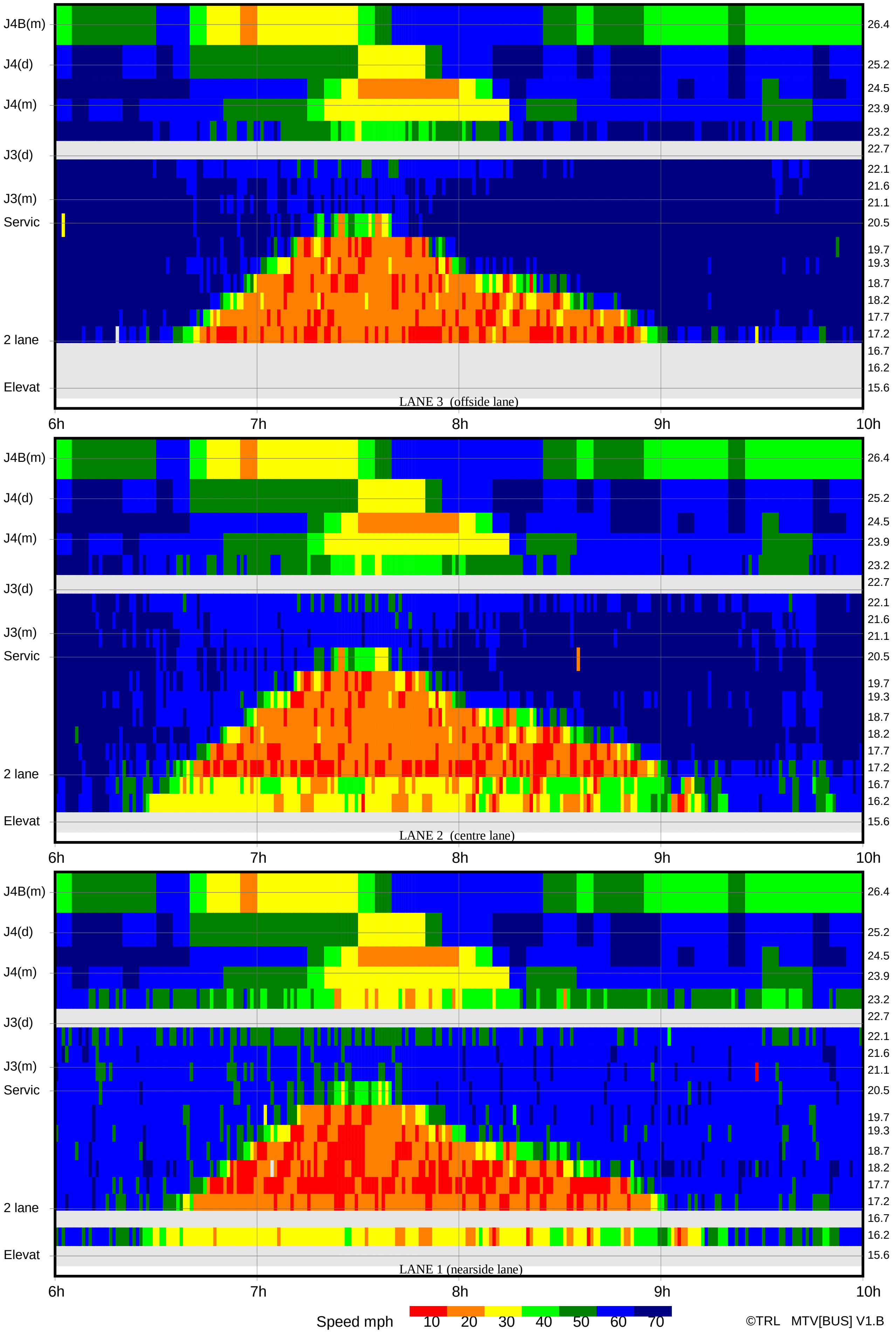
M4 BUS LANE – MONITORING SITES

ORIGINAL DRAWING SIZE: 420 x 594
ALL DIMENSIONS ARE IN MM
TOLERANCE ± UNLESS OTHERWISE STATED
THIRD ANGLE PROJECTION DO NOT SCALE

DRN JB	CHKD SB	SCALE NTS
DATE 27.8.98	DATE 28.8.98	
DRG. NO. MCY 1005		SHT. NO. 1/1

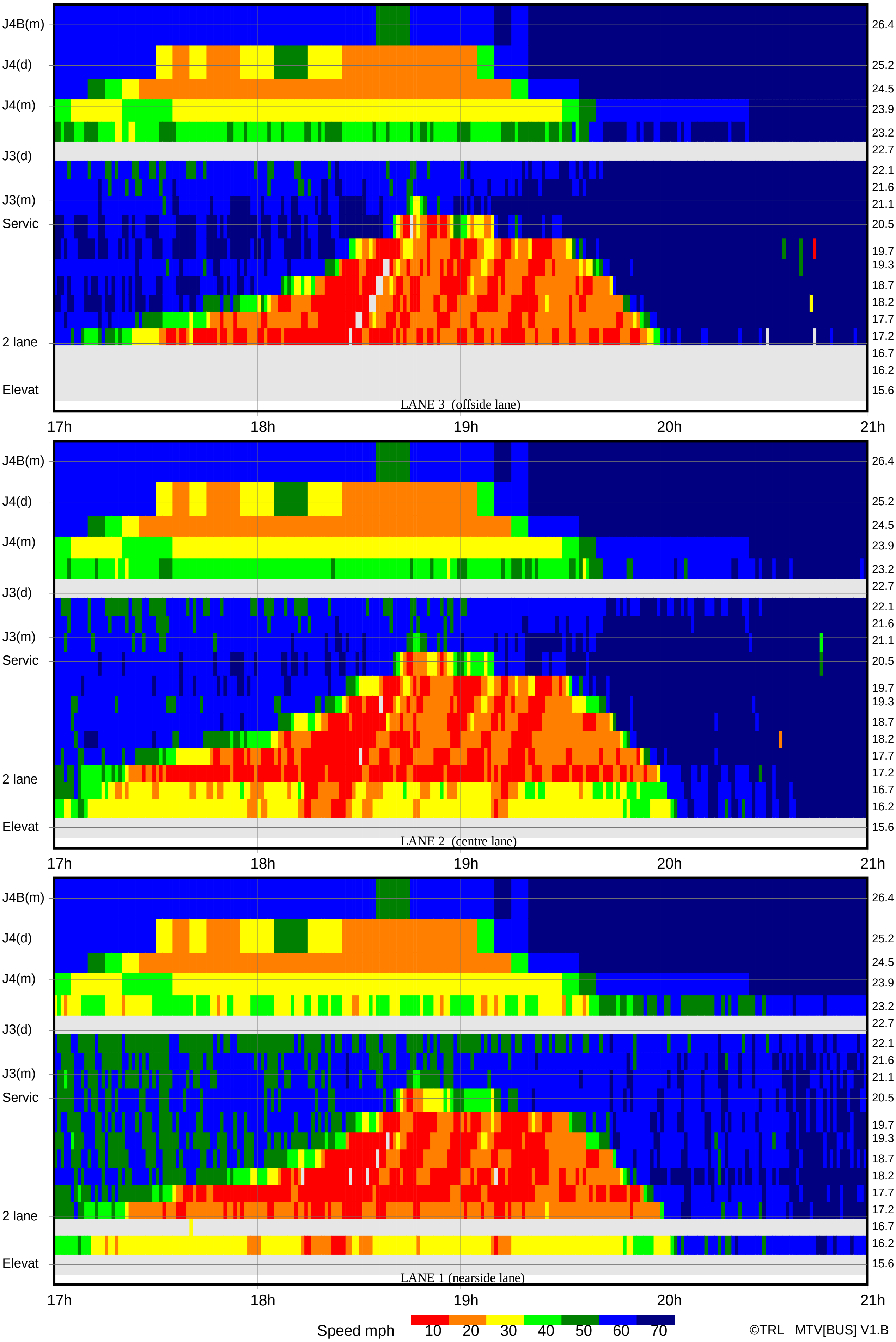
M4 Eastbound (B) lane speeds on Monday 2-Nov-1998

Figure 4: during pre-bus lane monitoring period



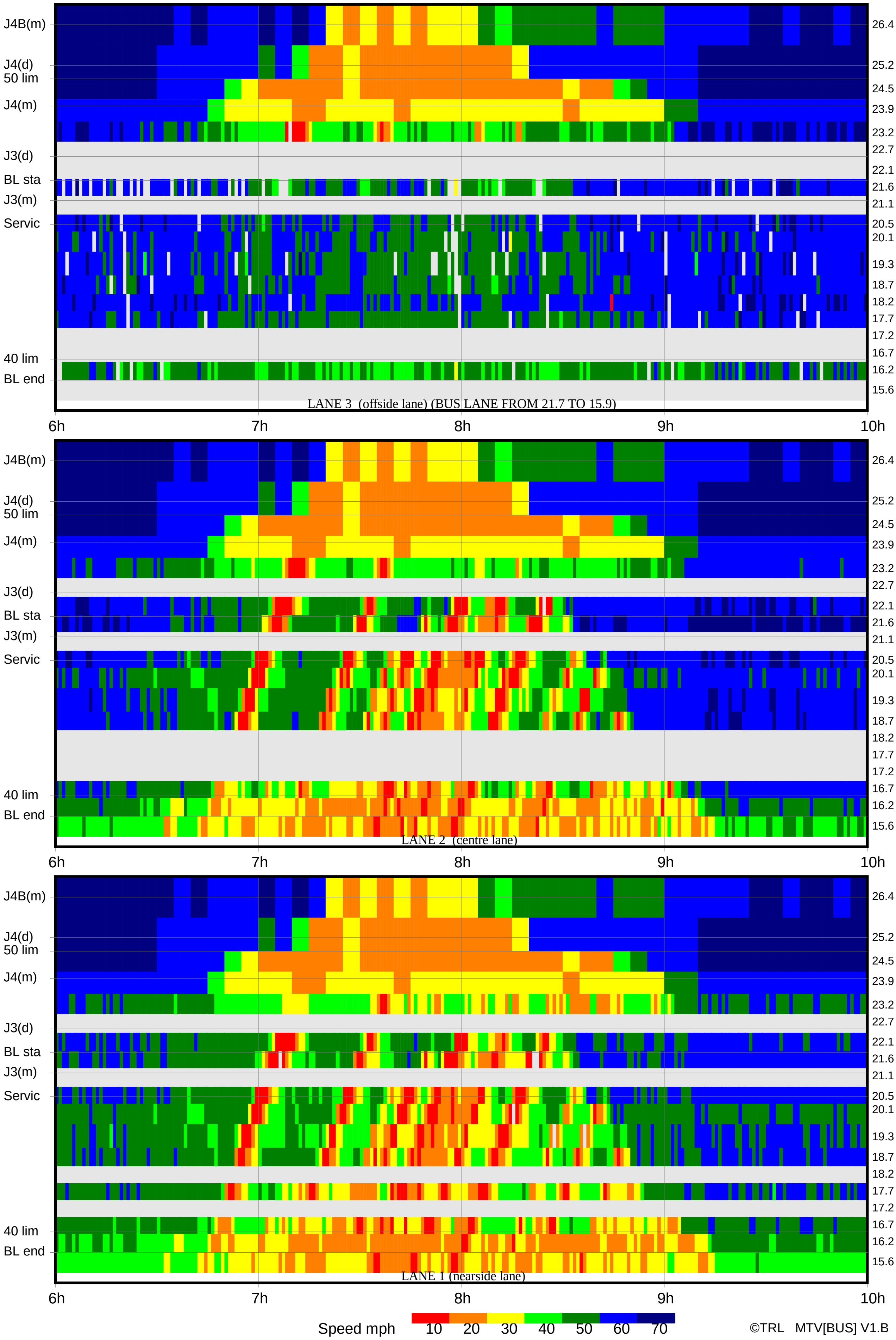
©TRL MTV[BUS] V1.B

M4 Eastbound (B) lane speeds on Monday 2-Nov-1998
Figure 5: during pre-bus lane monitoring period



M4 Eastbound (B) lane speeds on Monday 1-Nov-1999

Figure 6: bus lane operational



M4 Eastbound (B) lane speeds on Monday 1-Nov-1999

Figure 7: bus lane operational

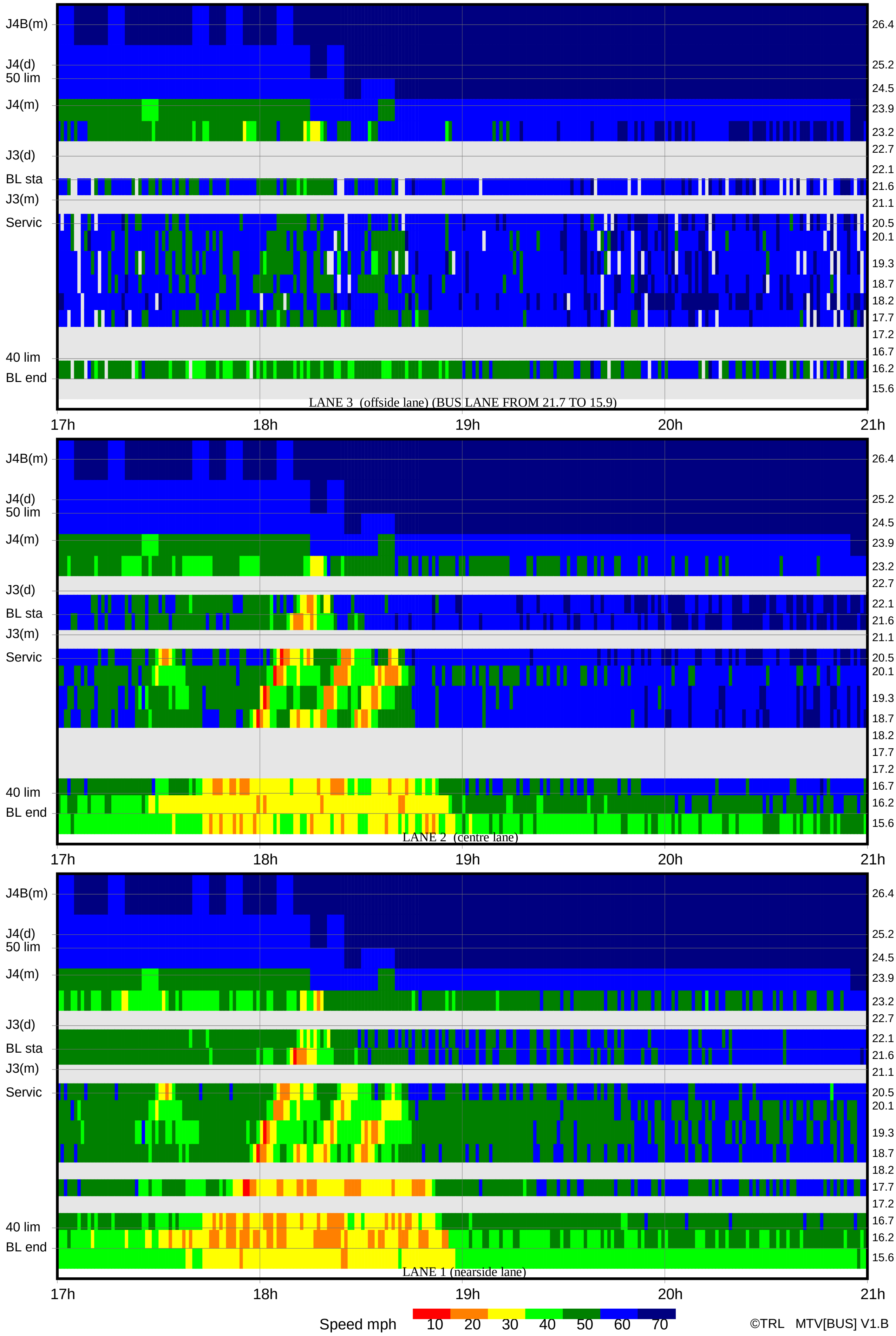


Figure 8
Typical car journeys along M4 at 7am on a November weekday

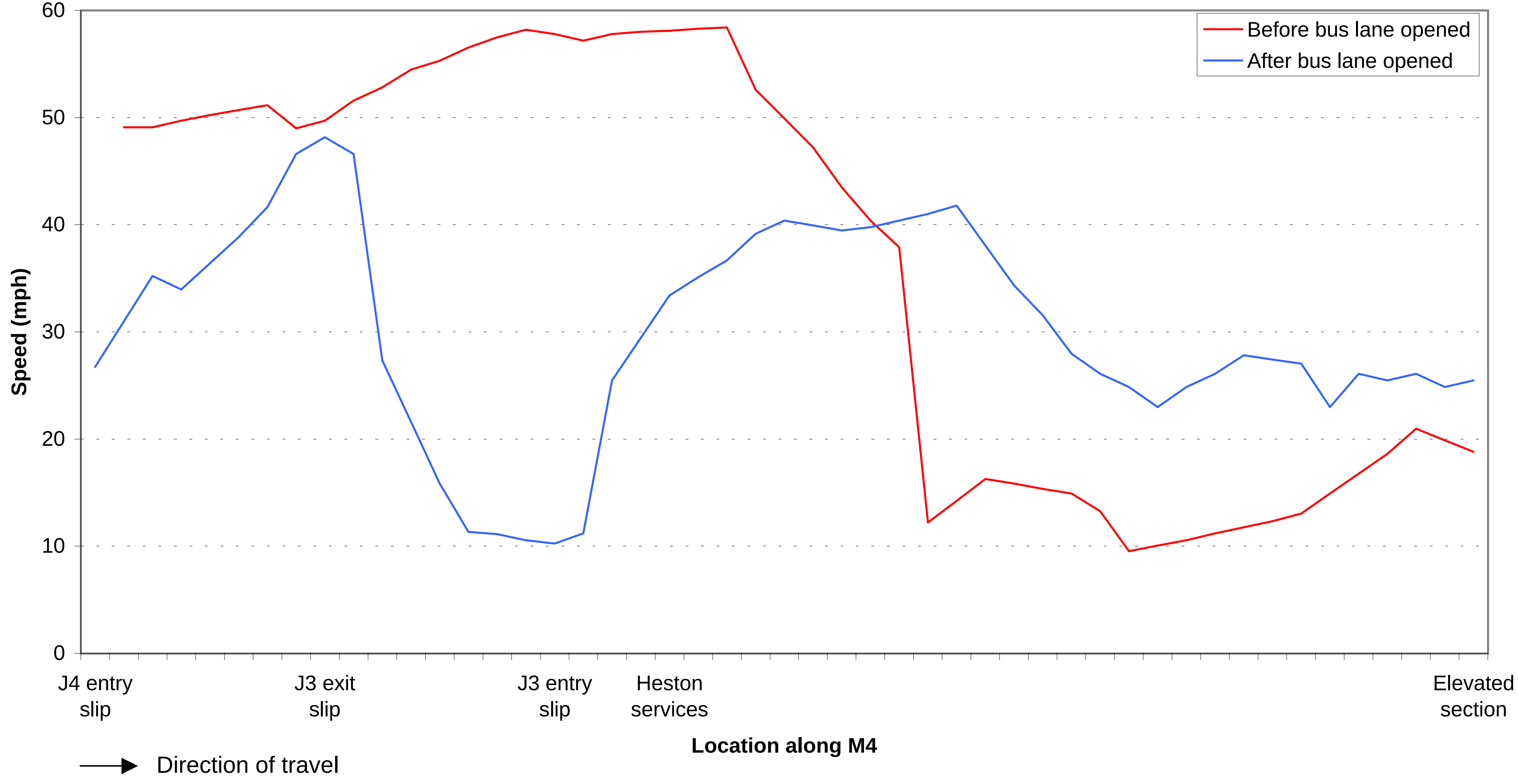


Figure 9
Speeds for all vehicle types at M4 J3: comparison of pre-bus lane monitoring period (Nov 98) and since bus lane opened (Nov 99)
(site 21/6: lane 1)

