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1 Introduction

1.1 Purpose of Document

This report describes the work that has been undertaken to establish the business case for Variable Mandatory Speed Limits (VMSL) in a Controlled Motorways environment. Since the introduction of VMSL on the M25 Controlled Motorways scheme in 1995, the Highways Agency (HA) has commissioned a number of studies to optimise system performance and to quantify the impact of the system with the aim of establishing the business case for implementation and developing guidelines for future roll-out. The scope of this particular document is to provide a summary of the work undertaken and the key results from the various studies.

1.2 VMSL (Controlled Motorway)

Since 1995, VMSL has been operational on the western quadrant of the M25, a dual 4-lane motorway between Junction 10 (A3) and Junction 15 (M4).

The VMSL (Controlled Motorway) scheme on the M25 has the following key features:

- Mandatory speed control, using variable speed limits displayed on special Controlled Motorway Indicators (CMI)s equipped with ‘Red Rings’, mounted above each lane on standard gantries (installed at nominal 1km intervals);

- Automatic signal setting in response to traffic conditions, driven by a more advanced version of the Motorway Incident Detection and Automatic Signalling (MIDAS) system, with additional driver information on Enhanced Message Signs (EMS);

- Provision of automatic speed enforcement using camera technology.

Figure 1a – Gantry Mounted CMI s and EMS
The basic principle of the Controlled Motorways environment is congestion management using Mandatory variable speed limits that are appropriate for the traffic conditions. This harmonises traffic speeds and reduces the severity of shockwaves (thereby reducing stop-start driving). Smoothing traffic flow in this way helps to delay the onset of flow breakdown and advances the recovery of traffic flow from congested conditions.

The VMSL (Controlled Motorway) system displays 60mph and 50mph congestion signal settings in response to the traffic conditions on the motorway. The congestion signal settings respond to the number of vehicles per minute passing over the loop detectors (the traffic flow). At calculated thresholds, the speed limit displayed to drivers is reduced and increased as required.

The Controlled Motorways environment has been introduced in a phased manner. The first implementation was between J10-15 on the M25, and was extended from Junction 15 to Junction 16. The results in this report are principally based on this extension.

During 2004 and 2005, the M25 between Junctions 12 and 15 underwent major widening works to provide access to the new Terminal 5 at London’s Heathrow Airport. A fixed 40mph speed limit applied within the roadworks area. In this area, there was no opportunity to dynamically control the traffic, as the gantries holding the signals were removed prior to the works commencing. In order to improve the progression of traffic into the roadworks it was decided that VMSL should continue to operate on the lead-in to and the exit from the roadworks. Several changes were made to the operation of VMSL (Controlled Motorway) in the vicinity of the widening works to aid the progression of traffic into the roadworks. The main feature was a gradual reduction in speed limits approaching the roadworks during periods of high flow. During periods of low flow, no additional speed limits were displayed. The queue protection system continued to provide protection for any queueing traffic on the approach to the roadworks.

1.2.1 System History for M25 J10-15

A trial of mandatory speed limits on the M25 was announced in 1990 in the M25 Action Plan\(^1\). The business case for a fixed 50mph speed limit was strongly negative, so the concept of VMSL (Controlled Motorway) was developed during 1993 and 1994 by the HA.

In August 1995, the VMSL (Controlled Motorway) system was introduced between Junctions 11 and 15 using a fixed time plan (setting mandatory speed limits at certain times of day, regardless of current traffic conditions) to control speeds. The fixed time plan was derived using historical traffic data to establish when flow thresholds were likely to be exceeded. It was intended that the fixed time plan would operate for a 3-month period while drivers became accustomed to the system, after which a new system driven by actual traffic flows would be introduced.

During the first two weeks of operation, the fixed time system was monitored in detail by the HA. It was discovered that the signals were not always suitable for the traffic conditions; this was confirmed by the number of complaints received from drivers using this section of the M25. In response to this, the HA introduced automatic flow-based operation earlier than anticipated, in September 1995.

During the early operation of the system, various enhancements were made to the control parameters. Parameters such as the flow levels at which the signals are activated and the minimum time between signal changes were systematically changed. The effects of the changes on the signal setting sequences and on traffic behaviour were studied in detail as part of an on-going monitoring programme. This tuning optimised the signal settings, so that they were appropriate to the changing traffic conditions, and so that drivers saw a consistent sequence of logical signal settings. In order to avoid the signals switching on and off too frequently, the traffic data driving the signal system was smoothed by taking a continuous moving average (the level of smoothing being varied and optimised appropriately).

In November 1995, the system was enabled for the section between Junctions 10 and 11 (where works to widen the motorway to four lanes had just been completed), using the control parameters deployed between Junctions 11 and 15. Subsequent parameter changes were deployed over the whole section.

In April 1996, an optimal set of control parameters was determined. Because traffic conditions change over the years, tuning continues to be performed to improve the operation of the system. The tuning is carried out on a site-by-site basis, to allow for differences in traffic behaviour at various locations (e.g. motorway-to-motorway junctions are given different parameters to other junctions).

