Annex to the DfT Advanced Motorway Signalling and Traffic Management Feasibility Study Report

1. Introduction

1.1. This Annex supplements information in the main body of the report of the DfT study into the feasibility costs and benefits of extending advanced signalling and traffic management techniques more widely across the motorway network.

1.2. As background, Section 2 describes the development of existing schemes that include hard shoulder running, including those implemented abroad, and summarises the outputs from the preparation of business cases for the specific hard shoulder running schemes that are in operation or development in England.

1.3. Section 3 describes in more detail the methodology used to identify the priority hard shoulder running locations described in chapter 5 of the main report, as well as the additional considerations that can impact on the business case for hard shoulder running schemes that were not assessed in the initial location identification and prioritisation process.

1.4. Section 4 explains in more detail the methodology used to assess the overall business cases for the widening and hard shoulder running scenarios described in chapter 6 of the main report, and sets out the detailed results of the welfare analysis used to inform study's conclusions on the business case for hard shoulder running.

1.5. The final section gives more information about how the emissions effects of the hard shoulder running packages were modelled.

2. Background: the development of hard shoulder running

Development of hard shoulder running abroad

2.1. The use of the hard shoulder as a running lane was first introduced in Holland and Germany in 1996 and it has been introduced subsequently in the UK and US. Hard shoulder running provides additional capacity at times of heavy traffic and experience has shown that it can bring improvements in reliability and journey times. Hard shoulder running was first introduced in the UK in September 2006 on the M42 between junctions 3a and 7. The early success of this pilot led the Highways Agency (HA) to review its planned motorway widening schemes in summer 2007. That review has now been expanded, as part of this feasibility study, to cover the whole of the motorway network.

2.2. Various forms of advanced signalling and traffic management (also known as Active Traffic Management or ATM) are practised around the world. However, only a handful of countries currently operate schemes where the hard shoulder is used as a running lane. These are the one scheme in the UK (the M42 pilot), 17 schemes in the Netherlands, 6 schemes in Germany and the one in the USA.

Netherlands

2.3. Temporary hard shoulder running during peak hours was first introduced in the Netherlands in 1996 as part of a wider programme to make better use of the existing infrastructure. Use of the hard shoulder is monitored manually from the traffic control centre using CCTV and is operated through variable signs mounted on gantries. When hard shoulder running is in operation the following measures are in place:

- The maximum speed limit is reduced from 120kph (75mph) to 90kph (56mph)
- Emergency Refuge Areas (ERAs) are provided approximately every kilometre
- Speed detection loops are placed every 500-600m on normal lanes and every 75m on the hard shoulder
- Maximum spacing between gantries is approximately 700m.
- The gantries display a green arrow when a lane is available for use and a red cross when it is closed. During hard shoulder running operation the maximum speed limit is also displayed
- Rescue vehicles are placed at junctions for rapid deployment in the event of an incident

2.4. Across the Netherlands, use of hard shoulder running has increased overall capacity at individual sites by between 7% and 22%. Travel time savings range from 1 to 3 minutes, journey time reliability has improved significantly and there has been no negative impact on road safety. A survey of public opinion of the first hard shoulder running scheme in the Netherlands showed that it was widely supported by drivers, relevant authorities and those living close to the scheme. It was, however, less popular with the emergency services who preferred to view hard shoulder running as a short-term rather than a permanent solution.

Germany

2.5. Germany is unusual in terms of traffic growth as there have been particular pressures on the road network since re-unification; traffic growth is predicted at 16% for passenger transport and 58% for freight by 2015. As a consequence, Germany has a major road building programme in place with 1,730km of new motorway, 2,162km of motorway widening and 717 new bypasses planned to be completed by 2015. There is also a comprehensive five-year plan to extend motorway traffic control over a further 1,200km of motorway, dynamic diversion capability over a further 2,400km and to add an additional 15 regional traffic control centres.

2.6. Germany has used hard shoulder running since 1996 and there are currently over 200km in operation. However, it is generally viewed as a short-term measure in advance of the major road expansion referred to above. It is typically implemented between junctions where there are particularly high traffic movements. The most successful hard shoulder running scheme in Germany is considered to be the combined A3 Offenbach – Obertshausen and A5 Bad Homburg – Frankfurt, which is roughly similar in design to the M42 pilot. It currently covers 60km and a further 25km is planned. It is only used however in 'emergency' or pre-defined situations to relieve congestion. During operation of the hard shoulder, the maximum speed limit is reduced from 120 kph (75mph) to 100kph (62mph).