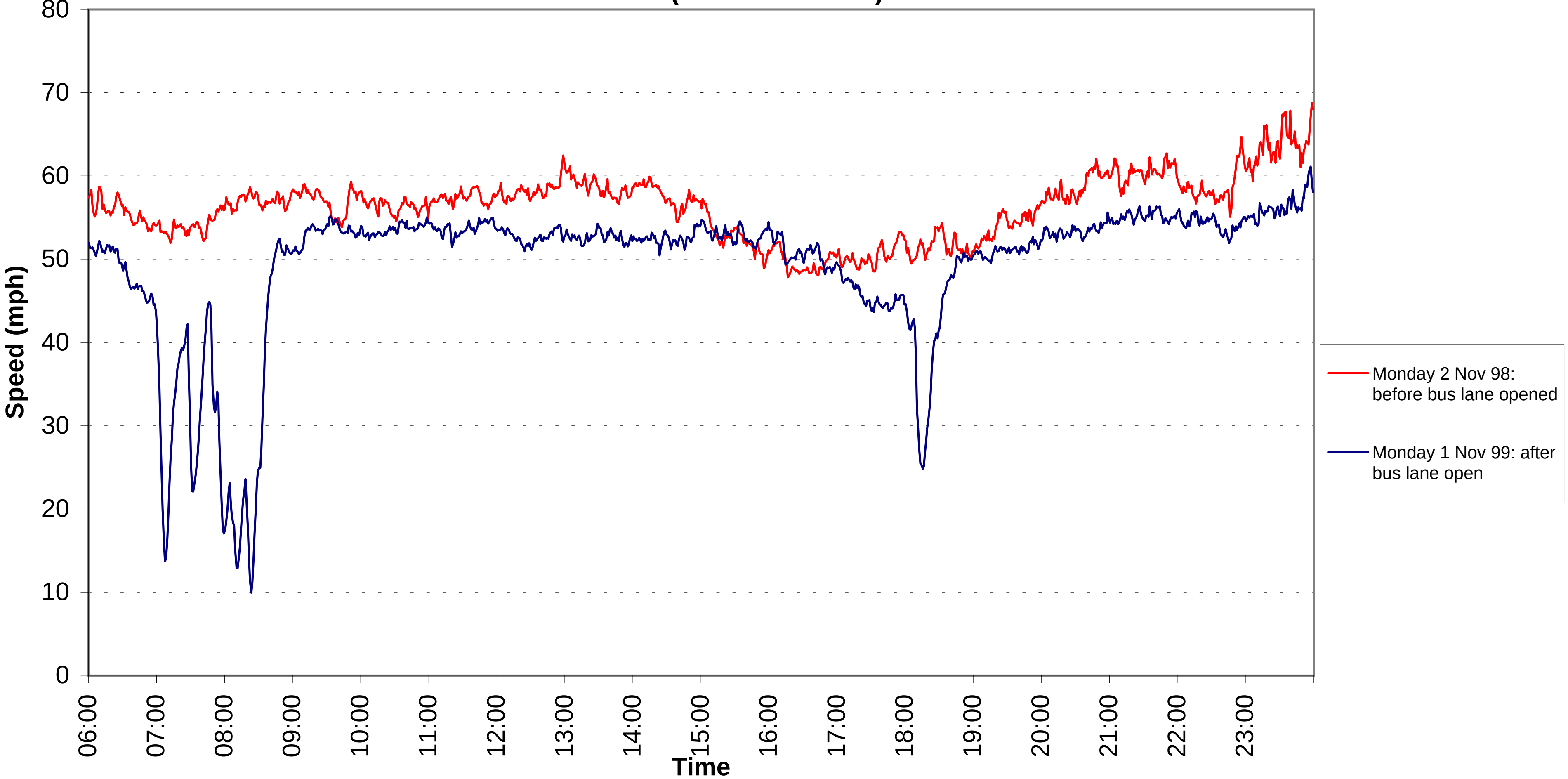


Figure 10

Speeds for traffic between M4 J3 and J2: comparison for pre-bus lane monitoring period (Nov 98: traffic composed of all vehicle types) and after bus lane opened (Nov 99: traffic composed of cars and HGVs)

(site 18/7: lane 1)

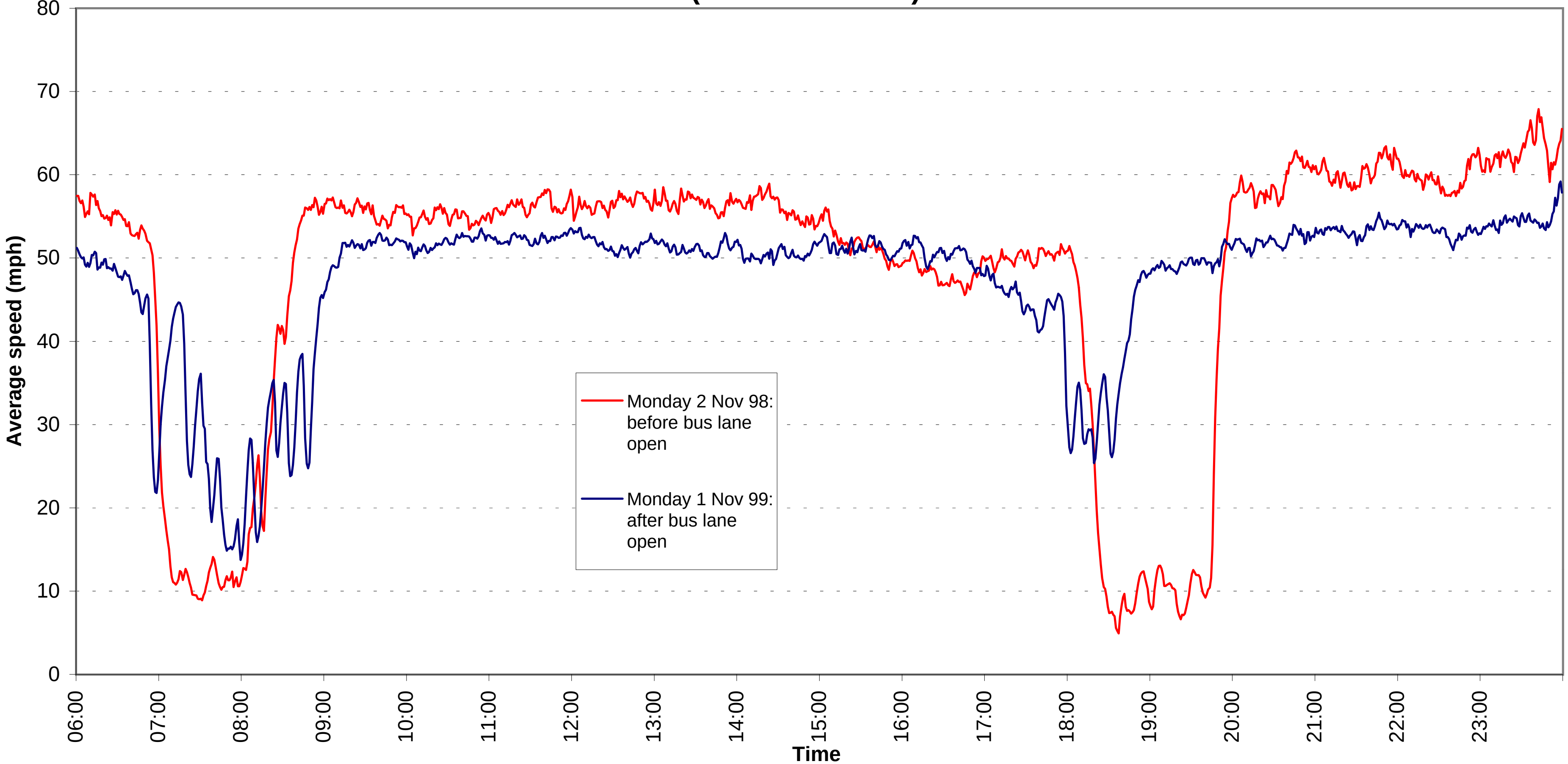


Figure 11
Journey time (M4 J4 - start of elevated section)
(8.4 km)
Average of typical days (11 Oct - 4 Dec 1998): before bus lane opened

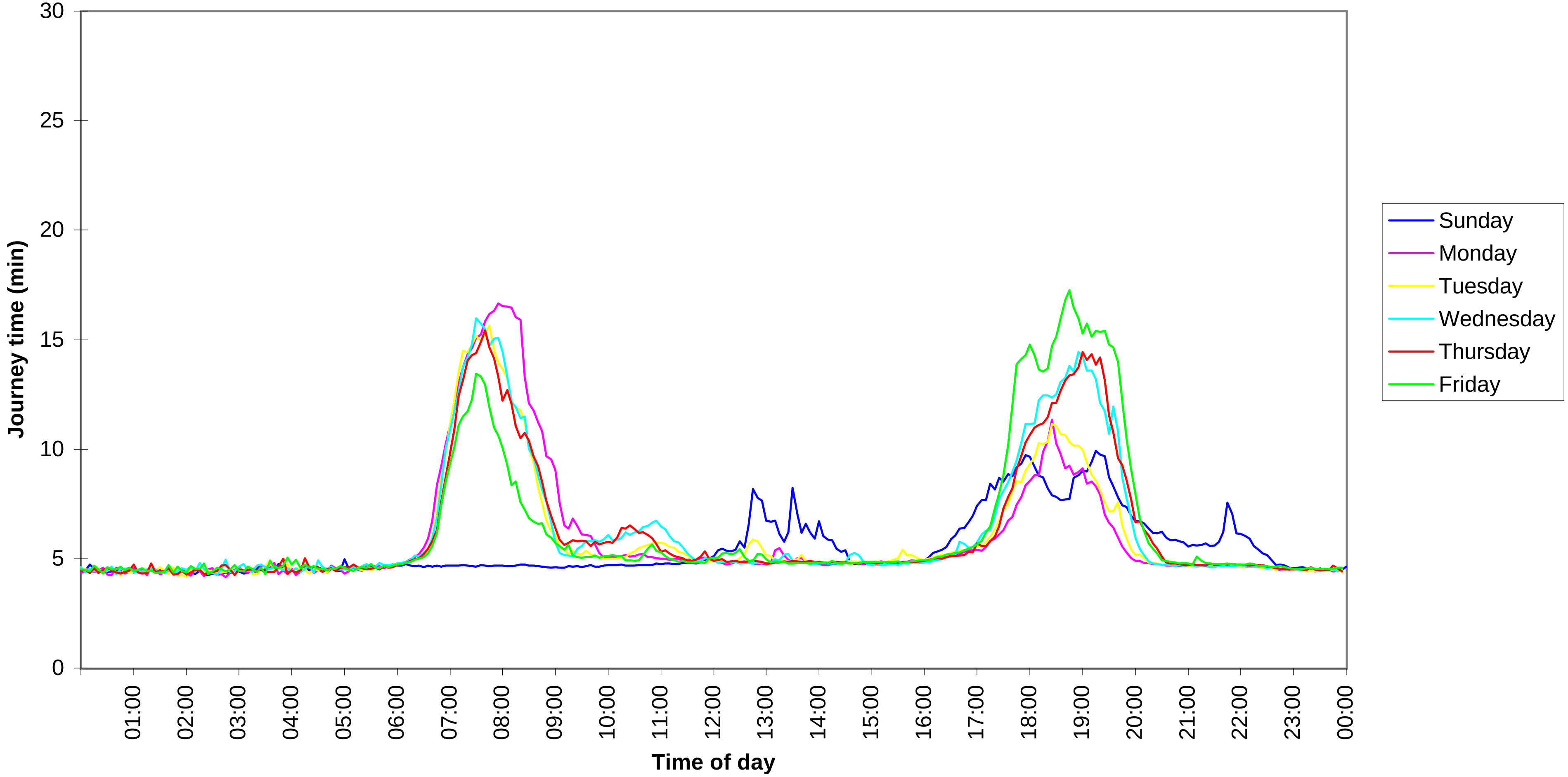


Figure 12
Car journey time (M4 J4 - start of elevated section)
(8.4 km)
Average of typical days (17 October - 3 December 1999): bus lane in operation

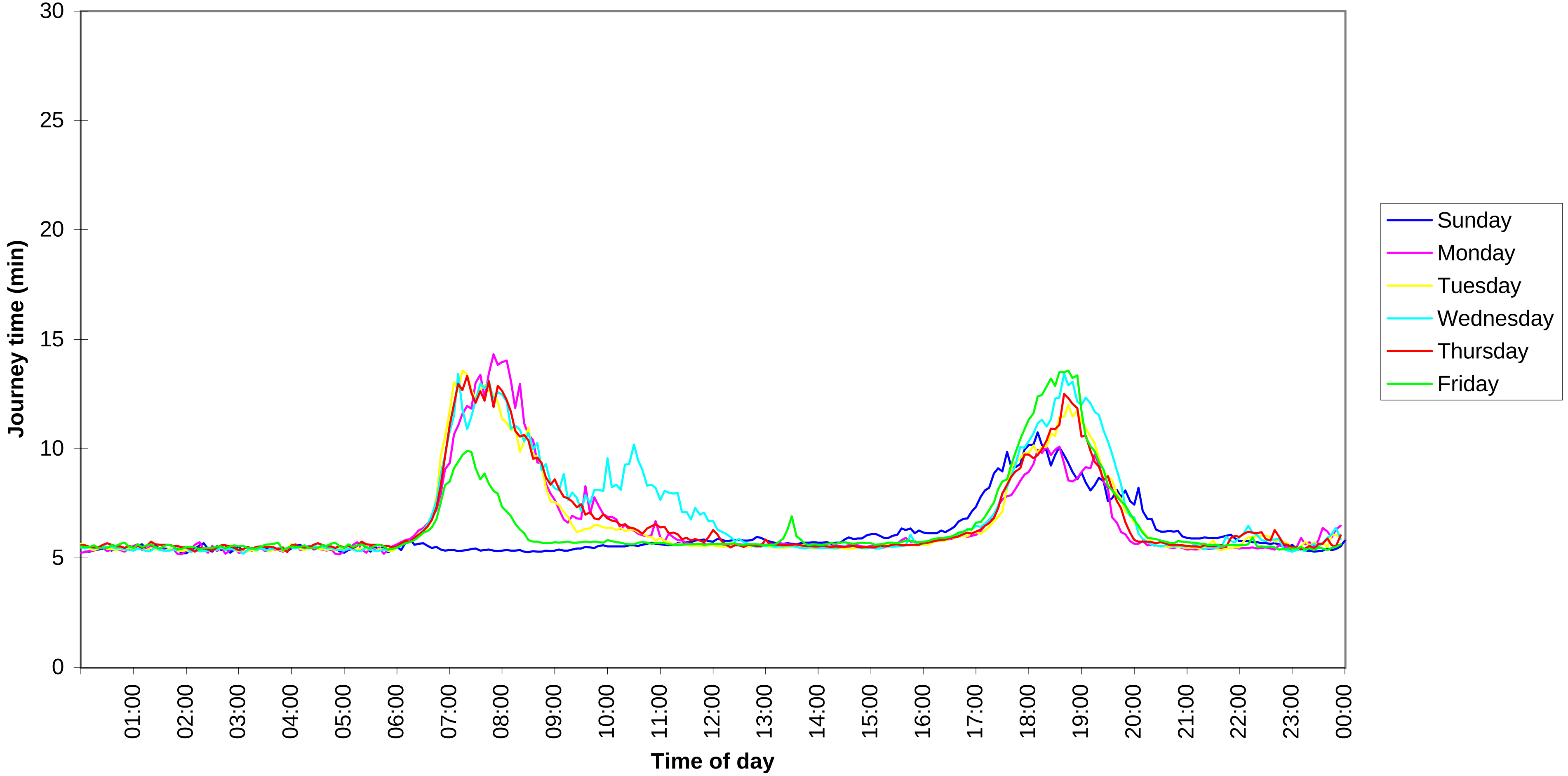


Figure 13
Bus journey time (M4 J4 - start of elevated section)
(8.4 km)