Analysis of the traffic signals during congested conditions showed that the signals were switching off in the presence of queues, because the flow level fell below the switch off threshold. The flow-based algorithm was unable to distinguish between free-flowing traffic conditions and low flows during heavy congestion. Drivers were complaining that the speed limits were increasing while the drivers were stuck in a queue. As a result, in February 1997 the HA modified the control algorithm to run on both flow and speed information. This prevented the signals switching off in the presence of queues.

In October 1997, the High OCCupancy (HOCC) incident detection algorithm was introduced. This detects queuing or slow-moving traffic and protects this traffic by automatically setting lower speed limits (40mph, with 60mph and 50mph settings further upstream to provide drivers with advance warning of the queues). The algorithm works in parallel with the VMSL (Controlled Motorway) system and offers greater scope to reduce accidents and consequential delays. The signal settings were monitored to ensure that drivers continued to see a consistent sequence of logical signal settings.
Early feedback from drivers, following the introduction of HIOCC, indicated that many thought the 40mph limit caused the queue. As a result the HA introduced a publicity campaign to explain the queue protection system.

In order to provide drivers with appropriate and relevant information, the setting of Enhanced Message Signs (EMS) was coordinated with the setting of signals. This feature was introduced between Junctions 10 and 13 in October 1998, and between Junctions 13 and 15 in July 1999. The EMS messages provide drivers with information about the reasons for the signal settings, and provide warnings of queues or congestion ahead. The message settings were monitored to ensure that they were consistent with the signal settings.

1.2.2 Monitoring of VMSL (Controlled Motorway)

The VMSL (Controlled Motorway) scheme has been monitored since its implementation in 1995. This monitoring has been used to optimise system performance and to assess the impact of VMSL (Controlled Motorway) Operation. The monitoring consisted of two major activities:

- Traffic and signal data were graphically analysed using the Motorway Traffic Viewer (MTV) software tool. This tool was developed as an aid to visualising and interpreting the traffic conditions and signal settings. It enables the traffic conditions over the whole section for a whole day to be viewed, and allows the relationships between the traffic conditions, the signal settings and the messages to be studied. It was used to support the ‘tuning’ of system parameters, to optimise the performance of the system.

- The effects of the scheme on traffic were analysed by monitoring traffic trends and traffic behaviour using pre-defined performance indicators. An assessment of the effects of the variable speed limits on accidents was carried out as part of the monitoring work, as well as an investigation into the effects on noise levels and air pollution. Also, a driver opinion survey provided valuable feedback on how the scheme was being received by its primary users.

1.2.3 Results of Monitoring

One of the HA objectives in installing the scheme was to prove the technology, i.e. to show that signals could be set using real-time traffic data. In addition, for the system to have an effect, it was necessary to show that drivers responded to the signals.

The monitoring showed that the VMSL (Controlled Motorway) system is reliable and that it sets consistent and coherent sequences of speed limits that are appropriate to the traffic conditions, and that are generally obeyed by drivers. VMSL (Controlled Motorway) has provided a beneficial environment for drivers using the section of the M25 where the system has been installed.

The modified Controlled Motorways environment used during the widening works in 2004 and 2005 was successful in allowing traffic to pass through the roadworks with a minimum of delay. Each time the traffic management changed, all modifications to the VMSL (Controlled Motorway) parameters were reviewed, to ensure that there was no conflict between VMSL and the fixed limit.
Since the implementation of the HIOCC automatic incident detection system during October 1997, the system has detected, tracked and protected the back of queues during both peak and off-peak periods. The Enhanced Message Signs (EMS) serve to provide additional textual information to drivers regarding the reason for a particular signal display.

The monitoring of the system has highlighted the importance of maintaining the MIDAS loop infrastructure because of the adverse impact faulty loops can have on overall system performance and credibility.

The data collected from the M25 J10-15 has shown improvements in journey times, headways and shockwave behaviour. These improvements suggest that there may be long-term benefits from installing a VMSL (Controlled Motorway) system, with drivers using the information provided by the system to drive more smoothly to reduce the effects of flow breakdown. However, in the absence of comparable data from similar locations on other motorways, this cannot be proven.

Because of the limited data available from the M25 prior to August 1995, it was not possible to carry out an impact assessment as part of a ‘before’ and ‘after’ study for the system. The extension of the VMSL (Controlled Motorway) system to Junctions 15 to 16 enabled the effects of its introduction to be assessed.
2 The Business Case Study

2.1 Extending VMSL (Controlled Motorway)

A business case is an accepted way to evaluate the overall socio-economic benefits of a publicly funded scheme, shown against the costs necessary to make it happen. At the simplest level it involves calculating the ratio between costs and benefits derived over the life of a scheme, normally 30 years (see Figure 2.a).

The M25 between Junctions 15 (M4) and 16 (M40) was chosen as the site for extending VMSL (Controlled Motorway) to allow the Highways Agency to establish the business case for implementation and to enable the development of guidelines for the provision of VMSL (Controlled Motorway) at future sites. This location was one of the busiest sections of motorway in the country and the site already had Motorway Incident Detection and Automatic Signalling (MIDAS). It was also adjacent to an existing VMSL (Controlled Motorway) scheme, so it could be controlled using the existing software and infrastructure at the Heston Motorway Control Centre.