2.7. The scheme has the following features:

- The original layout of three 3.75m lanes with an inside hard shoulder was converted to four 3.50m lanes. The inside and outside lanes both have a narrow strip for safety purposes
- The system is controlled by gantry-mounted VMS which are spaced at 800-1000m intervals
- There are no ERAs
- The variable message signing is both gantry mounted and roadside. When the hard shoulder is not in operation the signs are blank so when no symbol is displayed above the hard shoulder it is assumed to be closed as a running lane
- The traffic control centre is alerted when flows reach 6,000 vehicles per hour, which tends to be in the peak periods, as this is considered to be the trigger point for activation of hard shoulder running. However, it is still only operated manually. Staff in the control centre can initiate the system manually at other times as required

- The operation of hard shoulder running is monitored manually using pan-tilt-zoom cameras spaced approximately every 750m. These are programmed to move every few seconds in a pre-determined pattern. Whilst the camera system is capable of detecting incidents on the hard shoulder there is currently no fully automatic incident detection system in place.

2.8. No negative impacts on road safety have been reported and a reduction in congestion has led to a consequential reduction in congestion-related accidents. One notable statistic is that there appears to be a significant reduction in accidents on the sections of motorway in advance of the hard shoulder running sections. This would appear to be due to the absence of congestion as hard shoulder running has evened flows and reduced slow moving traffic, thereby reducing tail-end shunts. Hard shoulder running on this section of motorway has increased capacity by 20% (7040 vehicles per hour at 94kmh (59mph) with hard shoulder running compared with 5620 vehicles per hour at 75kmh (47mph) without). Journey times have therefore improved and traffic flow is particularly improved at the junctions. Furthermore, public opinion of the scheme has been extremely positive.

USA

2.9. The Virginia Department of Transport currently operates a managed lane strategy on the I-66 in Fairfax County which allows use of the hard shoulder during peak hours. At the same time the lane adjacent to the central reserve is converted to a temporary Hgh Occupancy Vehicle (HOV) lane. A study recently published by the US Transportation Research Board concludes that the system in Virginia is a cost-effective and efficient means of increasing the capacity of the route. The study found no evidence that use of hard shoulder running at peak times had any effect on the number or characteristics of accidents in the study area and goes on to recommend hard shoulder running as a strategy that should be considered elsewhere in the US with the addition of a number of advanced signalling and traffic management features such as incident detection systems and variable message signs. Speed limits with and without hard shoulder running are 55mph (88kph).

The development of hard shoulder running in the UK

2.10. Three potential sites for the Active Traffic Management pilot were identified on the M25 along with the M42 site. The M42 was chosen for the pilot, mainly because the back office control infrastructure existed and there was strong stakeholder support, including from the local police. In July 2001, John Spellar, the then Minister for Transport, announced that ATM would be piloted on a section of the M42 corridor between junction 3A and 7, to the South-East of Birmingham.

2.11. The ATM pilot brings together a number of technologies, and includes hard shoulder running, to demonstrate how they can be used to together to maximise their benefits. The M42 location was deemed to be suitable for a number of reasons:

- High levels of traffic flow on both carriageways
- Higher than national average accident rates, particularly between junctions 5 and 6
- The combination of local and strategic traffic using the motorway
- Congestion points where traffic joins and leaves the motorway
- The traffic problems associated with major events at the NEC, Birmingham International Airport and Birmingham International Train Station
- Future forecast growth in the area

2.12. The implementation of ATM on the M42 allows existing motorway space to be used more flexibly. It is a toolbox of traffic management measures, including automated signalling and enforcement, driver information displays and comprehensive traffic monitoring, enabling rapid incident detection and response. Sensors in the road collect traffic information that is relayed to automatic systems and operators at the Highways Agency's West Midlands Regional Control Centre (RCC). This is used to plan a more flexible use of the motorway lanes, including opening up the hard shoulder and setting variable speed limits to respond to traffic levels or incidents and avoid or reduce congestion. When the hard shoulder is in use as a running lane, the maximum speed limit is 50mph (80kph).

2.13. Information and instructions for motorists are conveyed via the display of real time information and instructions on overhead gantries. The control centre uses the latest proven technology to oversee the operation of the motorway 24 hours a day, and CCTV enables operators to mobilise a quick and effective response if incidents occur. Emergency refuge areas are provided for broken down vehicles and are equipped with emergency telephones.