Average of typical days (17 October - 3 December 1999): bus lane in operation

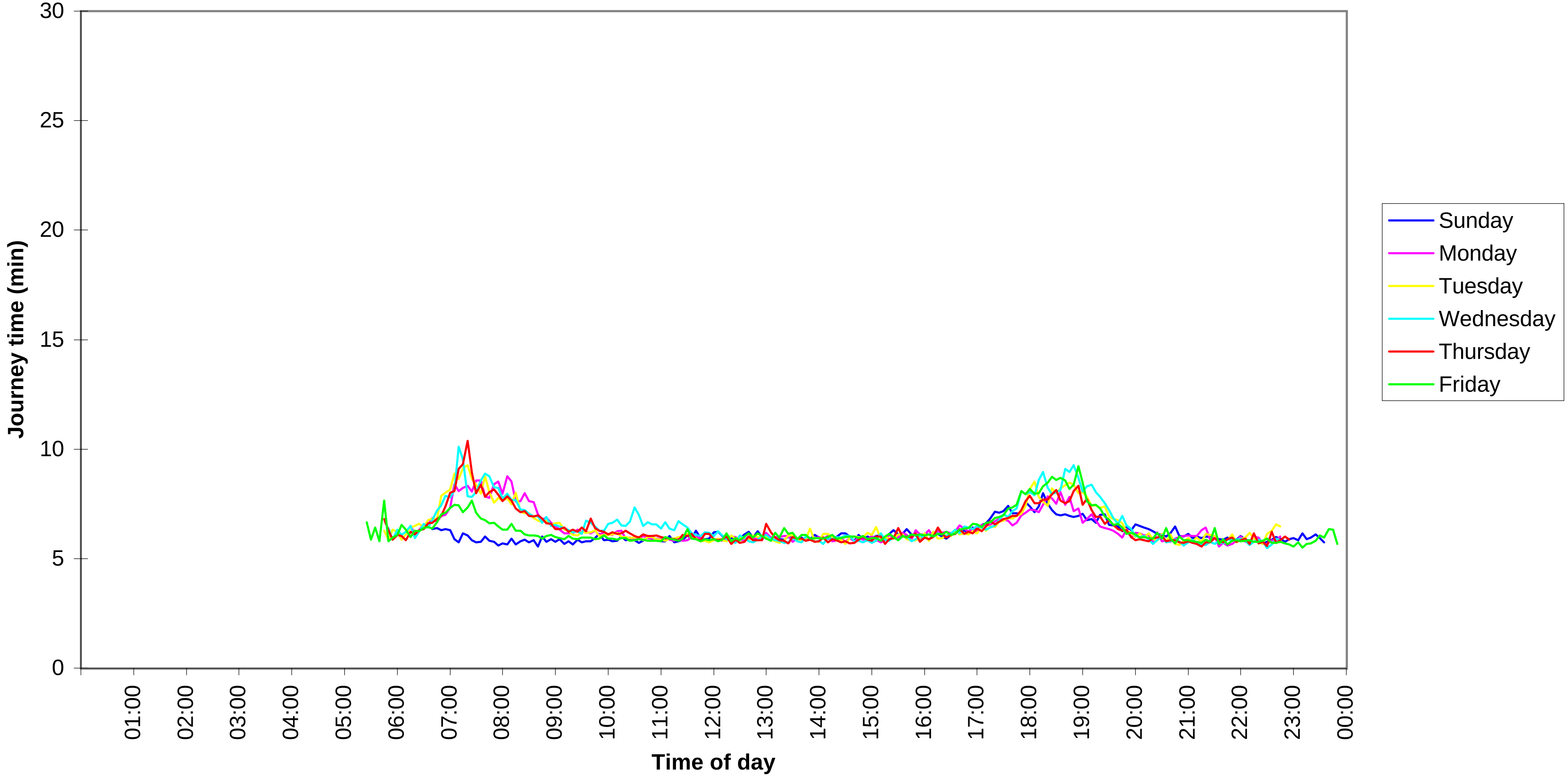


Figure 14
Journey time (M4 J4 - start of elevated section)
(8.4 km)
Weekdays excluding incidents

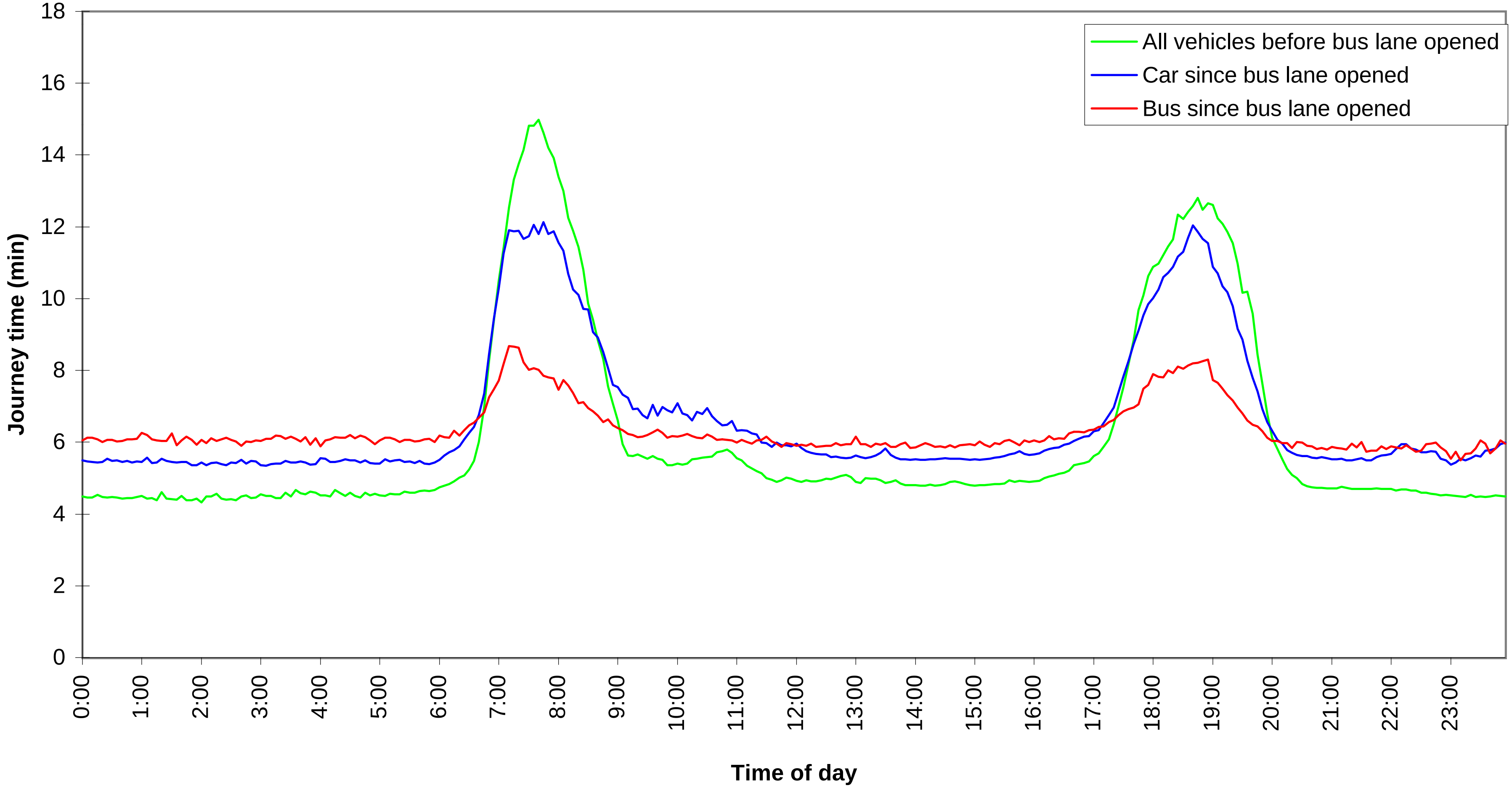


Figure 15
Journey time (M4 J4 - start of elevated section)
(8.4 km)
All weekdays (including incidents)

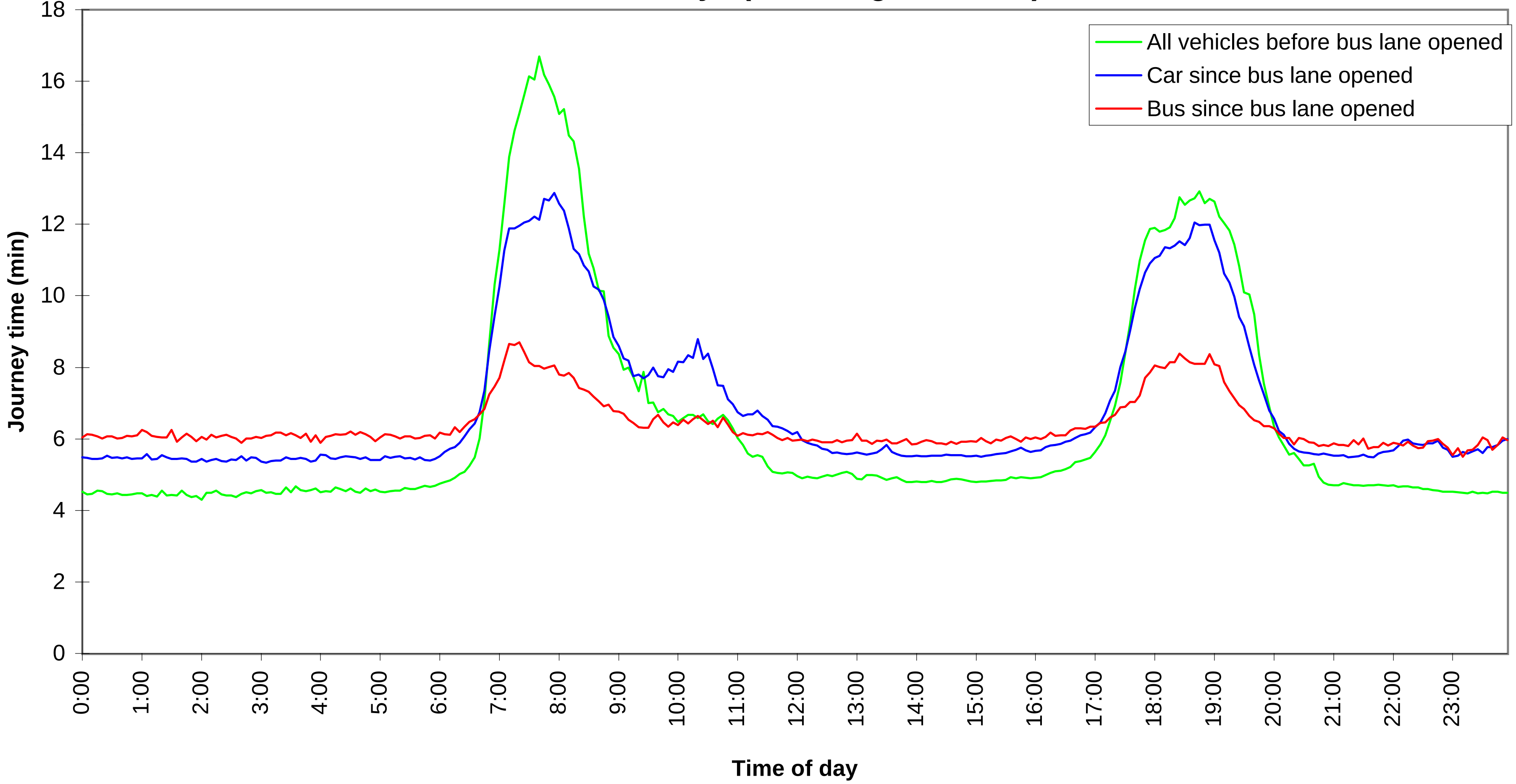


Figure 16
Average weekday journey times (M4 J4-J3)
(1.2km)

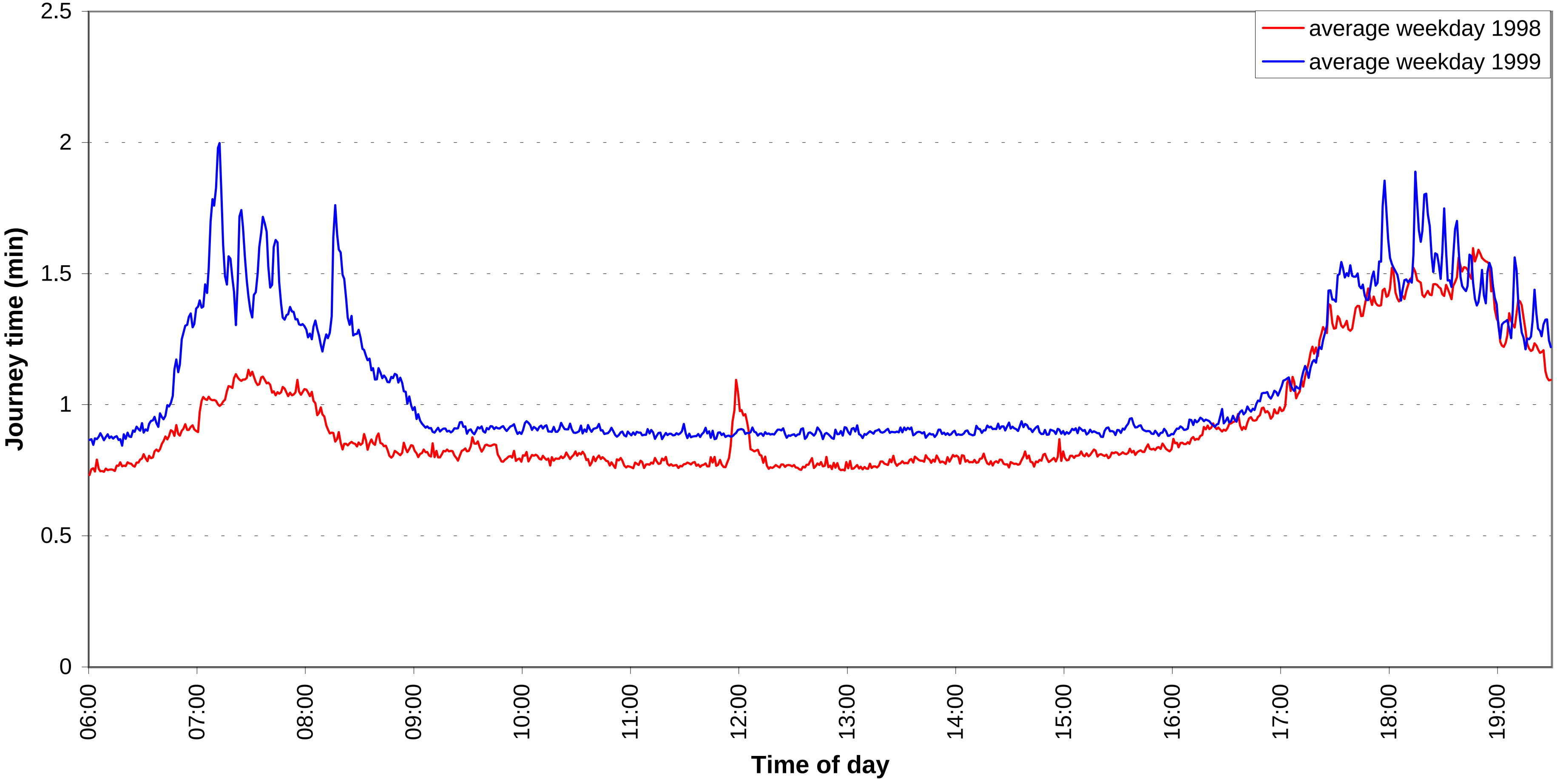


Figure 17
Journey time variability (M4 J4 - start of elevated section)
Weekdays excluding incidents

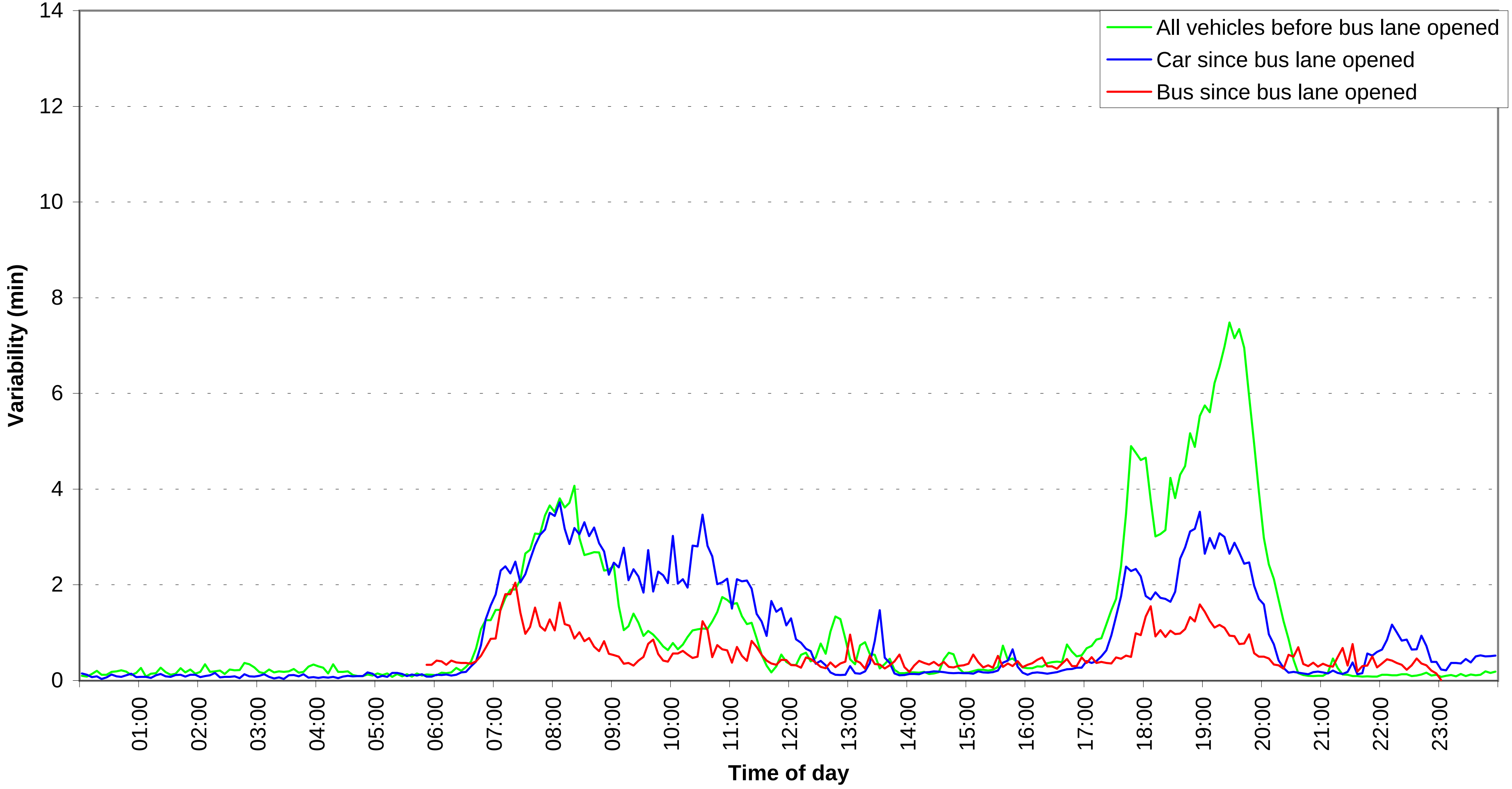


Figure 18
Journey time variability (M4 J4 - start of elevated section)
All weekdays (including incidents)