The extension of VMSL (Controlled Motorway) provided the opportunity to more accurately assess the effects of controlled operation. One objective of the extension was the development of the next generation signal and enforcement technology (with a view to reducing cost of installation and operation through increased efficiency of technology), and development of a business case for the provision of VMSL (Controlled Motorway) on future candidate sites.

\textbf{Figure 2.a – A schematic illustrating the components of a business case}

The M25 between Junctions 15 (M4) and 16 (M40) was chosen as the site for extending VMSL (Controlled Motorway) to allow the Highways Agency to establish the business case for implementation and to enable the development of guidelines for the provision of VMSL (Controlled Motorway) at future sites. This location was one of the busiest sections of motorway in the country and the site already had Motorway Incident Detection and Automatic Signalling (MIDAS). It was also adjacent to an existing VMSL (Controlled Motorway) scheme, so it could be controlled using the existing software and infrastructure at the Heston Motorway Control Centre.

The extension of VMSL (Controlled Motorway) provided the opportunity to more accurately assess the effects of controlled operation. One objective of the extension was the development of the next generation signal and enforcement technology (with a view to reducing cost of installation and operation through increased efficiency of technology), and development of a business case for the provision of VMSL (Controlled Motorway) on future candidate sites.
2.2 Method and Data Collection

The study team assembled for this project included recognised experts in traffic behaviour, air quality, noise pollution, accident analysis, statistics, and economic appraisal. The project team was accountable to a specially created Steering Group, comprising suitably qualified representatives from the Department for Transport and the Highways Agency. Methodology and results were reviewed on at least a quarterly basis, with interim meetings focussing on more technical detail as required.

In determining the methodology for guiding the business case work, the Project Steering Group recommended that the New Approach to Traffic Appraisal (NATA) be adopted. The Business Case itself was established using a ‘before and after’ comparison of key variables such as journey time, safety and capacity. The ‘before’ scenario was the conventional gantry-mounted lane-signalling and cantilever mounted carriageway signals, with manually set signals and automatic queue protection using advisory speed limits. The ‘after’ scenario (after implementation, i.e. with VMSL (Controlled Motorway) operational) was VMSL (Controlled Motorway) with mandatory variable speed limits, speed enforcement, and congestion algorithms.

It was recognised that to follow the lengthy procedure for assembling a suitable business case on a scheme by scheme basis would not be an efficient use of public money. To overcome this, the study developed a ‘Generic Business Case’ and a supporting ‘Generic Assessment Tool’, which would provide clear guidance on how potential candidate sites around England could be assessed for VMSL (Controlled Motorway) operation.

Whilst data from M25 Junctions 15 to 16 provided an opportunity to test the Generic Business Case and Assessment Tool, it was clear that more examples would be required before generic templates could be used confidently without depending on specific data collection and analysis. The Generic Business Case Methodology and Assessment Tool delivered under this project provide the basis for this future development.

The project team conducted a comprehensive data analysis as part of developing the business case methodology. Data collection for the VMSL (Controlled Motorway) project took place from the implementation of the VMSL (Controlled Motorway) scheme in August 1995 right through to February 2003. The detailed analysis of the impacts of the scheme on Junctions 15 to 16 was based on data collected before and after the introduction of VMSL (Controlled Motorway) in March 2002. There were several sources used to collect this data, which are listed as follows:

- Traffic monitoring data collected during a two year period ‘Before’ VMSL (Controlled Motorway) and a one year period ‘After’ VMSL (Controlled Motorway);
  - MIDAS loop detectors, providing continuous data on a minute-by-minute averaged basis for flows, speeds, vehicle type and vehicle spacing;
  - Signal setting and EMS databases provided information on the signals set;
  - Specific journey data from instrumented vehicles, driven in each direction to collect information about stop-start behaviour and verify journey time measurements;
o Automatic Number Plate Recognition (ANPR) data, used to gather a larger volume of information on actual journey times between Junctions 15 and 16;

- Environmental data collected during a six month period ‘Before’ and ‘After’ VMSL (Controlled Motorway):
  - Noise surveys carried out between Junctions 15 and 16 to assess the impact of the scheme on the noise levels close to the road;
  - Exhaust emissions measured and modelled using typical driving profiles (from the instrumented vehicles) and a large database for vehicle emission values;

- Extensive accident data were also collected for the whole period covering January 1990 to September 2002, the main database was ‘STATS19’ injury accident records;

- Historical and contemporary data collected as part of M25 J10-15 VMSL (Controlled Motorway) monitoring (including most of the variables already listed).

Once the data had been analysed, an assessment was completed of the economic benefits of the scheme and the costs associated with implementation, operation, maintenance and renewal. Non-economic benefits of the scheme were also assessed. Some of the data were used to help build a better picture of how the benefits have been achieved and how these relate to the way VMSL (Controlled Motorway) operates in practice.