2.14. A phased implementation of the pilot began in Winter 2004 and hard shoulder running was first implemented in September 2006. The operation of the pilot is being monitored and an initial report on its effectiveness can be found online at:
http://www.dft.gov.uk/pgr/roads/tpm/m42activetrafficmanagement/

Planned hard shoulder running schemes

2.15. The potential for extending hard shoulder running around the Birmingham Box was first acknowledged in October 2001, as part of the West Midlands Area Multi-Modal Study's (WMAMMS) 2031 plan. The Birmingham Box comprises sections of the M5, M6 and M42 and provides a "ring road" to the West Midlands Conurbation. The Box as a whole acts as an interchange between several motorway and trunk roads that link all parts of the country. These include the M6 (north and south), M42, M5, M40 and M54.

2.16. A subsequent feasibility study confirmed that the Birmingham Box was a suitable location for extending the principles of the ATM pilot because of the prevalent conditions. Much of the Box passes through urban areas with a significant proportion having development up to the highway boundary. Furthermore, many of the motorway sections are elevated, particularly on the M5 and M6. Early analysis had concluded that traditional engineering (such as widening) would be extremely disruptive during construction, as well as very expensive. The study concluded that hard shoulder running was the only practical method of increasing capacity on many sections of the Birmingham Box.

2.17. In December 2006 the Secretary of State for Transport announced that Phases 1 and 2 of the scheme had strong potential to provide a significant benefit to productivity:

- **Phase 1**: M6 Junction 4 to Junction 5, M40 Junction 16 to M42 Junction 3A and M42 Junction 7 to Junction 9
- **Phase 2**: M6 Junction 8 west to Junction 10A

2.18. In October 2007, following further detailed design, the Secretary of State confirmed the implementation of a £150m scheme to implement ATM with hard shoulder running on the above sections of the Birmingham Box, funded through the Department's Transport Innovation fund for productivity.

Highways Agency review of motorway widening schemes

2.19. In spring 2007, the Highways Agency commenced a review of motorway widening schemes in its major schemes programme. The review has considered all motorway schemes not yet completed or under construction, except where the nature of the scheme meant that it was clear that no opportunities for hard shoulder running existed (e.g. a junction improvement scheme). No schemes on the all purpose network were considered. Based on this, the schemes identified for further investigation were:

- M1 J10-13 widening
- M1 J 31-J42 widening (5 schemes)
- M1 J25-28 Contract 1 widening
- M1 J21-30 Contract 2 widening
- M62 J25-J28 widening
- 4 proposed M25 widening schemes within the DBFO contract

- M27 J3-4 widening
- M27 J11-12 climbing lanes

2.20. The aim of the review was to provide advice on the viability of hard shoulder running as an option to be fully appraised alongside the option to widen so that a preferred option decision can be made.

2.21. The review concluded that hard shoulder running could provide a viable alternative to widening for the five schemes on the M1 (between J31 – J42), the M62 (J25 – J28) scheme and for the M1 J21 – J30 Contract 2 scheme. Detailed analysis is ongoing to develop a fully worked up option appraisal to ascertain the costs, benefits and fit with strategic objectives of the hard shoulder running option for these schemes. The next steps will depend on the outcome of this appraisal and will necessarily be guided by the relative deliverability, affordability, VFM and incremental benefits associated with the schemes.

Conclusions that can be drawn from business cases developed to date

2.22. This section reports the results of the business case assessment for the M42 pilot (J3a - 7) and Birmingham Box phases 1 and 2. The schemes have been assessed using DfT's standard appraisal framework, the New Approach to Appraisal (NATA). This approach enables decision-makers to take a consistent, evidence-based view on the impacts of a new transport scheme.

2.23. For each scheme a business case has been produced which produces a NATA Benefit Cost Ratio (BCR). This, together with other non-monetised impacts, is used to produce a value for money (VfM) rating[1]. The categorisation of impacts are shown in figure 1 below[2]:

Figure 1: Categorisation of impacts on value for money

Impacts included in value for money assessment			
Qualitative/quantitative assessment		Monetised values (NATA BCR)	
Areas for development	Some valuation evidence		
Townscape Water environment Accessibility Social inclusion Integration Biodiversity Heritage	Wider economic benefits* Landscape Reliability Air quality Journey ambience Regeneration	Risk of death or injury Noise Carbon Physical fitness	Time savings Operating costs Private sector impacts Cost to the Exchequer

*Reliability and wider economic benefits are monetised in some appraisals.

[1] http://www.dft.gov.uk/about/how/vfm/guidanceonvalueformoney
[2] Source: Towards a Sustainable Transport System – Supporting Economic Growth in a Low Carbon World, DfT

The VfM rating can be poor, low, medium or high.