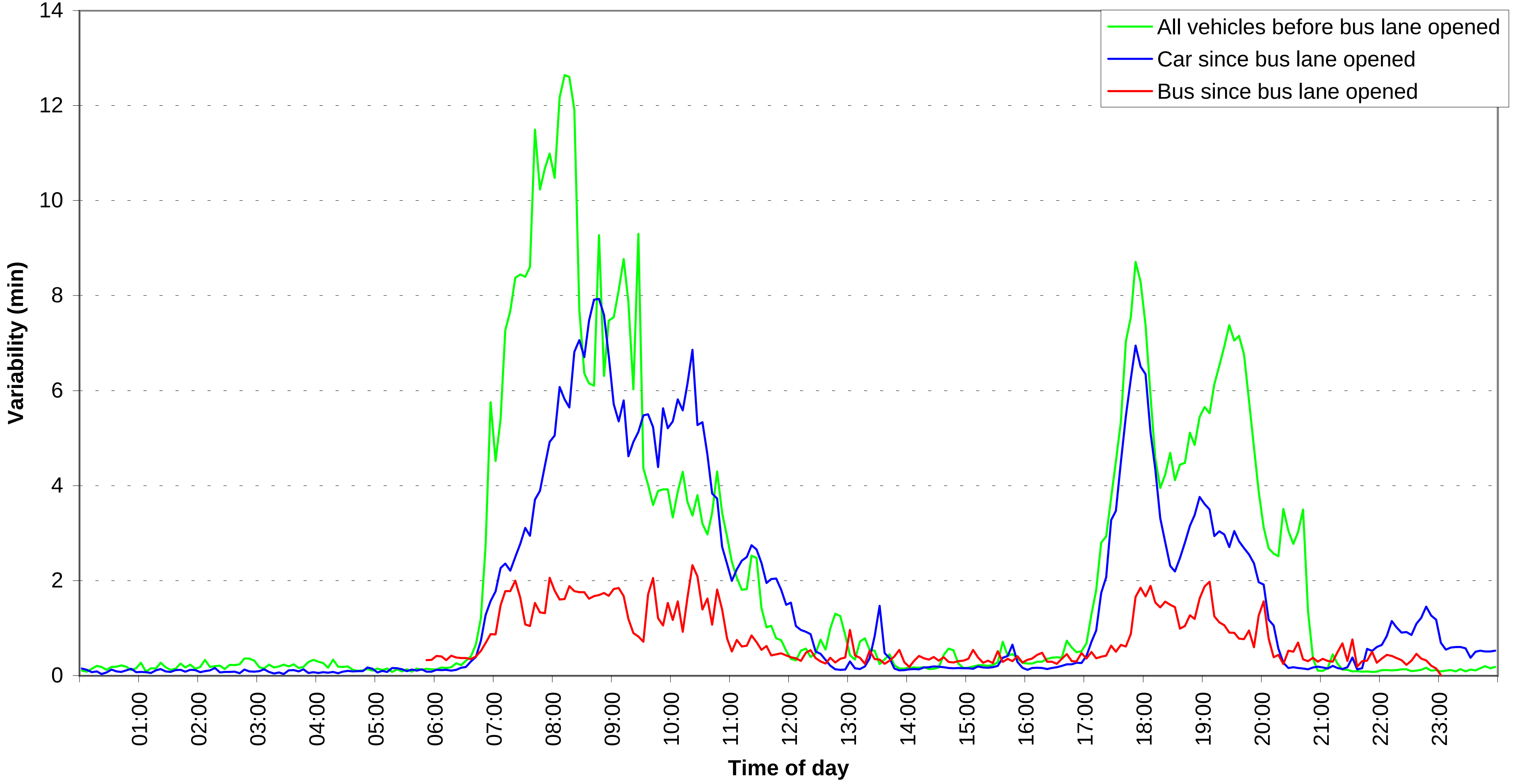


Figure 19

Average weekday journey times for days without incidents for the pre-bus lane monitoring period (Oct 98 - Nov 98) and since the bus lane opened (June 99) (M4 J4 - start of elevated section: 8.4km)

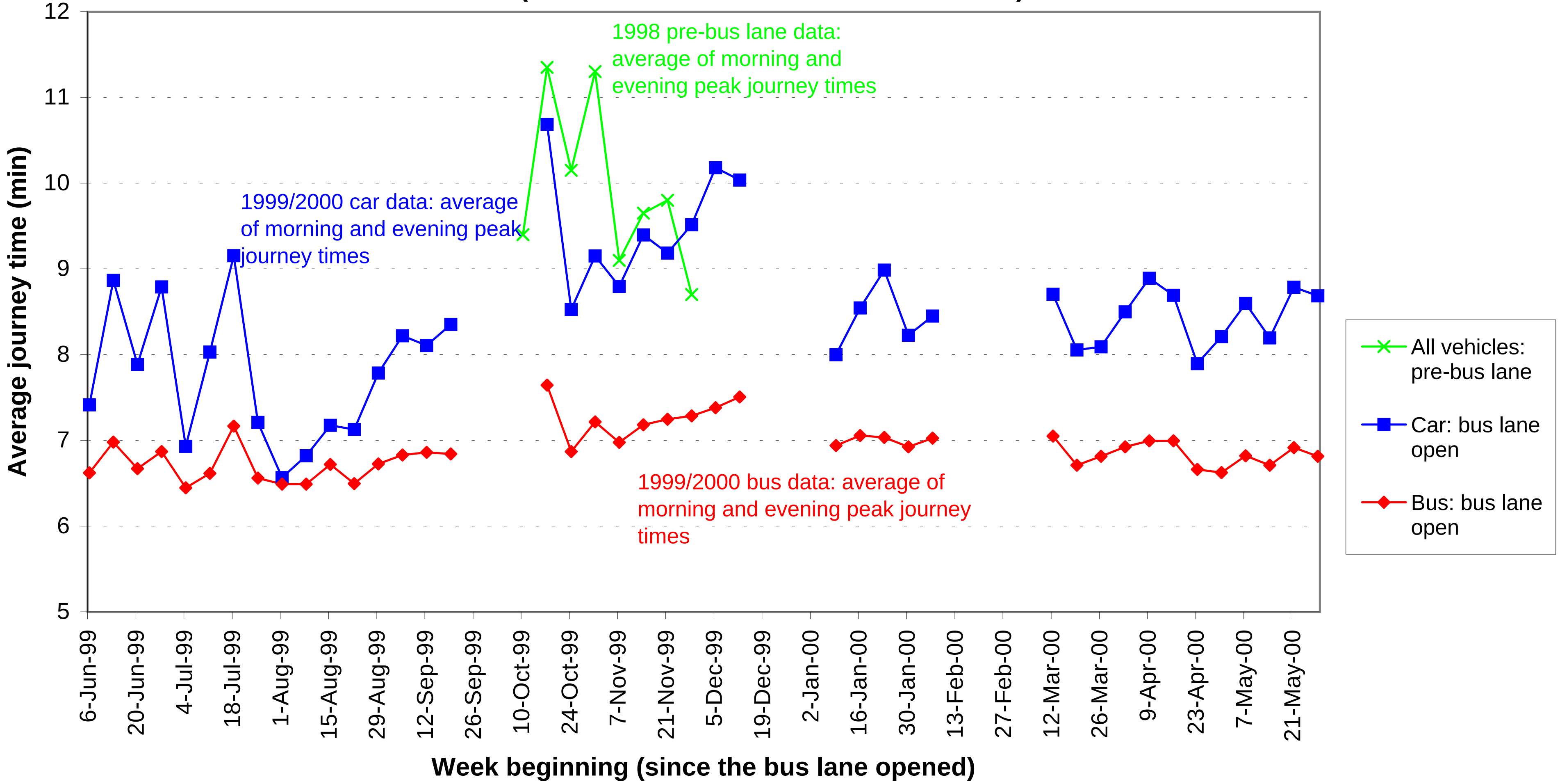


Figure 21
Use of M4 Bus Lane
(18 - 22 October 1999: bus lane in operation)

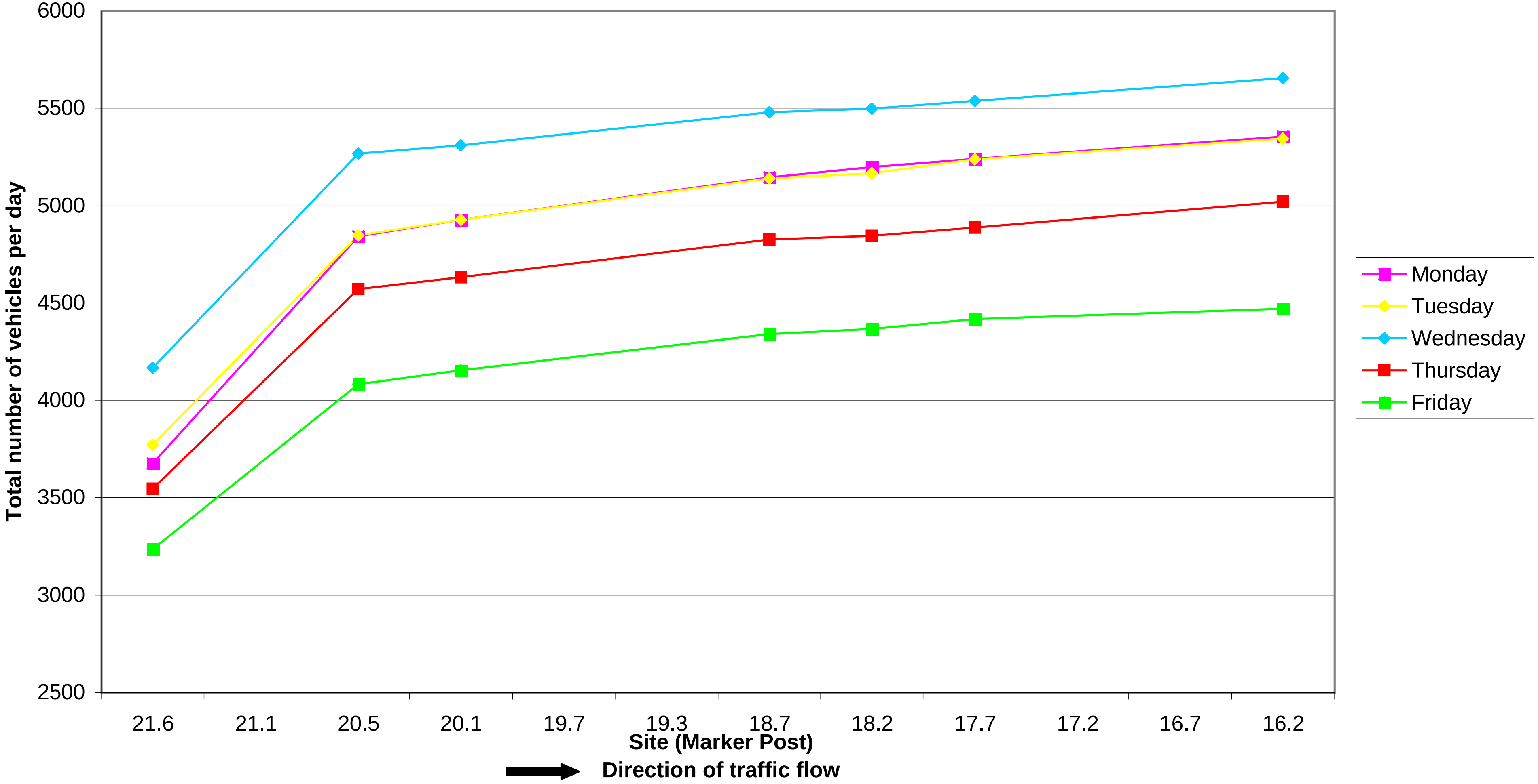


Figure 22

Locations and causes of congestion: M4 November 1998 (before the bus lane) and November 1999 (after bus lane opened)