2.3 Performance Measurements

A number of performance measurements were calculated from the traffic data for M25 J15-16. These were derived on a month by month basis beginning at the start of the ‘Before’ period in January 2000. The measurements are as follows:

- The volume of traffic getting through the section – ‘throughput’;
- The average journey times;
- The reliability of those journey times;
- The overall amount of flow breakdown; and,
- The percentage of traffic using each lane – ‘lane utilisation’.

The performance measurements were calculated separately for each carriageway, for weekdays and weekends, and by time of day. To make the performance measures representative of typical periods, the data were filtered to exclude bank holidays, days with major incidents and occasions of extreme weather.

To gain additional understanding of traffic behaviour and where benefits were being realised, some additional measurements were obtained. These included:
• Shockwave Characteristics – The frequency and severity of ‘shockwaves’ in which drivers would be repeatedly braking and accelerating. This type of congestion is distinct from stationary traffic and can be influenced by variable speed limits;

• Speed Compliance – The percentage of drivers exceeding the displayed speed limits. This gave an understanding of how effective the system was at influencing traffic; and,

• Vehicle Headway – The time gap between the front of one vehicle and the front of the next, measured for each individual vehicle.

To retain context, the results were compared against contemporary data from M25 J10-15.

2.4 Results of Data Analysis

This section summarises the results of the data analysis. Most of the results are based on the analysis of the introduction of VMSL (Controlled Motorway) on Junctions 15 to 16; some are based on longer term trends observed for VMSL (Controlled Motorway) on Junctions 10 to 15. The results are described in greater detail in separate reports2,3.

2.4.1 Congestion and traffic flow

During the first year of operation the 15-16 VMSL (Controlled Motorway) section absorbed a 1.5% increase in throughput over 5-hour peak periods, without a detectable increase in congestion levels.

Traffic conditions have improved as a result of the reduction in frequency and severity of shockwaves. Overall, drivers will experience less stop-start conditions, and the variation in speed will also be lower. The longer-term study on Junctions 10 to 15 has shown a reduction from seven to five in the typical number of shockwaves that occur during the morning peak period.

2.4.2 Journey times

Journey times are the most easily understood measure of performance, as any change in journey times has a direct impact on drivers. Journey times have been calculated for the section of the M25 under observation. Following the introduction of VMSL (Controlled Motorway) on Junctions 15 to 16, weekday journey times on the anticlockwise carriageway reduced, whereas on the clockwise carriageway, journey times increased. It is likely that the different trends are due to different congestion levels. There is more congestion on the anticlockwise carriageway than on the clockwise carriageway. Where there is little or no current congestion (such as on the clockwise carriageway during the morning peak period), then the introduction of VMSL (Controlled Motorway) is likely to have had a detrimental effect, assuming that the flows are sufficient to set the signals. The speed restrictions will have slowed the traffic down, thereby causing delay.


3 Speed-control and incident-detection on the M25 Controlled Motorway (Summary of Results 1995-2002). PR/T/095/02. TRL Limited.
Similarly, off-peak journey times increased following the introduction of VMSL (Controlled Motorway). The VMSL (Controlled Motorway) system is designed to provide benefits during periods of high flow. During off-peak periods, the additional restrictions (e.g. new infrastructure, such as gantries, signs and speed enforcement cameras) reduce the average speeds, even though speed limits are not being displayed. This reduction in speed represents an improvement in speed compliance with the National Speed Limit, which is likely to lead to safety benefits.

Overall, weekday journey times during the day (averaged across both carriageways) were unchanged compared to the previous year. Off-peak journey times increased by an average of 3 seconds per journey compared to the previous year, due to improved compliance with the speed limits. Weekend journey times have also increased.

The longer-term data collected from Junctions 10 to 15 showed that journey times on that section reduced during 2001 and 2002, despite an increase in total throughput. This is consistent with an improvement in driver behaviour: drivers ‘conditioned’ to the system could be driving more smoothly to prevent or reduce the effect of flow breakdown. However, in the absence of comparable data from similar locations on other motorways, this cannot be proven.

2.4.3 Journey time reliability

Good journey time reliability is essential for drivers to plan their journey when travelling on the motorway. The introduction of VMSL (Controlled Motorway) has improved journey time reliability in certain key periods. The main improvement in journey time reliability has been on the anticlockwise carriageway, for weekday mornings and evenings. On the clockwise carriageway, there has been a small improvement in journey time reliability for weekday evenings. It is worth noting that whilst there were increases in journey times on the clockwise carriageway during weekday evenings, the increases were compensated by a more predictable overall journey.

2.4.4 Level of driver stress

Driver stress is difficult to quantify and measure, so an indirect approach was introduced. Driver surveys were conducted to gauge how drivers felt about using the VMSL (Controlled Motorway). From the comments received it was clear that drivers were positive about the specific benefits (such as increased journey time reliability and reduced stop start driving), and a more calm driving experience when compared to other standard sections of motorway.

2.4.5 Lane utilisation

The introduction of VMSL (Controlled Motorway) has resulted in a more balanced use of lanes. The traffic is now more evenly spread across all four lanes.