2.24. Figure 2 gives the results for these two schemes. Both schemes indicate good BCRs, over 3.0. However, in order to make a full VfM assessment the non-monetised impacts must be considered. From figure 2 it can be seen that there are few significant non-monetised impacts. This is because hard shoulder running requires no new land take and therefore usually only has a slight/moderate adverse impact on landscape, biodiversity, heritage, water environment etc. It therefore appears that these schemes offer high VfM.

2.25. The VfM of these specific schemes can only give a very rough indication of the case for other potential hard shoulder running schemes. In practice the VfM will vary due to, inter alia, more/less expensive infrastructure being built, the nature of the current congestion at each section of motorway and the scale of non-monetised impacts for each scheme.

Figure 2: Existing Business Case outputs

Scheme name	VFM	Cost	BCR	Accidents	Environmental impacts						Reliability
					Land take	**CO_2**	**Landscape**	**Noise**	**Air quality**	**Biodiversity**	
M42 pilot	Possibly high	£117m (Q3 2005)	3.5	Reduction observed (see discussion below entitled 'Accidents'	nil	Unknown	Slight adverse	Reduction of 1.8dba	Neutral		Reduction in variation of journey time
ATM Birmingham Box TIF scheme	Possibly high	c.150m	3.3	1308 accidents saved, 24 fatal, 147 serious and 2609 slight casualty reduction.	nil	Slight beneficial – reduction in CO_2 worth £9m	Slight Adverse – existing gantries and lighting will be used, but some new infrastructure	650 fewer households annoyed	Neutral (based on M42 pilot)	Neutral	Moderate Beneficial – reduction in merging disruption

3. The development of the hard shoulder running location prioritisation methodology

3.1. To enable the identification and prioritisation of motorway links for further analysis, an assessment of the economic effects of introducing hard shoulder running on the motorway network was carried out using a spreadsheet tool previously developed by the HA and based upon the principles inherent in the Department's Cost Benefit Analysis (COBA) programme. The spreadsheet looks at each link on the motorway network (though we excluded the M25 and sections where widening schemes have reached or are close to public inquiry). Taking 2006 traffic flow profiles for every dual 3 lane motorway link from the HA's traffic database as a starting point, traffic growth is applied at the rate used in the Department's National Transport Model. (Where possible growth from the relevant NTM region was used, and for all others the England NTM growth - around 1½ % a year - was used.)

3.2. The results of the M42 hard shoulder running pilot have been used to develop a speed flow curve and to determine the flow at which hard shoulder running is 'switched on'. This is when flows reach 1500 vehicles per lane (4500 vehicle across a three lane carriageway). This is equivalent to a speed of around 60mph. This assumption was developed for hard shoulder running with a 50mph speed limit but we have assumed the same switch on flow for hard shoulder running with a 60mph limit.

3.3. The spreadsheet calculates benefits derived from faster link speeds and reduced queuing and merging delays associated with a four lane motorway (D4M) and with a three lane motorway (D3M) plus hard shoulder running, compared with a standard D3M motorway. Changes to vehicle operating costs (mainly fuel) and changes to indirect taxation (a function of fuel) are also calculated. Other outputs are the first year when hard shoulder running would become active and the number of hours the hard shoulder would be open for in the first year and subsequent years.

3.4. The spreadsheet assumes that the hard shoulder is brought into operation at the optimum times. Operational practice on the M42 pilot has been to set the 50mph speed limit in advance of the time when flows would dictate that the hard shoulder is needed. Similarly, the hard shoulder is switched off after the point when the hard shoulder is required i.e. flows are below the threshold at which it is needed.

3.5. No account is taken within the spreadsheet of the effect on accidents, journey time reliability and the implications for future maintenance operations. The spreadsheet method does not take into account the wider network effects of hard shoulder running. Since each link is assessed individually, the effect of contiguous links may be to reduce benefits, but the wider network (beyond the motorway) effects may counterbalance this. Changes in accidents and emissions are not included. Variable demand is not explicitly modelled though this is reflected to some extent since the growth factors are from the NTM which is a variable demand model. We assessed the wider network effects subsequently using the National Transport Model (NTM).