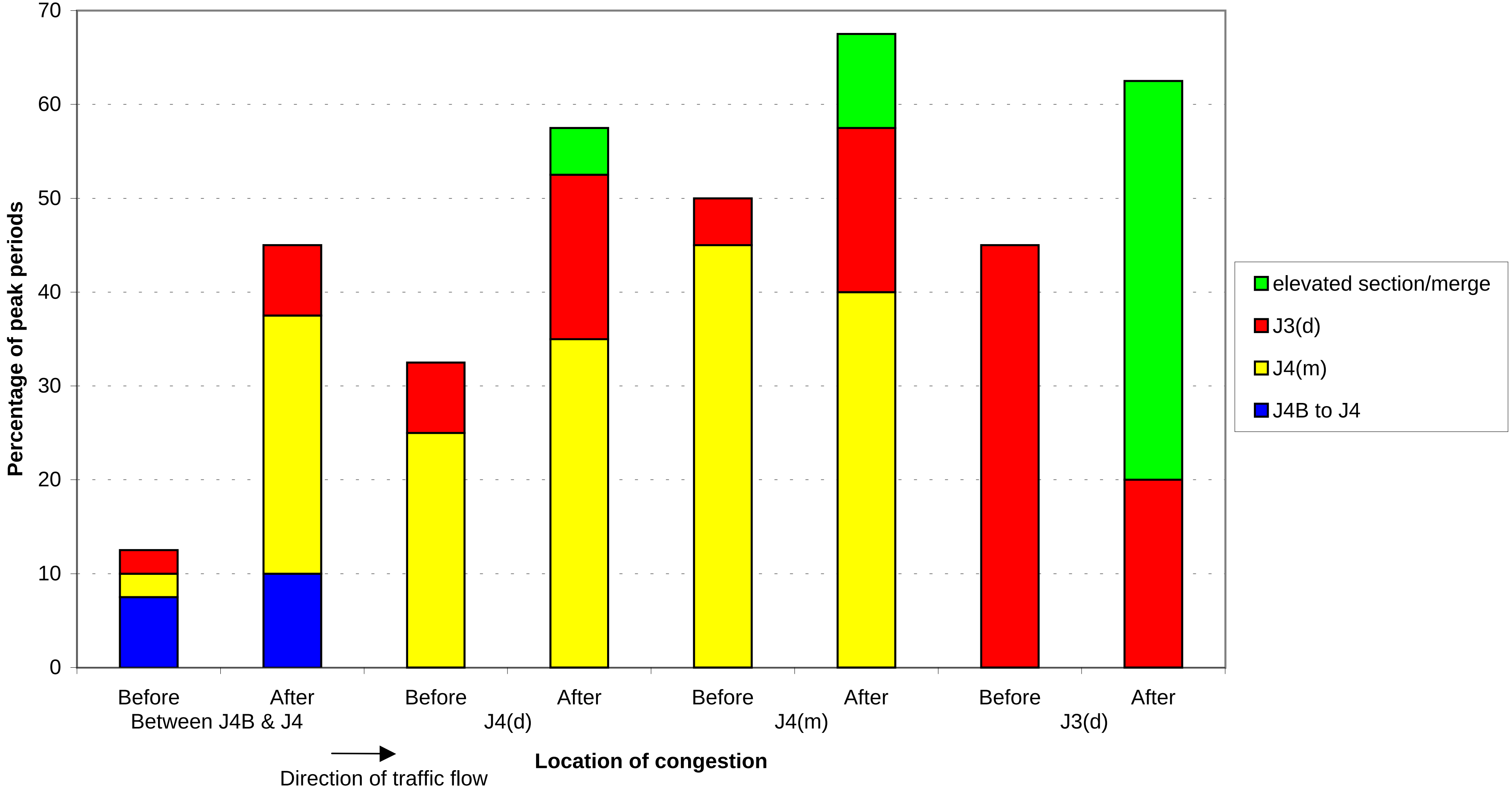


Figure 24
Composition of traffic in M4 Bus Lane: Thursday 4th November 1999

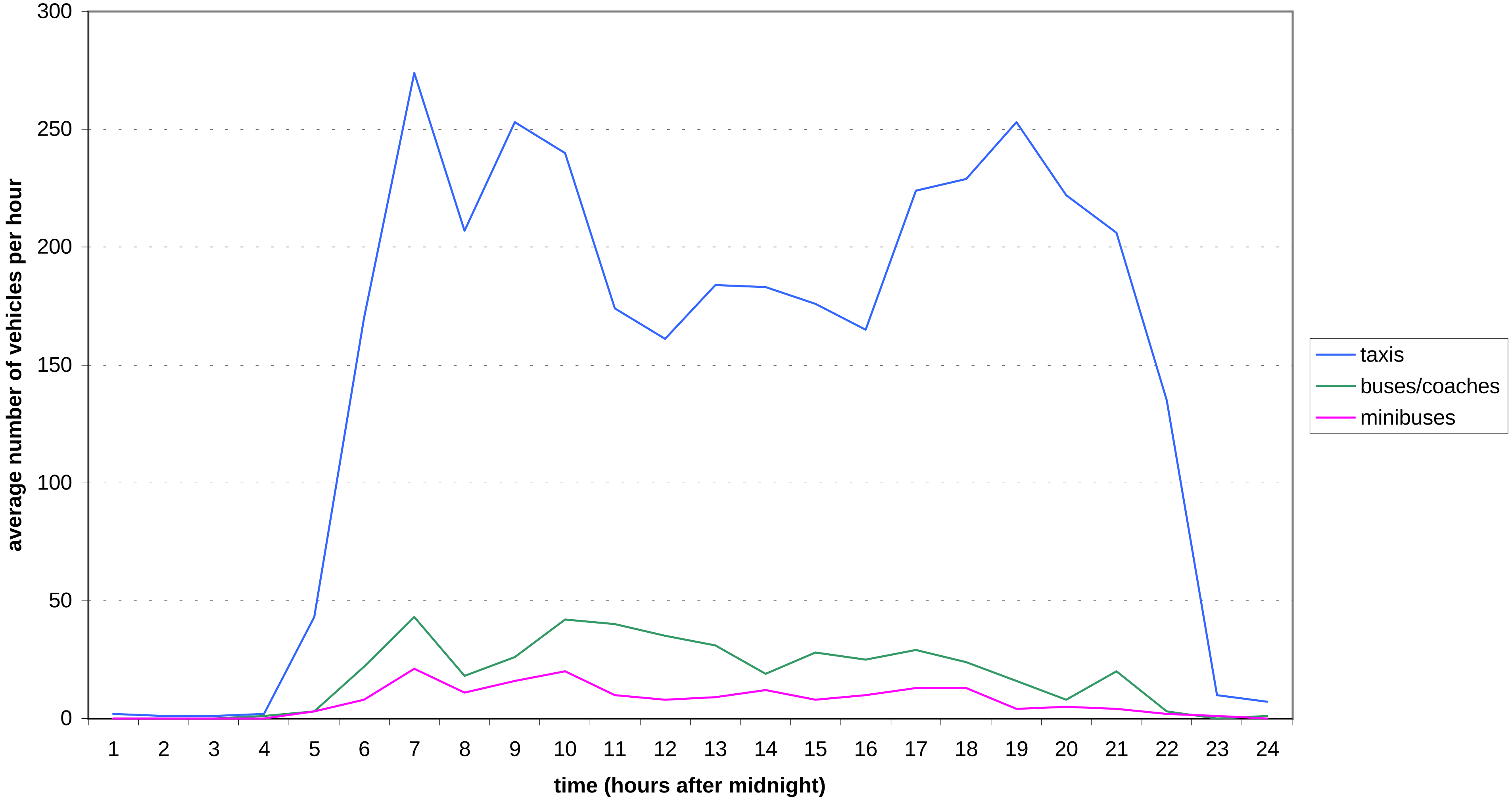


Figure 25
Average daily (weekday) flow in M4 bus lane

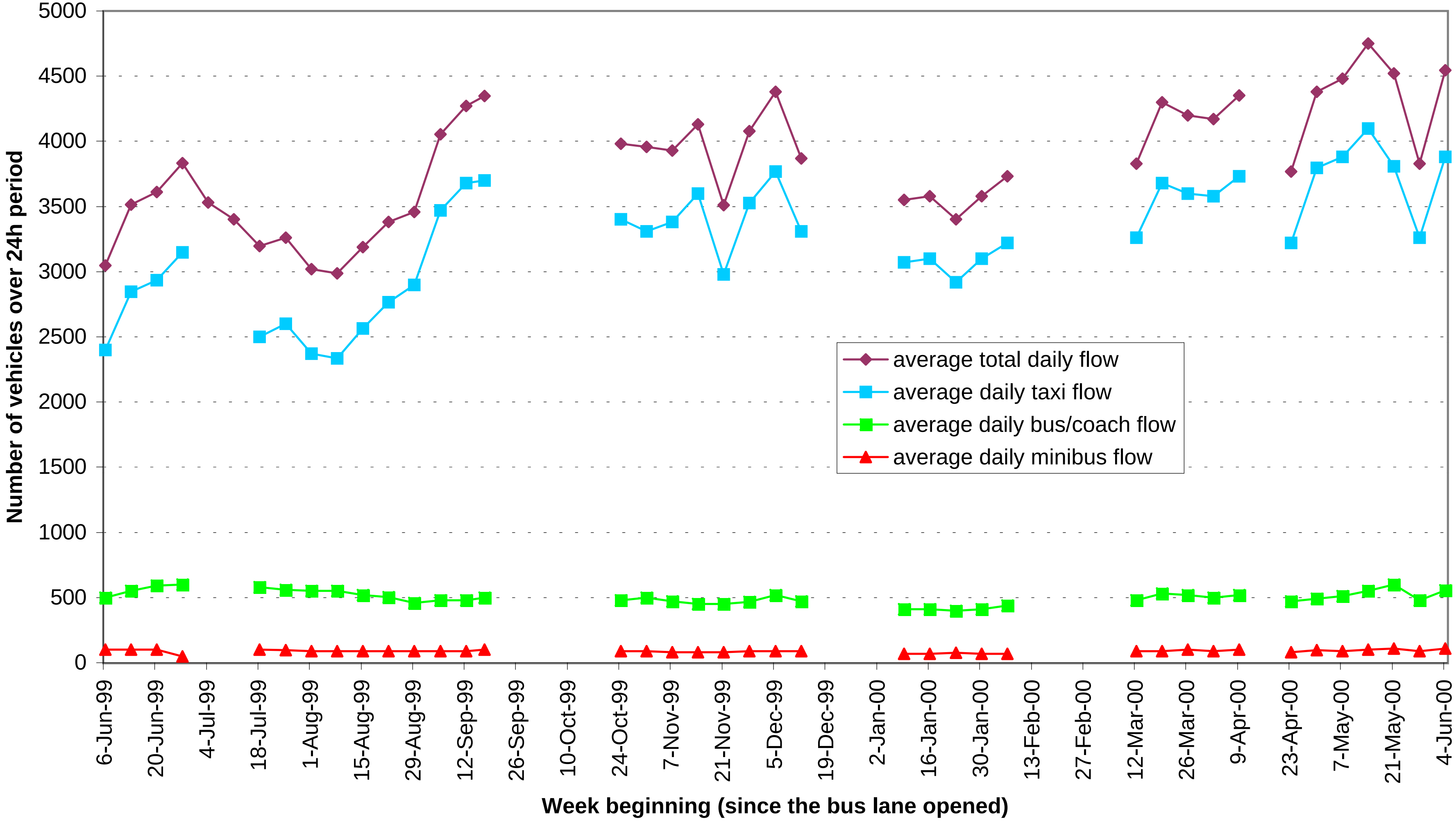


Figure 26
Entry and exit slip flows

(average weekday flows, 9 - 13 November 1998): before the bus lane opened

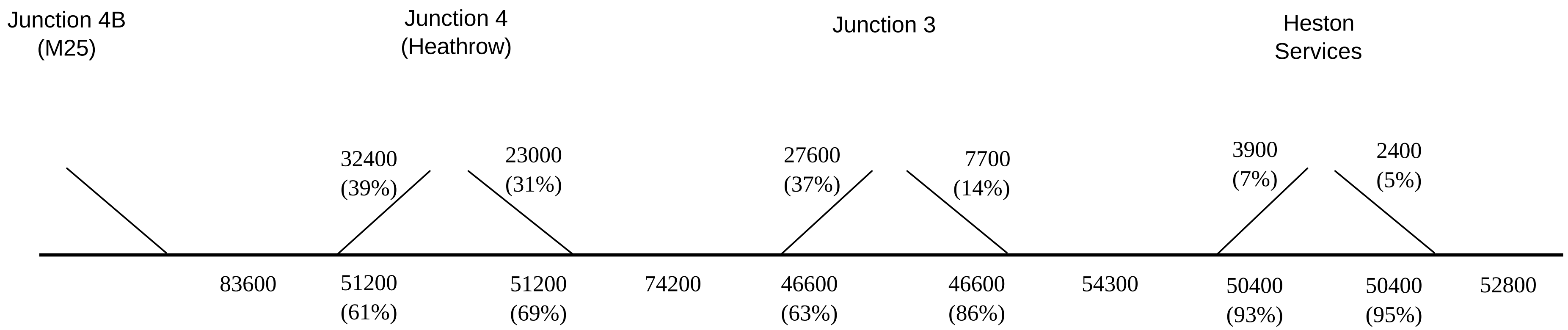


Figure 27
Entry and exit slip flows

(average weekday flows, 8 - 12 November 1999): bus lane in operation

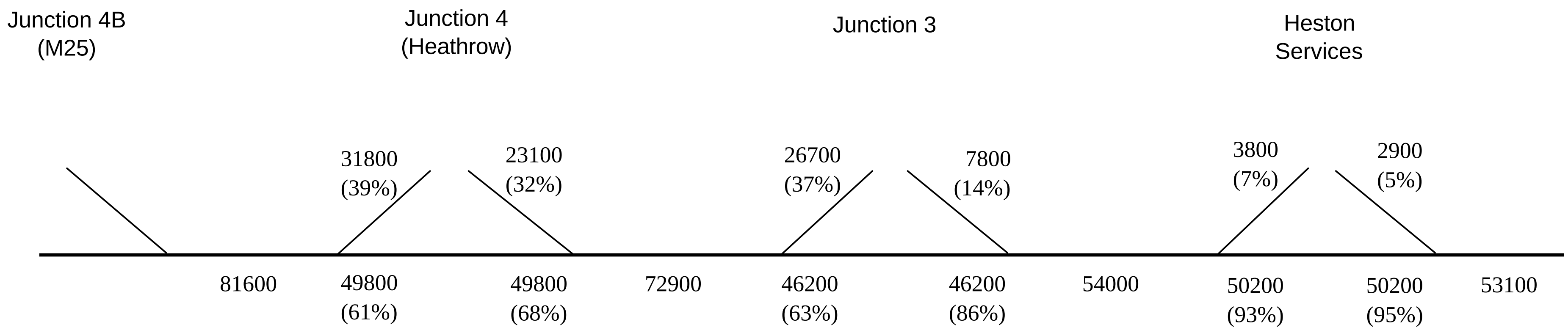


Figure 28
Average weekday flows on M4 J3-2

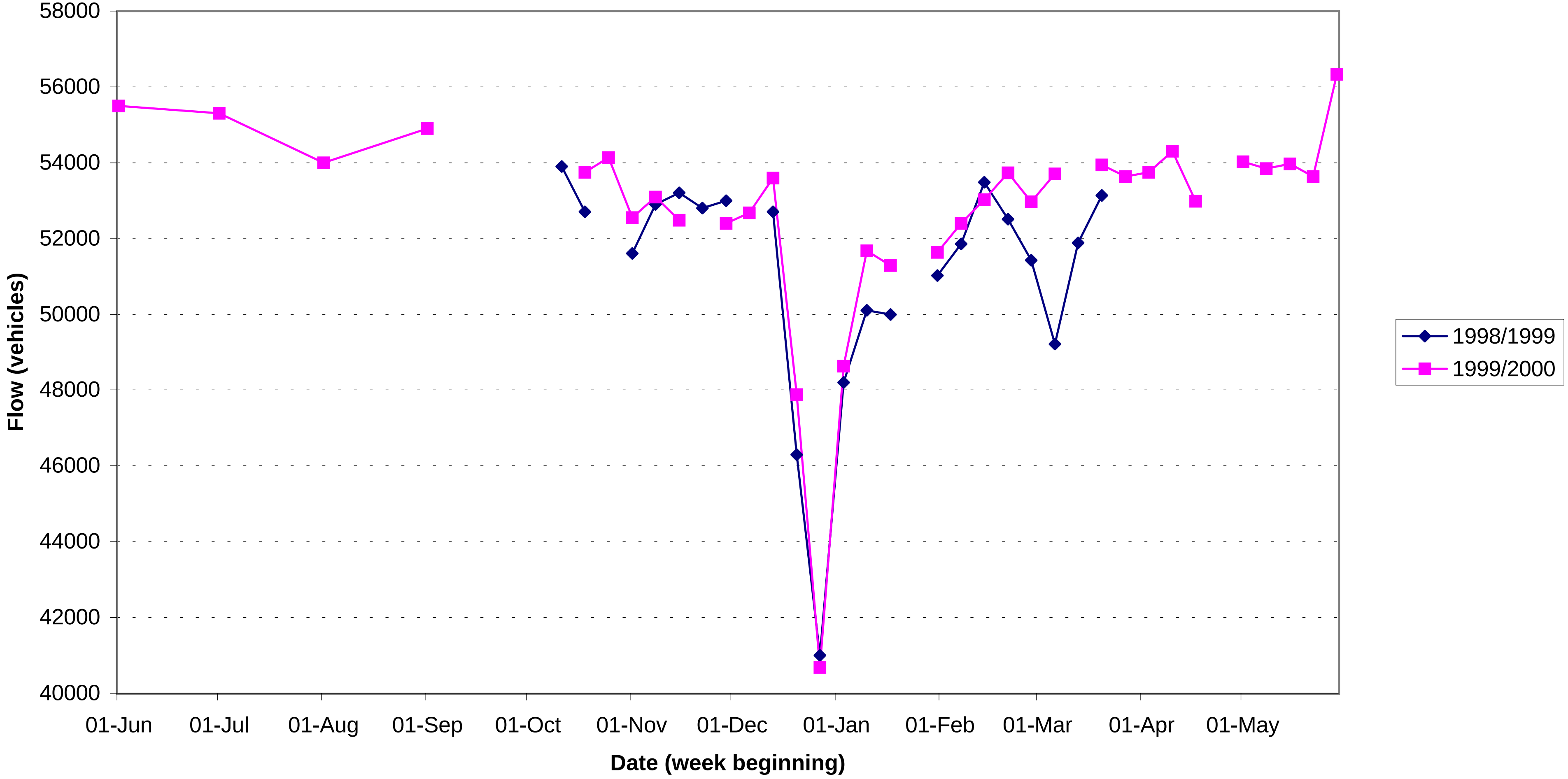


Figure 29

GPS data 17 November 1999 7:55 - 8:41: bus lane in operation

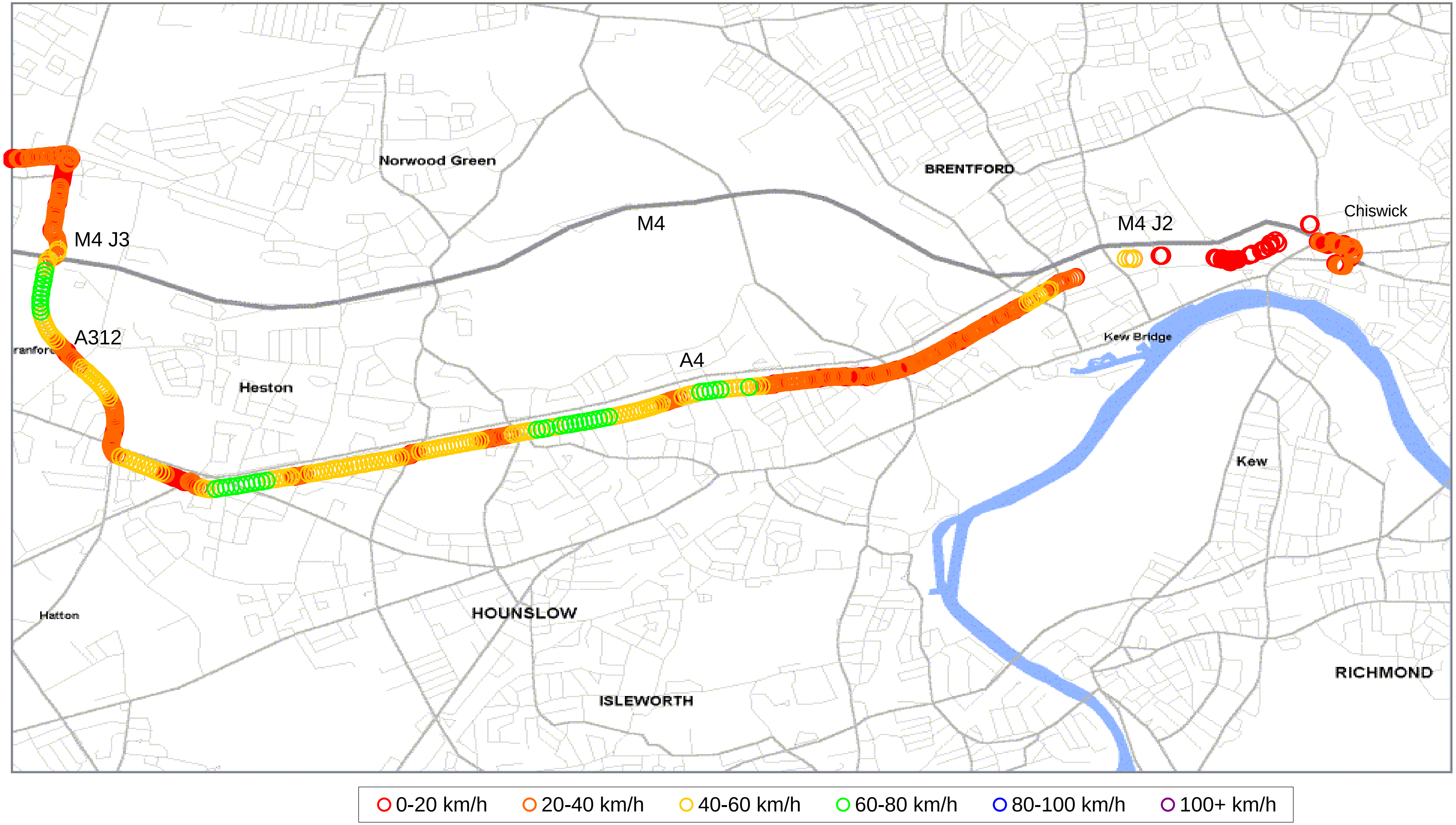


Figure 30

Weekday traffic approaching M4 J3, on A312 northbound

(week beginning 30 November 1998: during pre-bus lane monitoring period)