2.4.6 Accidents

British motorways have lower accident rates compared with similar roads in the rest of Europe. In order to recognise if a change in accident numbers from year to year is really significant or just part of the normal variation, it is necessary to have a large amount of data. The accident study covered Junctions 10 to 16, to ensure that the largest data set possible was used.
The initial accident study analysed and modelled data covering almost 13 years (January 1990 to September 2002). Data was also taken from the remainder of the M25 to allow comparison against trends. Following the publication of these reports further analysis was carried out. The revised estimates being based on the period 1st January 1987 to 31st December 2003, using only ‘official’ STATS19 data. The further analysis found the impact of introducing the Controlled Motorway driving environment is an estimated reduction in injury accidents of 15% during the period of operation.

Another important comparison is for damage only accidents. Data obtained from the Police showed that following the introduction of VMSL (Controlled Motorway), the ratio of damage only accidents for every injury accident dropped by a factor of 20%. Since the number of injury accidents fell, the number of damage only accidents also fell.

2.4.7 Speed compliance

Safety benefits are likely to be as a result of a culmination of changes to the driving environment resulting from the introduction of VMSL (Controlled Motorway). For example, there has been an increase in the compliance with posted speed limits, in particular for the more critical 40mph where the increase in compliance is 5%. This is likely to be a result of the change from advisory speed limits to mandatory (and the associated enforcement of the speed limits), and so this effect should be transferable to other motorways.

There has also been an increase in compliance with the National Speed Limit overnight (see Section 2.4.2).

2.4.8 Driver behaviour

There has also been a reduction in speed differential between lanes for most periods, together with a more uniform distribution of headways over a range of speed bands. The reduction in speed differential, combined with an improvement in lane utilisation, may reduce the desire to change lanes for overtaking. The more uniform distribution of headways (fewer headways of less than 0.8 seconds and of more than 1.5 seconds) may reduce the necessity for braking, without reducing the capacity of the road. Although the proportion of vehicle headways below one second has marginally risen, this does not seem to have affected accidents, possibly because of the MIDAS queue detection. Finally, there has been a reduction in the frequency and severity of shockwaves, reducing the overall risk of end-of-queue accidents.

2.4.9 Environmental – Emissions

Vehicle emissions have been reduced as a direct result of implementing VMSL (Controlled Motorway). The reduction in stop-start driving and the improved compliance with the speed limits have decreased emissions overall between 2% and 8% depending on the particular emission measured. Fuel consumption has also improved. This is one of several indicators producing positive economic benefits resulting from VMSL (Controlled Motorway).

2.4.10 Environmental – Noise

The noise impact resulting from the introduction of the VMSL (Controlled Motorway) scheme on Junction 15 to 16 has been found to be beneficial. The reduction in stop-start driving and the improved compliance with the speed limits have reduced the weekday
traffic noise adjacent to the carriageway by around 0.7 decibels. Whether the findings can be generalised to other schemes may require further work, although reductions of up to 2.3 decibels in source noise have been shown to occur alongside the M25 between Junctions 12 to 14 when the VMSL (Controlled Motorway) scheme was opened in 1995.

2.4.11 Impact of using MIDAS with VMSL (Controlled Motorway)

The work reported on here looked at the benefits from VMSL alone, using data up to 2002; however the system in use on the M25 includes both VMSL and MIDAS operating in tandem. As a separate study was taking place into the benefits of MIDAS, work was carried out to assess the impact of having both systems operating together. This work had the benefit of being able to use data up to 2005.

This demonstrated that the safety benefits of MIDAS and VMSL are independent of each other and also suggested that the overall safety benefit from the combined system is the sum of the two. The safety benefit from MIDAS has been shown to be 13%, so with 15% from VMSL the overall safety benefit is 28%.

2.5 User Reactions to VMSL (Controlled Motorway)

User reaction is a key factor to be considered when assessing the merit of further deployment of VMSL. It can be understood in the following terms:

- Public opinion of the current scheme;
- Drivers’ perceptions of its benefits; and
- Likely reaction of the public to further deployment of VMSL (Controlled Motorway).

2.5.1 Public opinion of the current scheme

User surveys were undertaken in 1996 after VMSL was installed between Junctions 10 and 15 of the M25. Public response was highly favourable, with over two thirds of drivers wanting the system extended to other areas of the M25 or to other congested parts of the motorway network.

Consultations undertaken as part of the Orbit Multi Modal Study for London, highlighting the opinions of the general public, transport groups, geographic groups and private groups that are affected by overall transport factors in London. Reactions from all bodies surveyed as part of the Orbit Study towards the VMSL (Controlled Motorway) scheme were positive. The general conclusions from this consultation were that the system should be expanded both on the M25 and elsewhere, although those surveyed also felt that more driver education and enforcement procedures should be put in place, alongside the technical components of the scheme, to get more out of the system.

2.5.2 Perceptions of the benefits of VMSL (Controlled Motorway)

The user surveys showed that 60% of drivers believed that the system had resulted in improvements. The Orbit Study consultation report listed specific reasons as to why drivers believe variable speed limits do or do not work, with suggestions for
improvements. A commonly stated solution to the perceived problems of variable speed limits is to combine education of drivers on what VMSL (Controlled Motorway) does with greater enforcement of the imposed speed limits. This would provide better control of the traffic, but without increasing the amount of braking.