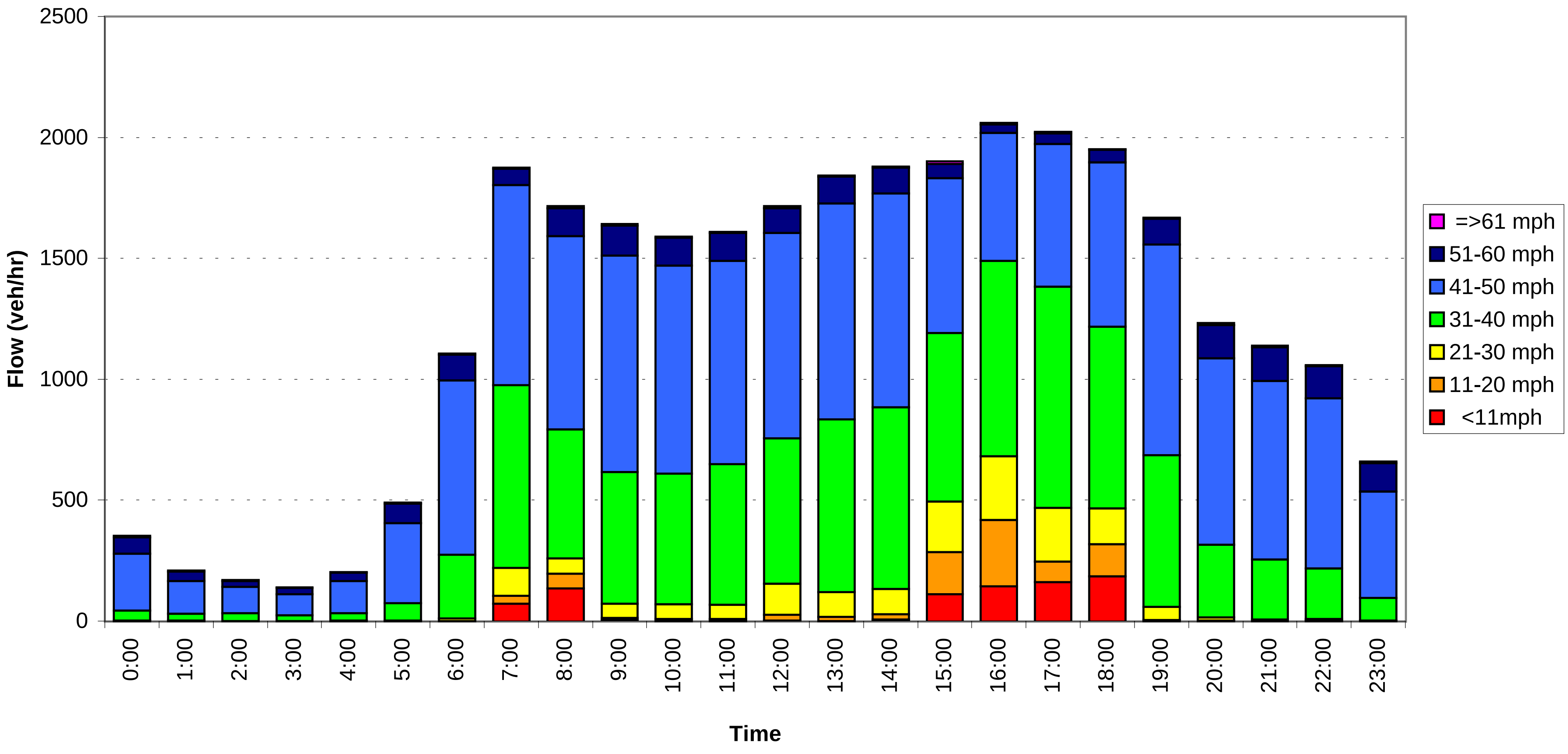


Figure 31
Weekday traffic approaching M4 J3, on A312 northbound
(week beginning 28 November 1999: bus lane in operation)

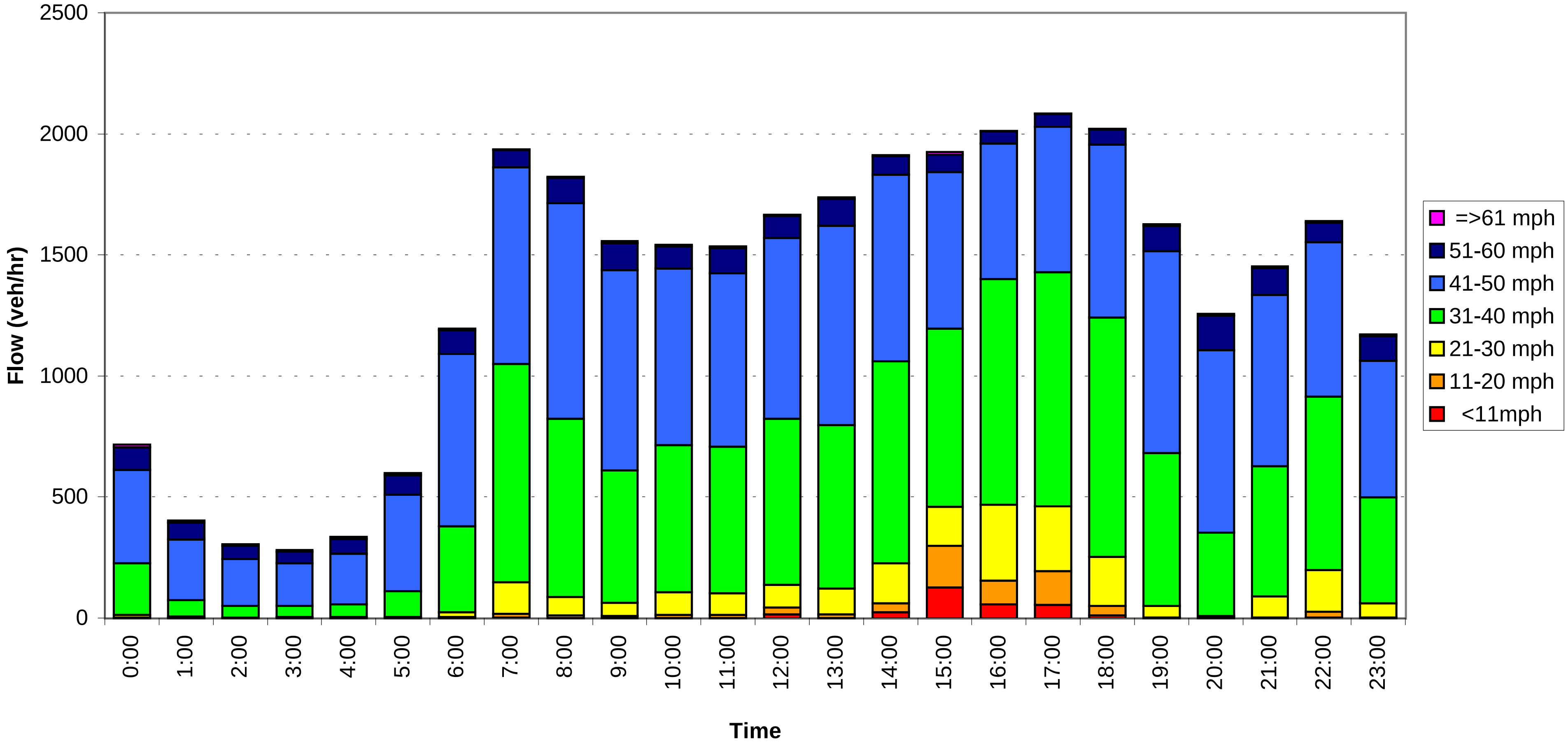


Figure 32
Extent of queueing for M4 Junction 3
(27 Oct 98 - 8 Dec 98): before bus lane opened

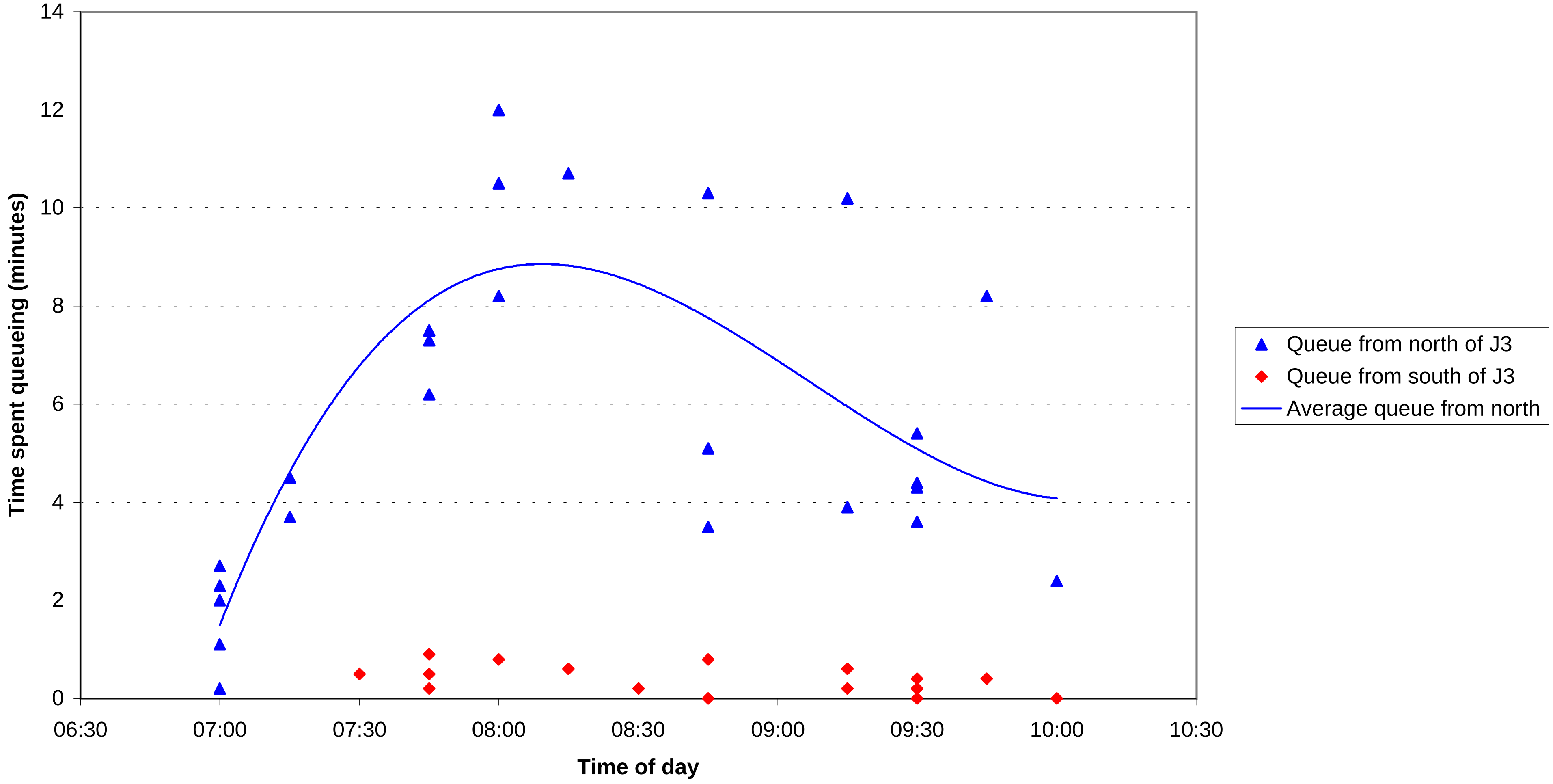


Figure 33
Extent of queueing for M4 Junction 3
(7th June 99 - 29th November 99: bus lane in operation)

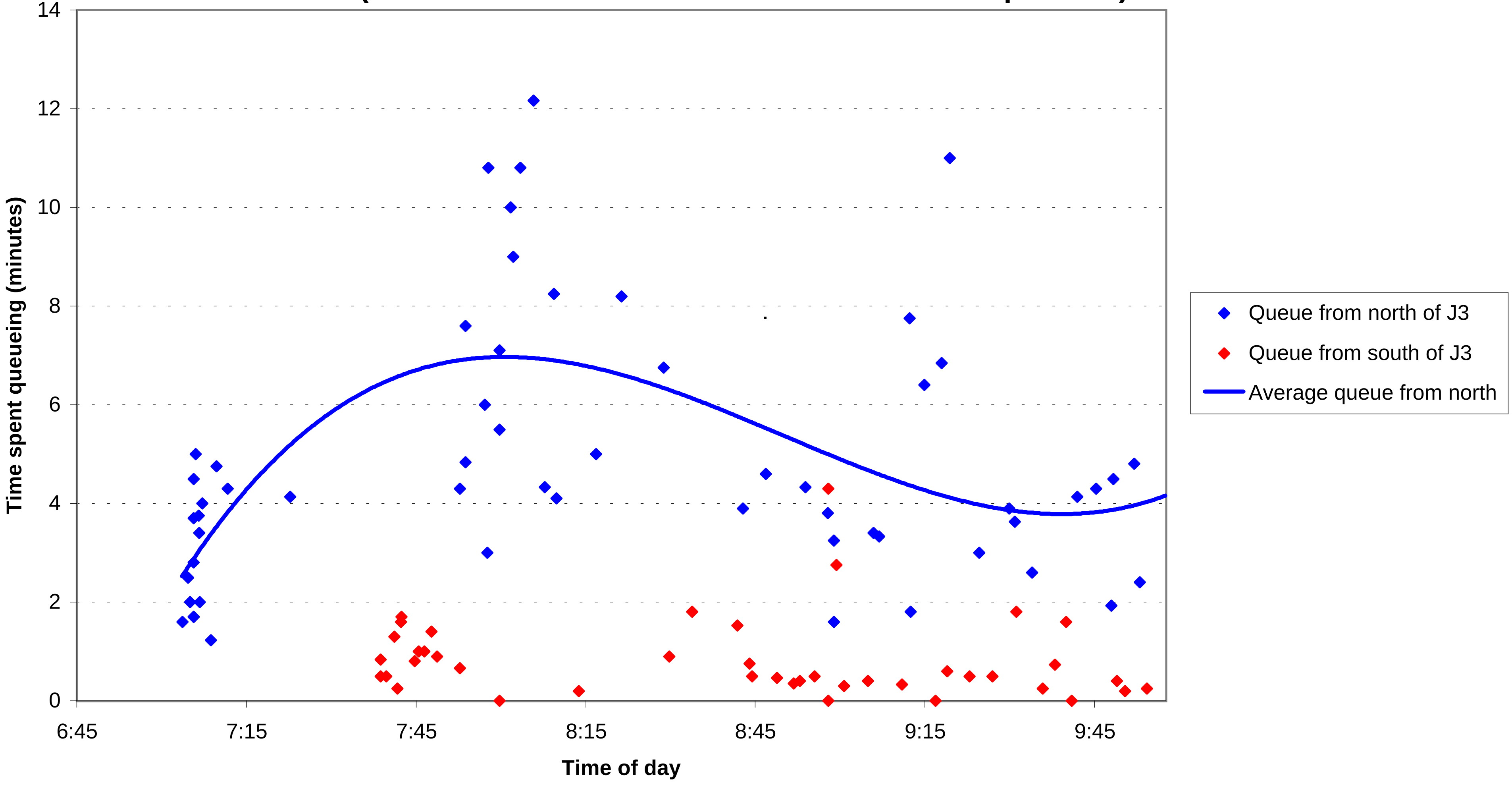


Figure 34
Speed distribution of traffic on M4 between 20:00 and 06:00
(during week beginning 30 November 1998: during pre-bus lane monitoring period)

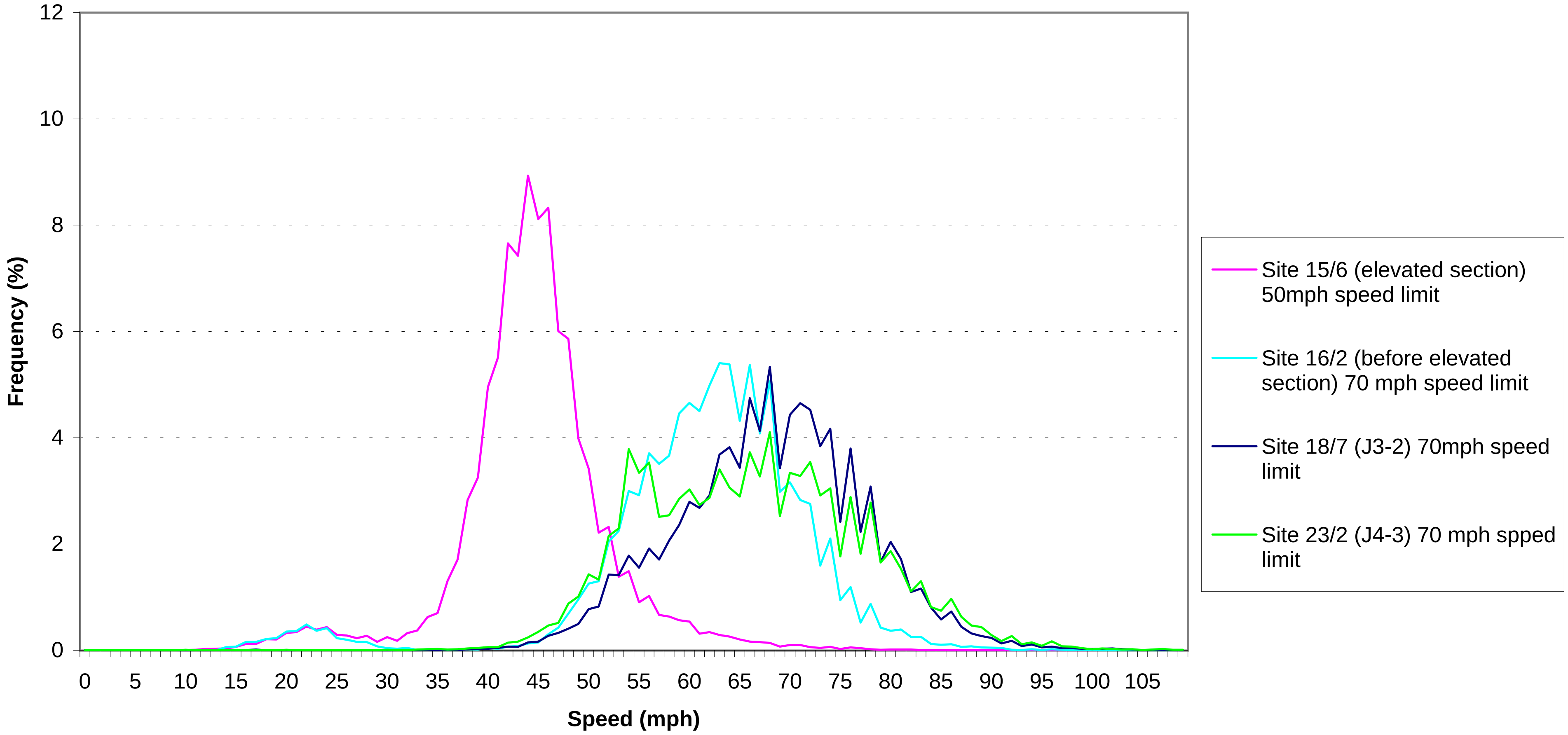


Figure 35
Speed distribution of traffic on M4 between 20:00 and 06:00
(during week beginning 4 July 1999: bus lane in operation)

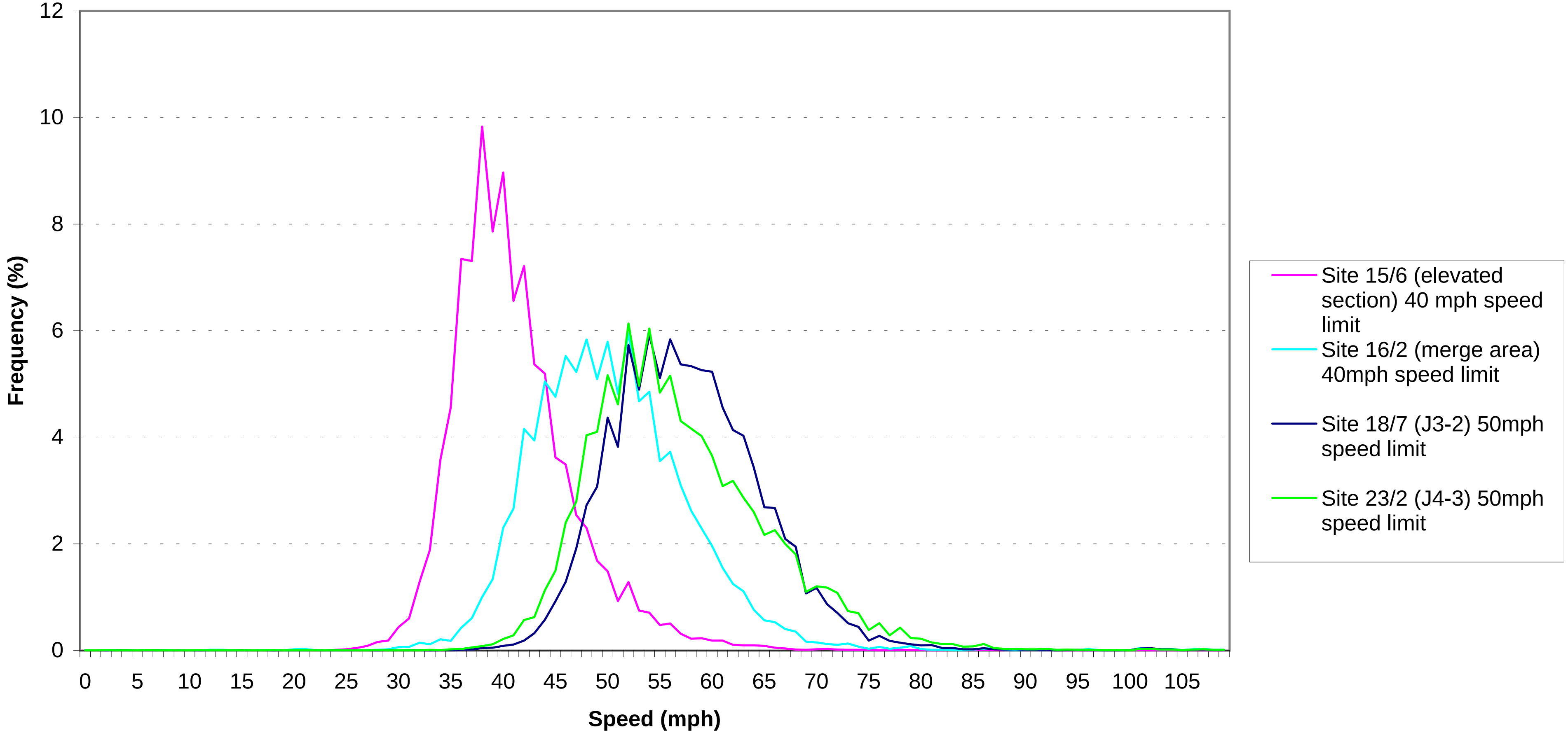


Figure 36
Speed distribution of traffic on M4 between 20:00 and 06:00
(during week beginning 14 November 1999: bus lane in operation)

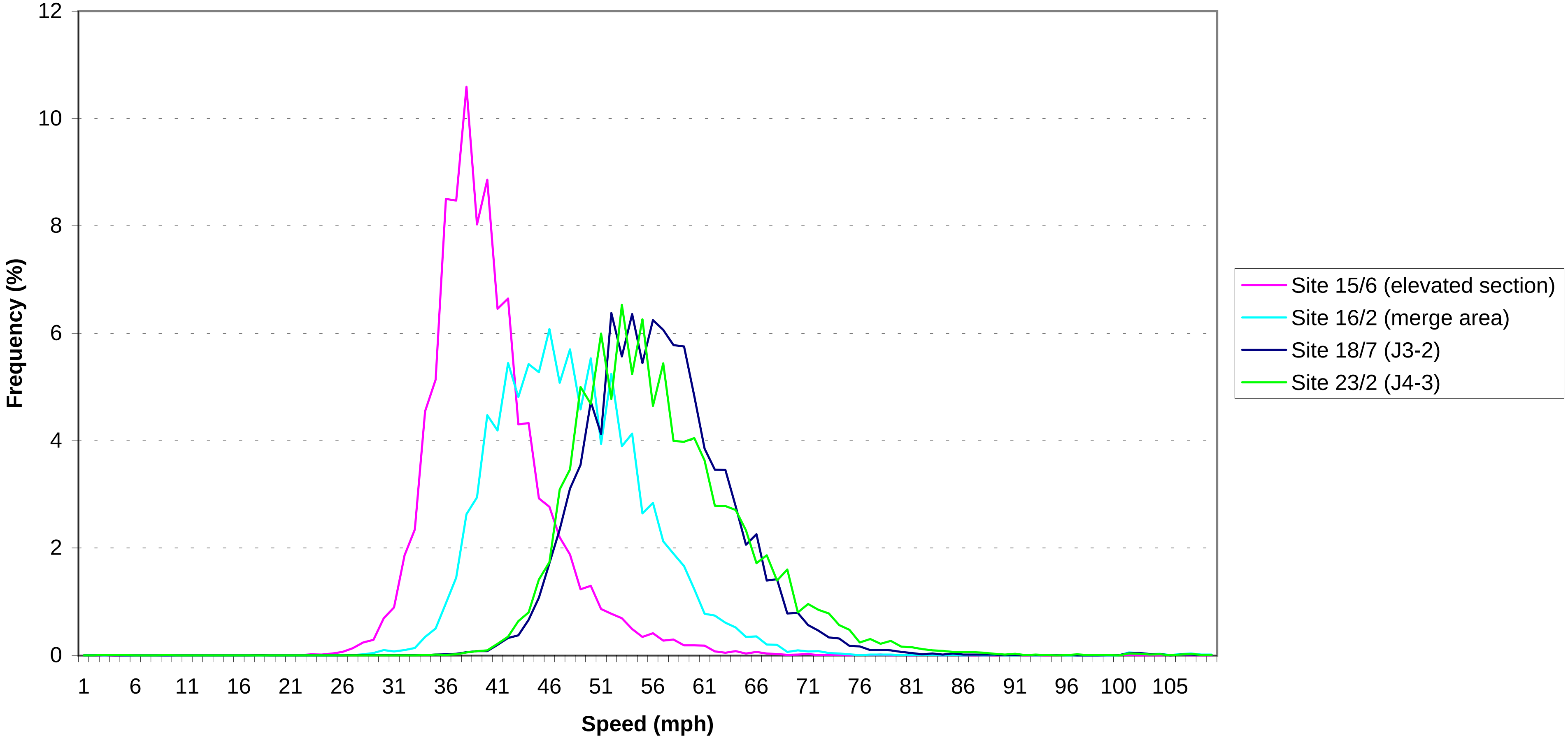


Figure 37
Speed distribution of traffic on M4 between 20:00 and 06:00
(during week beginning 7 May 2000: bus lane in operation)

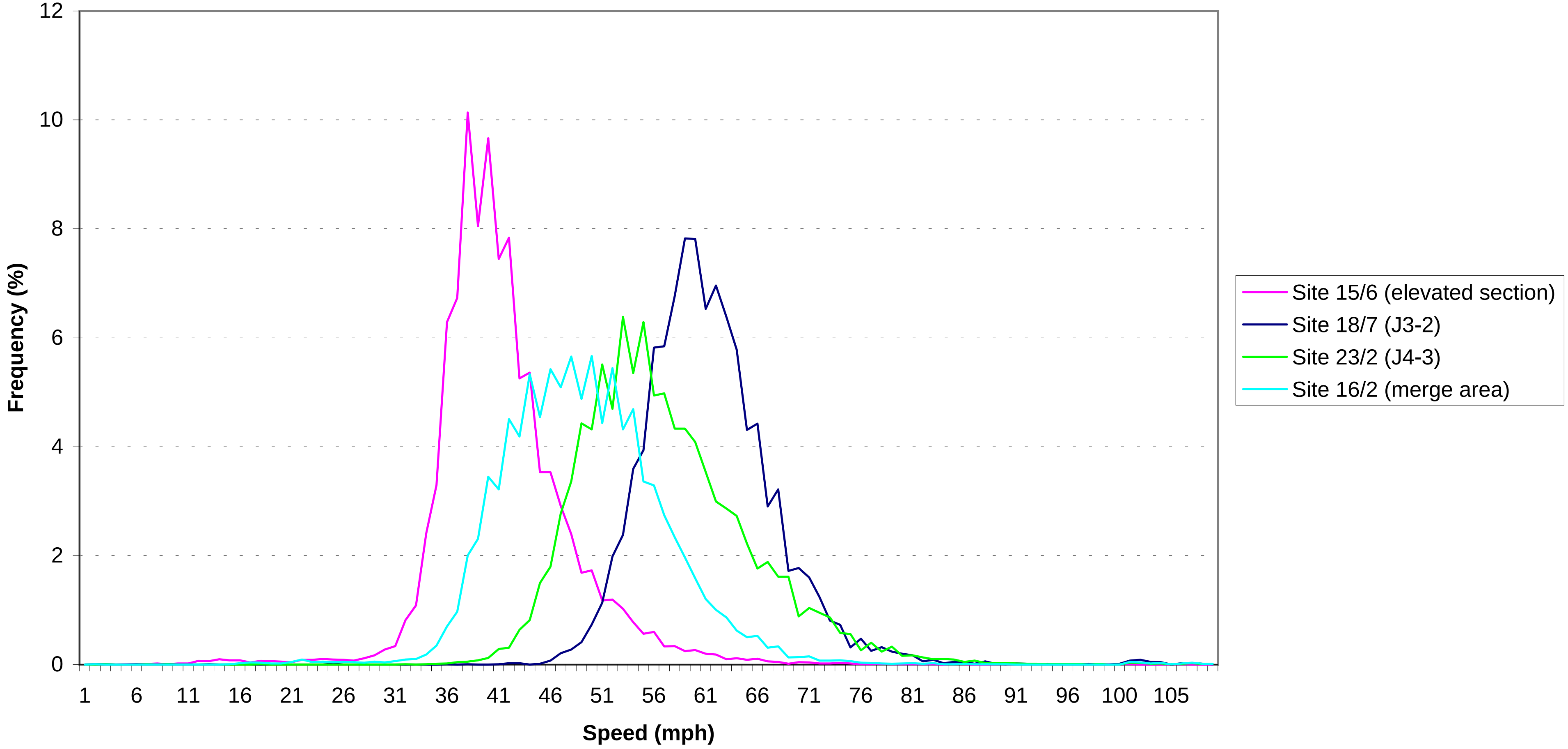


Figure 38
Speed compliance: Site 23.2 (M4 between J4 and J3)
(weekdays for week beginning 14 November 1999:bus lane in operation)

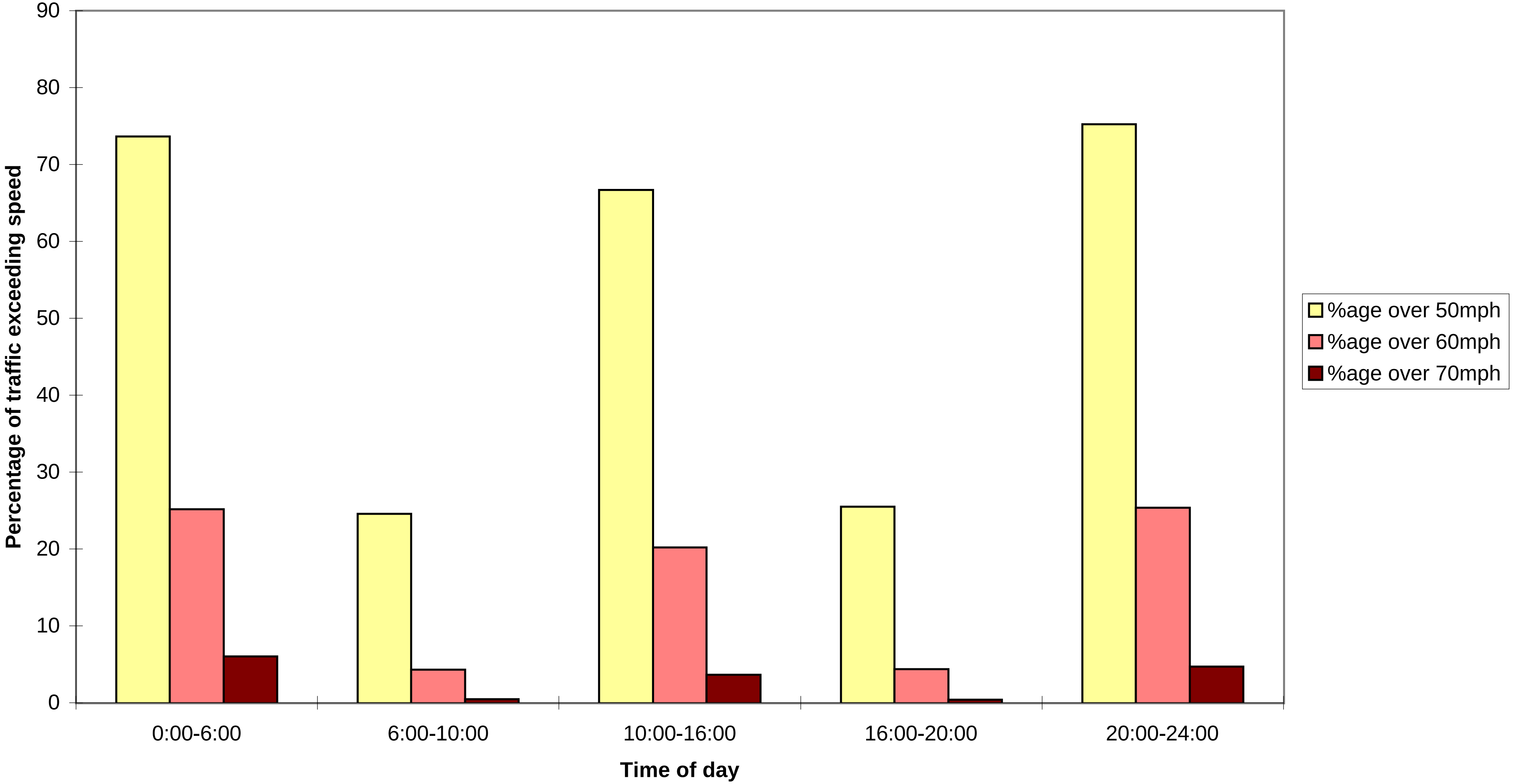


Figure 39
Speed compliance: Site 18.7 (M4 between J3 and elevated section)
(weekdays for week beginning 14 November 1999: bus lane in operation)