Users accepted that variable speed limits would smooth traffic flow, helping to prevent ‘stop-start’ conditions with the associated frustration and stress. There was an expectation that reducing congestion and reducing driver speeds, especially in and around congested areas, would improve the efficiency of the motorway. Some people also understood that variable speed limits could reduce frequent lane changing, thereby improving safety.

Regular users of the M25 VMSL (Controlled Motorway) section perceive the benefits of the system, but agree that more needs to be done to maximise these. They also believe that the system has other benefits, with a reduction in driver stress and a reduction in the frequency of lane changing. Opinion is generally that the system is worthwhile and should be expanded to other congested sections of the motorway network.

2.5.3 Likely reaction to further deployment

Studies commissioned by the Highways Agency have provided an insight as to how the public might react to the wider deployment of VMSL (Controlled Motorway). For example, 68% of respondents to the Driver Opinion Survey undertaken after VMSL (Controlled Motorway) were installed on the M25 said they would like to see VMSL (Controlled Motorway) introduced on other sections of motorway.

Sources of information also include the HA Road User Satisfaction Survey, which contains information on the satisfaction of road users with the current provision of information, monitoring and enforcement on the trunk road network. One of the principal findings from this periodic survey is that the most irritating aspect of a journey relates to congestion and resultant delays. The users themselves generally consider their journeys vital and do not wish to consider re-routing or using other forms of transport, they wish to see improvements in the current network to deal with the demand placed upon it. The users also wanted more information on congestion and delays.

Many users wish to see an improvement in the road capacity, but recognise that congestion occurs at specific times of day and in specific hotspots. This understanding leaves opinion divided between support for widening and support for congestion-responsive systems for network management (such as VMSL (Controlled Motorway)).

In summary, a programme of educating motorists as to how a system of mandatory speed limits with an appropriate level of speed enforcement can be of benefit in addressing congestion problems should increase the perceived (as well as the actual) benefits of the system.

2.6 Overall Scheme Results

The work undertaken to date has shown that there are impacts from introducing VMSL (Controlled Motorway), although only some of these can be expressed in monetary terms and included in the Business Case. Table 2.a summarises the key outcomes as a result of the implementation of VMSL (Controlled Motorway), related to its desired
impacts. The Table also indicates whether the impacts are primary (i.e. they are a direct measure of performance) or secondary (i.e. they have an effect on performance).

Table 2.a – Impacts of VMSL (Controlled Motorway)

<table>
<thead>
<tr>
<th>Impact Area</th>
<th>Indicators of Impacts</th>
<th>Primary or Secondary impact</th>
<th>Overall improvement (Y/N)</th>
<th>Included in Monetised Results (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journey times</td>
<td>There has been an increase in peak-time journey times on the clockwise carriageway and a decrease on the anticlockwise carriageway. Combining the two carriageways makes the peak-time effect of VMSL (Controlled Motorway) neutral. Off-peak, there have been small increases in journey times on both carriageways.</td>
<td>P</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Journey time reliability</td>
<td>There has been a small improvement in overall journey time reliability, indicating a smoother journey.</td>
<td>P</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Safety</td>
<td>Safety benefits arise as a result of a culmination of impacts on the driving environment and on driver behaviour. Injury accidents have been reduced by 15%, and there has been a 20% drop in the ratio of damage only to injury accidents.</td>
<td>P</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Noise</td>
<td>Weekday traffic noise adjacent to the scheme has been reduced by 0.7 decibels.</td>
<td>P</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Emissions</td>
<td>Emissions have decreased overall by between 2% and 8%.</td>
<td>P</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>The smoothing effect of the system has reduced fuel consumption, with a commensurate impact on emissions.</td>
<td>P</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Throughput</td>
<td>There has been no increase in the peak 1-hour throughput. However, the total throughputs during the 5-hour peak periods on the M25 Junctions 15-16 have increased by approximately 1.5%. There will be a benefit if this greater demand can be accommodated without a drop in performance.</td>
<td>P</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Speed limit compliance</td>
<td>There has been a reduction of 5% in the proportion of drivers exceeding the 40mph speed limit, which is now displayed as a mandatory limit.</td>
<td>S</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Headways</td>
<td>Drivers are leaving more uniform headways. As a result, there is likely to be less need for drivers to brake. The more uniform headways may be because drivers can optimise their headways in relation to the VMSL (Controlled Motorway) signals.</td>
<td>S</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Impact Area</td>
<td>Indicators of Impacts</td>
<td>Primary or Secondary impact</td>
<td>Overall Improvement (Y/N)</td>
<td>Included in Monetised Results (Y/N)</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------</td>
<td>-----------------------------</td>
<td>--------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Frequency and duration of flow breakdown (speeds less than 25 mph)</td>
<td>There has been a 9% reduction in the amount of time the flow on the anticlockwise carriageway is broken down, and a 3% reduction in the number of flow breakdowns occurring. There has been some increase in flow breakdown on the clockwise carriageway. A long term effect (observed on Junctions 10-15) has been a reduction in the number of shockwaves during the morning peak period. As drivers become accustomed to the VMSL (Controlled Motorway) system, they can modify their behaviour to reduce the effect of flow breakdown.</td>
<td>S</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Shockwave characteristics</td>
<td>There has been a reduction of 6% in the amount of stop-start driving during peak periods.</td>
<td>S</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Speed differential between lanes</td>
<td>There has been a general harmonisation in speed between lanes, with the standard deviation of the speed difference between lanes typically reducing by 1 km/h. The absolute difference in speeds between lanes 1 and 4 has typically reduced by 5 km/h.</td>
<td>S</td>
<td>–</td>
<td>N</td>
</tr>
<tr>
<td>Lane utilisation</td>
<td>There has been an increase in the utilisation of lanes 1 and 2 on the anticlockwise carriageway of between 1% and 2%, with a similar reduction in the utilisation of lanes 3 and 4. This gives a more even distribution of traffic across the carriageway.</td>
<td>S</td>
<td>–</td>
<td>N</td>
</tr>
<tr>
<td>User reaction</td>
<td>The VMSL (Controlled Motorway) scheme is well accepted and there is a perception of key benefits.</td>
<td>S</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