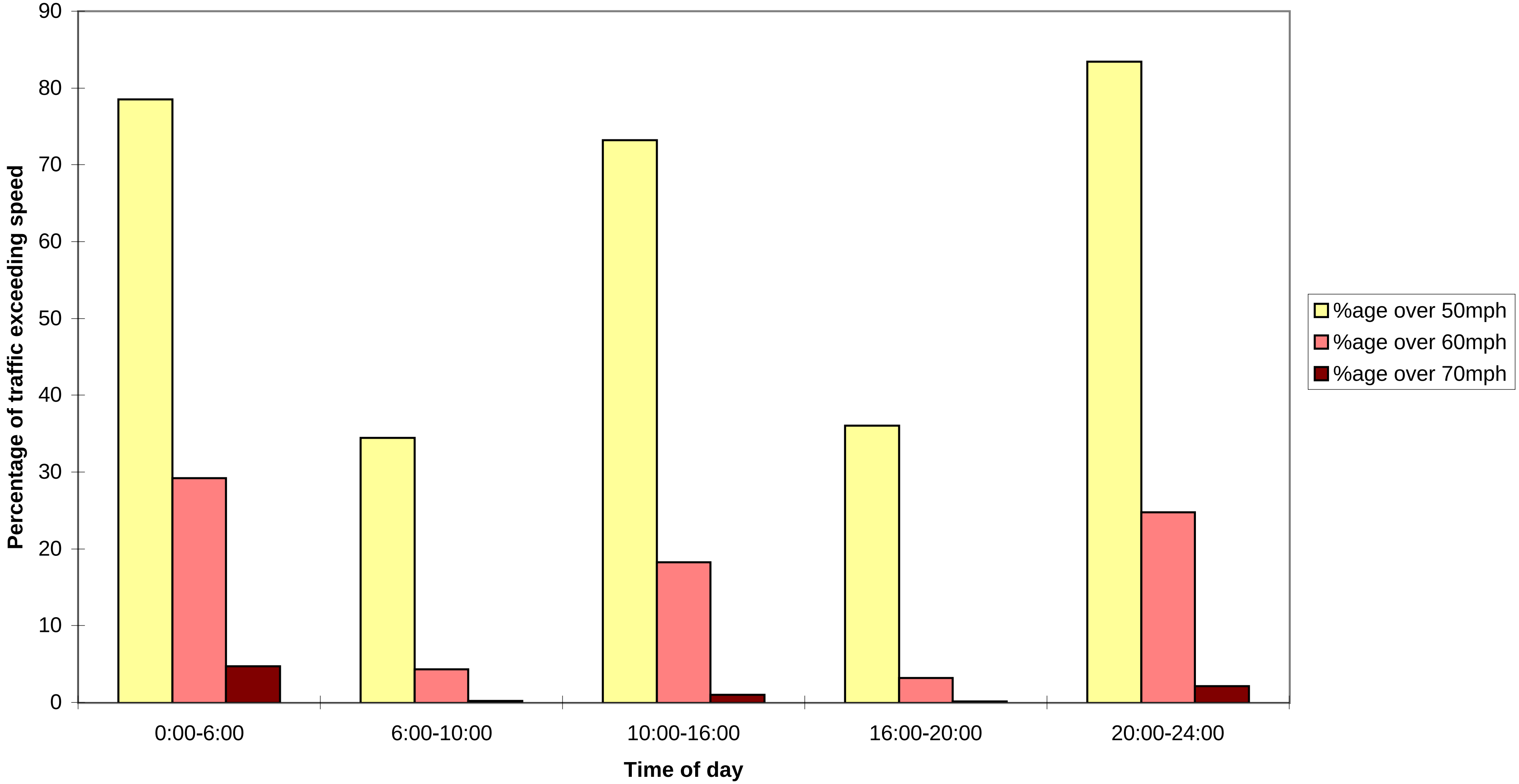


Figure 40
Speed compliance: Site 15.6 (M4 elevated section)
(weekdays for week beginning 14 November 99: bus lane in operation)

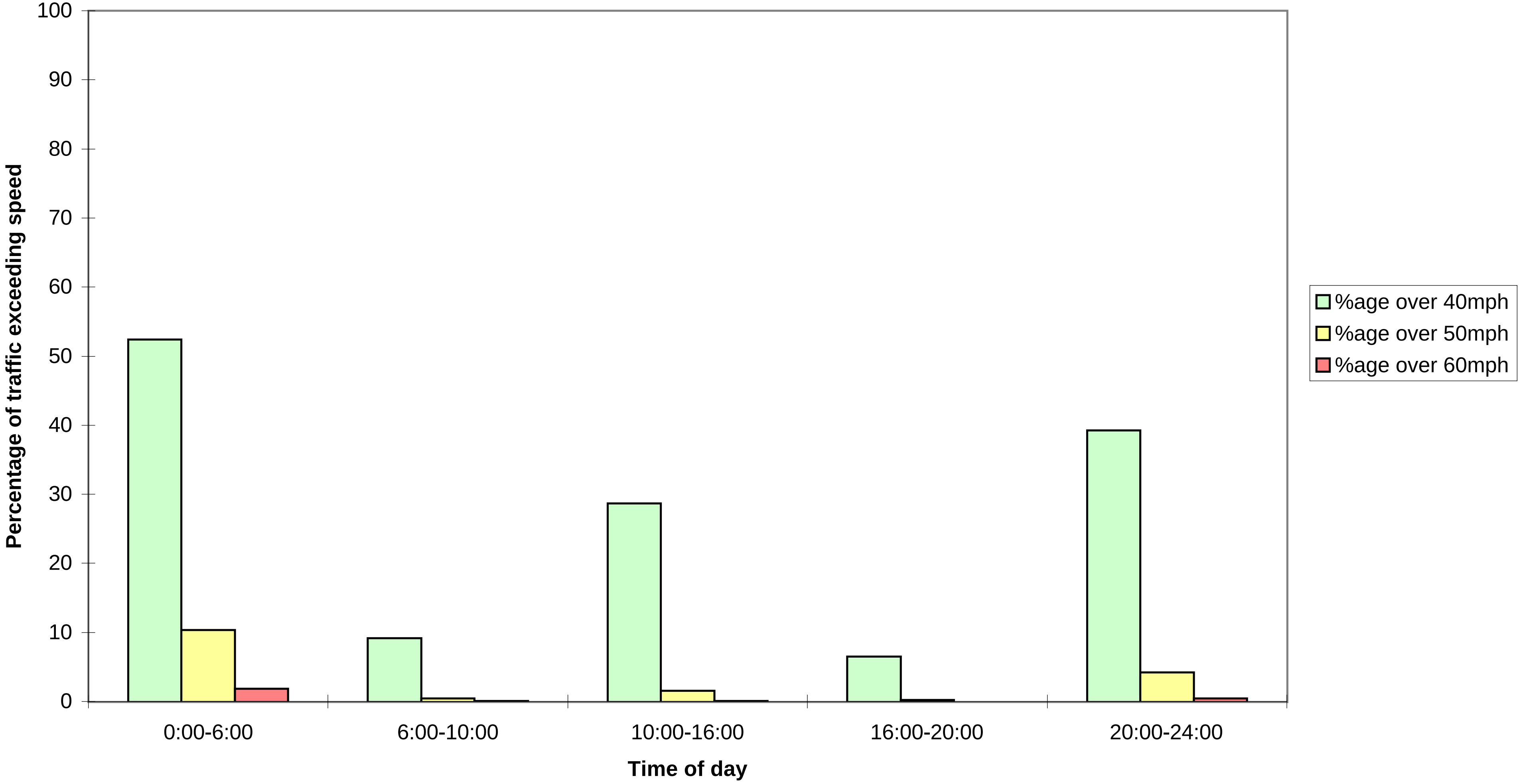


Figure 41
Results from the bus / coach driver survey: other vehicles they would allow in the bus lane

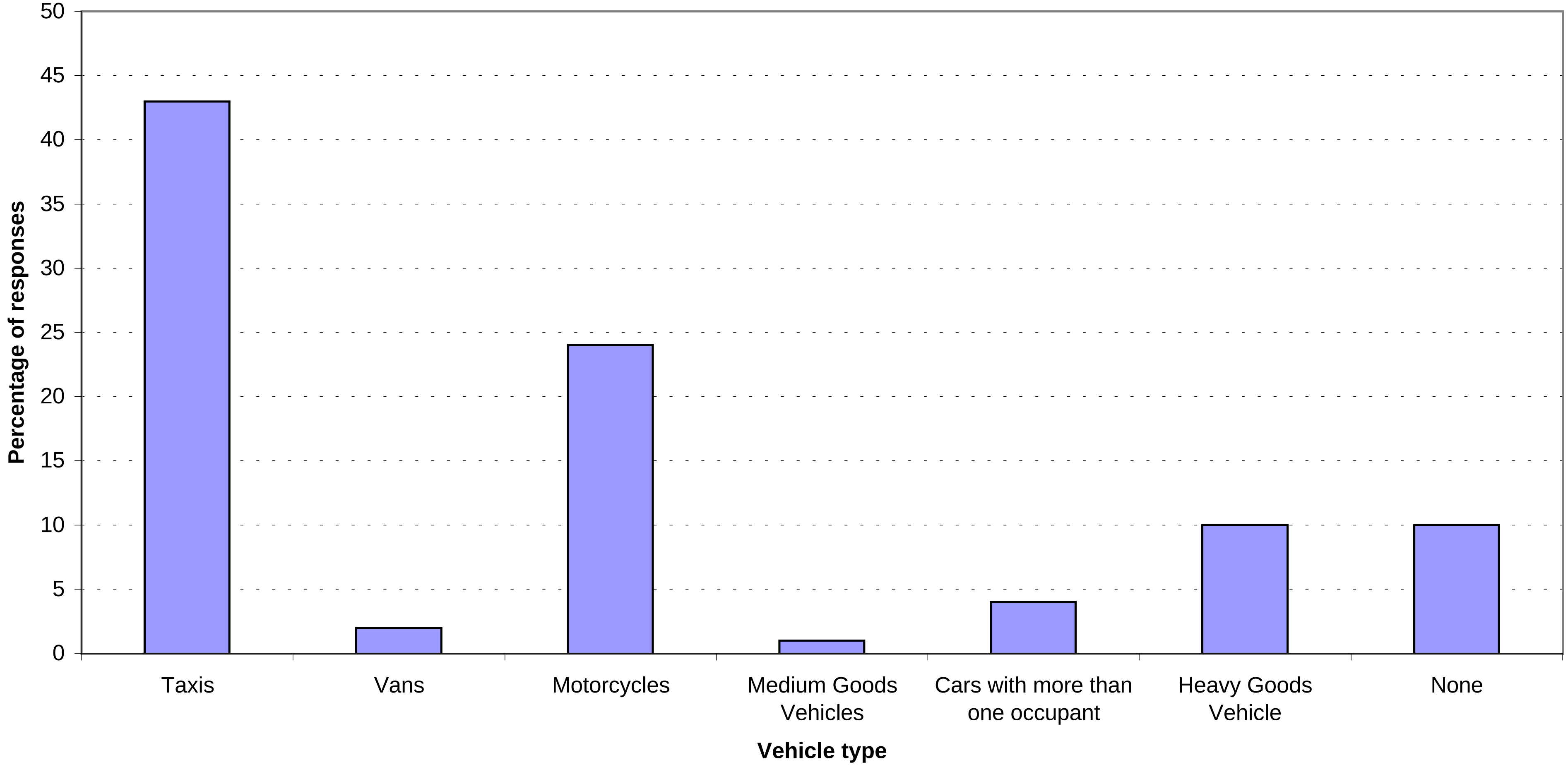


Figure 42
Results from the bus / coach driver survey: Locations of congestion before and after bus lane opened

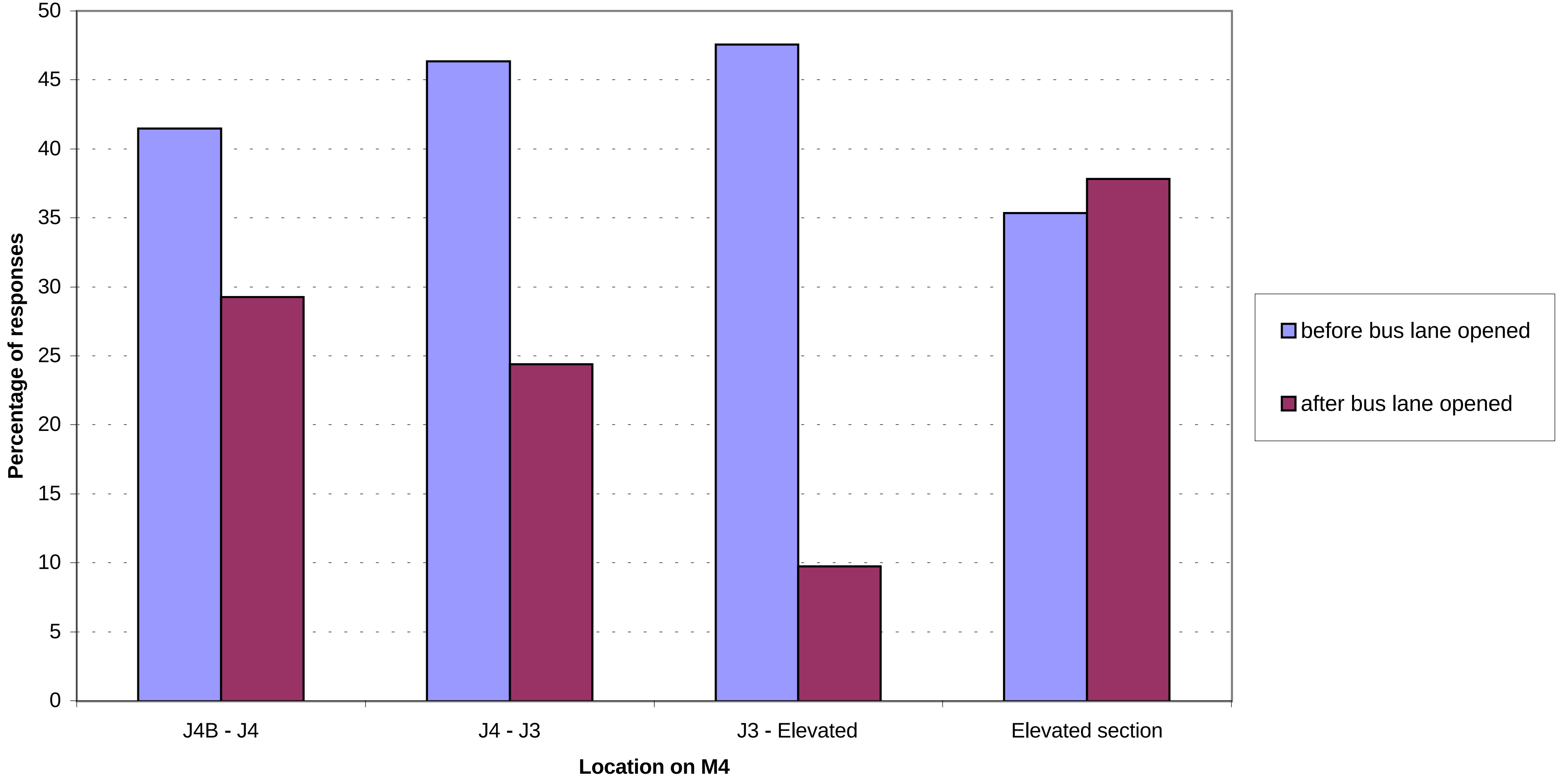
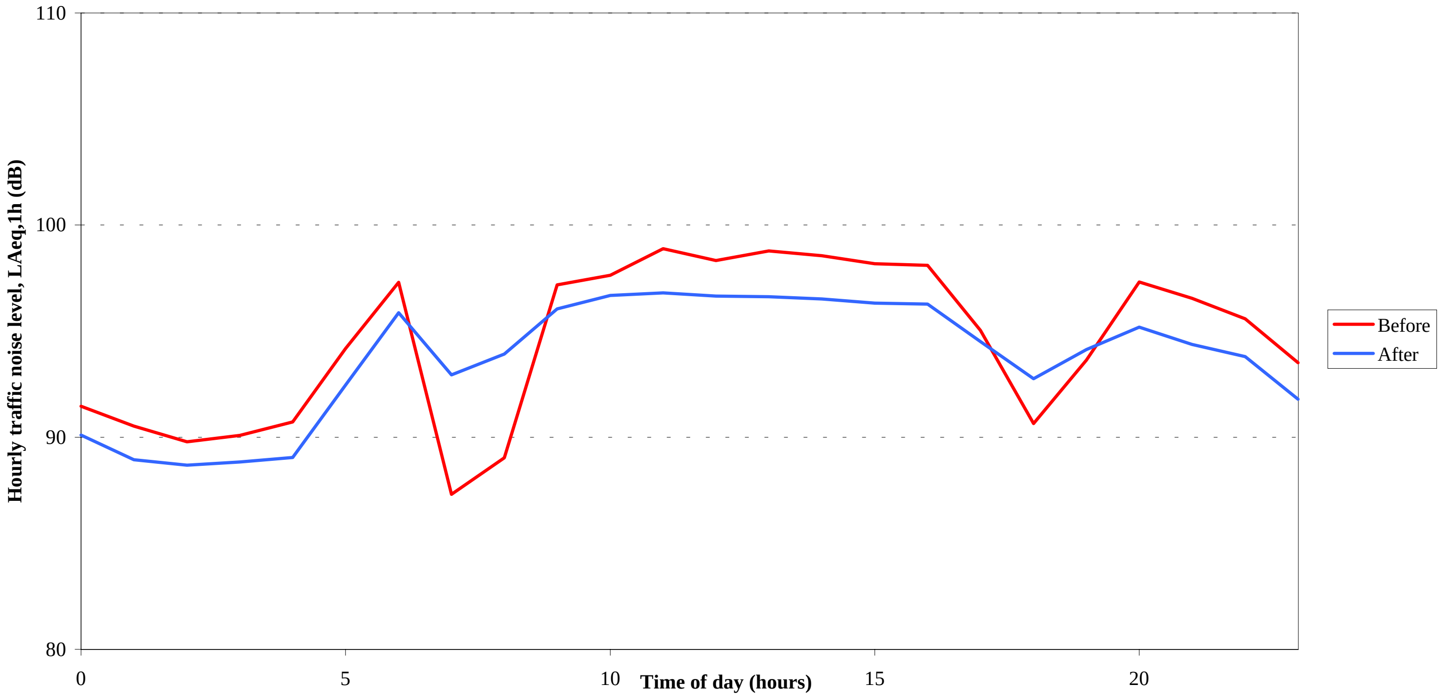


Figure 43
Comparison of traffic noise levels between Junctions 3 and 2

(a) Site 17/2



(b) Site 20/5