### 2.7 Cost of Implementation

For a scheme such as VMSL (Controlled Motorway), the money invested in the scheme should bring returns for society at least equivalent in value. The aim of the Business Case was to define, measure, and calculate the benefits produced from the introduction of the VMSL (Controlled Motorway) scheme and compare these to the cost of the scheme. The costs used for comparison are as follows:

- Implementation costs;
- Operational and maintenance costs;
- Costs for replacing electronic equipment at the end of its 15 year design life (renewal costs);
• Traffic delay costs during construction and renewal (the cost of delaying traffic so works can be carried out constructing and replacing the infrastructure).

The costs of constructing, maintaining, operating and renewing the Controlled Motorway environment have been compared with the costs of just maintaining, operating and renewing the existing base system, incorporating standard signalling control systems, signal gantries and MIDAS, over a 60 year period, to derive the additional costs attributable to the scheme. The additional costs have been estimated at £11.7m (2002 prices).

In future, the costs of implementation and operation for a comparable scheme will reduce, as cheaper technology and more cost effective ways of enforcing the speed limits are now available.

2.8 Junction 15 to 16 Economic benefits

The anticipated economic benefits of the VMSL (Controlled Motorway) scheme have been forecast over a 60 year period.

Positive economic benefits have been assessed as a result of a forecast reduction in accidents and a reduction in fuel consumption, as a result of smoother driving with fewer incidents of stop start conditions compared with the base scheme.

Although these benefits are partly offset by the economic costs of increased journey times for some drivers, the overall effect is positive. The total discounted benefits included within the Business Case have been estimated to be £54.4m (2002 costs and prices), which compares with a discounted cost of £8.4m (2002 costs and prices). This results in a benefit to cost ratio of approximately 6.5.

Beneficial effects such as those highlighted above have been observed both during the day to day operation of the network and when the VMSL (Controlled Motorway) system has been used as a traffic management tool during roadworks.

2.9 Roadworks Experience

During 2004 and 2005, the M25 between Junctions 12 and 15 has been undergoing major widening works to provide access to the new Terminal 5 at London's Heathrow Airport. A fixed 40mph speed limit applies within the roadworks area. In this area, there has been no opportunity to dynamically control the traffic, as the gantries holding the CMIs were removed prior to the works commencing. However, the Police advised that they would like to see the VMSL (Controlled Motorway) system continuing to operate on the lead-in to and the exit from the roadworks.

Consequently, a signalling strategy was devised to control the traffic approaching the roadworks. The basic operation of the VMSL (Controlled Motorway) system remains as normal, with signals being set if there is a high traffic demand or if there is queueing traffic ahead. In the final 2 miles of the approach to the roadworks, the signals become gradually more restrictive. This smoothes the traffic, enabling the transition into narrow lanes through the roadworks to be achieved without causing any additional congestion.

The new signalling strategy has been successful in allowing traffic to pass through the roadworks with a minimum of delay.
2.10 Lessons learnt from M25 J15–16 Study

Many improvements as a result of implementing VMSL (Controlled Motorway) have already been shown and the economic appraisal carried out for the Business Case proves positive on the M25 Junction 15 to 16.

Having completed the monitoring and evaluation exercise, it is clear that there are specific characteristics of the Junction 15 to 16 section of the M25, such as distinct variations in congestion levels between the two carriageways, which mean that further results will be needed from this and other sites to confirm the economic and other benefits of the wider deployment of such schemes.

The key reasons for this are outlined below:

- The data shows there is little or no evident congestion in the morning peak period on the clockwise carriageway. However, the flows were sufficient to set the signals, and these signals slowed the traffic down, thereby causing delay. The introduction of VMSL (Controlled Motorway) has had an adverse effect on journey times. Given that the traffic patterns differ from those on Junctions 10 to 15, the signal thresholds could benefit from further tuning.

- Analysis of traffic data also suggests that drivers learn to use the information provided by the VMSL (Controlled Motorway) system to drive more smoothly to reduce the effects of flow breakdown. As VMSL (Controlled Motorway) has been operational on the adjacent section of the M25 (from Junctions 10 to 15) since 1995, drivers on that section are likely to have modified their driving behaviour. As many of those drivers also travel between Junctions 15 and 16, there are likely to have been improvements in performance already occurring on this section between 1995 and 2000, which have not been taken into account.

To aid decision making on any future deployments of VMSL (Controlled Motorway), the results from the business case study and lessons learnt regarding the impacts of VMSL (Controlled Motorway) have been incorporated into a Guidance Note and Generic Assessment Tool.
3 Continuing Development

Building on the knowledge gained through this project, a clearer set of criteria for VMSL implementation has been developed. As part of the business case work for M25 Junctions 15 to 16, the potential benefits of the deployment of VMSL (Controlled Motorway) at other sites has been assessed through the development of the Generic Business Case.

The Generic Business Case has investigated the feasibility of implementing VMSL on a generic section of motorway with the aim of calculating an overall economic worth from the benefits that can be achieved. These benefits have been assessed using a Generic Methodology, based on the analysis of impacts of VMSL on the M25.

A guidance note incorporating a Generic Assessment Tool has also been developed to identify those sites where VMSL (Controlled Motorway) are likely to be cost effective.

3.1 The Generic Business Case Example

Current understanding of the actual economic benefits is limited to the business case analysis carried out for the scheme implemented on the M25 between Junctions 15 and 16. The business case analysis carried out on that site has attributed economic values to the scheme's impacts on the following:

- Journey time;
- Accidents, and
- Fuel consumption.

There are other beneficial impacts, related to improvements in journey time reliability identified in the business case that have not, as yet, been ascribed an economic value. Other beneficial impacts which cannot currently be measured in economic terms, although it may become possible to attribute an economic value to these impacts in the future, relate to:

- Noise;
- Vehicle emissions, and
- Driver stress.

Other beneficial impacts of the scheme that have been identified and quantified, relate to:

- Frequency and duration of flow breakdown; and
- Enhanced safety.

The results obtained from the M25 J15 to 16 study indicate that there is a positive business case for this section of motorway. Whether there might be a positive business case for implementation of VMSL elsewhere can be assessed through application of the
A generic Business Case methodology to sites that might be considered appropriate for VMSL (Controlled Motorway).

A particular ‘generic’ D4 Motorway site was chosen, 10km in length with an AADT of 150,000 and a national average accident rate and this proved to have a positive business case, with a benefit to cost ratio of 3.9.

3.2 Guidance Note on VMSL (Controlled Motorway)

A number of tools have been developed to assist decision making on VMSL. They are based on current understanding of the functionality of VMSL. The Guidance Note summarises how these tools can be applied in practice. It provides a framework for decision makers to apply the knowledge gained from the Business Case Study to their own sites.

The Guidance Note allows decision-makers considering the introduction of VMSL (Controlled Motorway) to:

- Identify how suitable a site is for the introduction of VMSL and identify circumstances where VMSL may not be appropriate;
- Rank a series of potential sites and decide which sites are better suited to the application of VMSL (Controlled Motorway), and
- Identify the level of work required for Business Case Development based on the merits of VMSL.

To facilitate these aims the Guidance Note incorporates a Generic Assessment Tool (GAT) to guide decision makers through the evaluation process. The GAT can also be used for the purpose of choosing between competing sites; generating numeric results for a range of criteria that can provide a basis for comparison.

The results of applying the GAT process allow decision-makers to make an informed decision on whether or not to proceed with implementing VMSL (Controlled Motorway) and identify where applications other than VMSL (Controlled Motorway) might be more appropriate.
4 Conclusions

The Business Case Study for VMSL (Controlled Motorway) has shown that there are likely to be benefits from the introduction of VMSL (Controlled Motorway) at other sites.

The primary benefits identified through this study are:

- Smoother and more reliable journeys in certain periods;
- Reduction in stress for drivers;
- Reductions in the number and severity of accidents;
- Reductions in traffic noise, vehicle emissions and fuel consumption; and,
- Improved driver behaviour.

Some of these benefits (e.g. a reduction in accidents) have a monetary value. Others (e.g. reduced driver stress and environmental benefits) do not currently have a monetary value, but they are still important benefits. If all the benefits are taken into account, the case for installing VMSL (Controlled Motorway) at further sites is likely to be even more favourable, providing that the proposed sites have suitable characteristics as identified within this study.

Guidance on the nature of sites where VMSL (Controlled Motorway) are most likely to be cost effective has been developed, along with a Generic Assessment Tool to aid the decision making process.

Those benefits taken forward into the cost benefit analysis outweighed the cost of implementation on M25 J15 to 16. The Generic Business Case Methodology as applied to the Generic Example suggests that the introduction of VMSL (Controlled Motorway) at other sites could prove economically viable. Caution is required with interpretation of the results, since they are highly sensitive to small variations in traffic flows.

The implementation of VMSL (Controlled Motorway) at other sites needs to be approved on a site by site basis using the Guidance and Generic Assessment Tool derived from the M25 study. The results from any subsequent implementation should be used to validate and refine the current suite of decision making tools.