3.6. The forecast benefits from this work were then compared with the estimated cost of delivering the roll out of the potential hard shoulder running schemes identified to derive benefit cost ratios. The assumptions underlying the cost estimates include:

- Hard shoulder running through junctions will be part of the design and will comply with the appropriate design standards (adopting a 'do minimum' approach)
- All construction will be within the existing highway boundary
- Emergency Refuge Areas and gantries will be spaced at approximately 800m intervals
- Power is available, but may need upgrading
- Some existing communications facilities are available although further provision of fibre optic cable and longitudinal cable is likely to be necessary
- New drainage is required for Emergency Refuge Areas and spill traps only and will be designed to cope with an additional 20% flow to accommodate for climate change. Where possible existing drainage will be used
- Lighting and CCTV will be required
- Vertical concrete barriers in the central reserve will not be provided as part of the scheme
- Strengthening of the hard shoulder and structures may be required

3.7. Based on the above, and experience from delivery of the M42 pilot, a baseline cost estimate of £3m/km was assumed in defining priority links, with contiguous links combined into schemes. These schemes were included in the NTM modelling that was carried out to develop the business case for the wider roll out of hard shoulder running. The business case development work is described in chapter 6 of the main report.

The significance of the "monetisable" impacts not included in the prioritisation process, and assumptions used in the business case

3.8. A number of impacts of the implementation of hard shoulder running were not captured in the initial assessment and prioritisation that was carried out. These are discussed below:

Network Impacts and Variable Demand

3.9. Reducing congestion on a motorway link by providing hard shoulder running is likely to increase traffic flows on the motorway compared with a conventional D3M because some traffic will reassign to the motorway from other more congested routes and because of demand responses, primarily trip lengthening.

3.10. The impact on traffic demand of providing an additional lane at periods of high demand through hard shoulder running has not been assessed at a link level. Results at an aggregate level from the NTM indicate that traffic flows would increase by about 2% on the motorway network as a result of implementing a wide package of hard shoulder running but only by 0.1% over the whole network.

3.11. The effect of reassignment will be to increase benefits compared with those that have been assessed using the spreadsheet tool. There are two reasons for this; the reassigned traffic will be travelling faster than it would have done on its previous route and because of the consequential congestion reduction on the routes from which traffic has reassigned.

3.12. Trip lengthening (known as re-distribution) on the other hand will tend to reduce benefits because the additional vehicle kilometres are likely to make the network more congested and reduce overall journey times.

3.13. The extent to which the beneficial effects of reassignment will outweigh, or be outweighed, by the likely disbenefits of redistribution, will depend upon local circumstances and therefore will vary from link to link.

3.14. There will also be economic impacts across the wider road network associated with hard shoulder running though these are likely to be similar to those that would be achieved from widening to D4M.

Maintenance delays

3.15. The two major components of road user delay costs associated with the maintenance of managed motorways are major maintenance, such as re-surfacing, and the replacement of the electrical equipment needed for driver information, safety and enforcement which will probably be necessary after 15 years.

3.16. Major maintenance schemes on motorways make use of contra flow traffic management layouts which utilise the hard shoulder. Though the hard shoulder will continue to be available once hard shoulder running has been established, it will no longer be available as an *additional* lane, at least during periods of peak demand. Because hard shoulder running can accommodate higher traffic growth than the existing D3M, any traffic over and above that which would have occurred with a D3M, will create additional delays.

3.17. The effect of hard shoulder running will be to increase future maintenance costs compared with D3M and also compared with a conventional widening to D4M. The delays can be assessed by modelling using either a macro traffic model or the Department for Transport's QUeues And Delays at ROadworks (QUADRO) programme.

3.18. Traffic delays associated with future maintenance will be different for each option. The same road space will be available for managing traffic through roadworks in both the D3 (base case) and D3+hard shoulder running (HSR) options, however, traffic volumes in the future will be higher with hard shoulder running. Future traffic volumes will be similar under D4 and D3+HSR, but there will be more road space available under D4.

3.19. The extent to which delays affect traffic will depend on the operating restrictions that are placed on the maintenance contractor. Normal practice is to require the contractor to ensure that there is no loss of capacity during peak periods. However, future maintenance would be easier to achieve with the D4M option than with D3M+HSR and consequently major maintenance operations with D4M are likely to be undertaken more quickly and at lower cost. Against the base case, the D3+HSR option would be expected to have slightly higher delay costs, while D4 would be expected to show reduced delay costs.

3.20. However, the actual size of these costs would be scheme specific and would depend on the amount of work that was carried out outside peak periods, with a trade-off possible between delay and operational costs. This impact has not been included in the appraisal carried out.

Accidents

3.21. The results of monitoring of the M42 ATM pilot so far has only approximately 6 months of data, which is too short an assessment period for the purposes of ascertaining, robustly, its effect on accidents. Accident information for at least three years and preferably five years should be used to fully assess a scheme's effect on safety. However, during the 6 month trial period, personal injury accidents (PIAs) reduced from 5.2 per month (based on 5 years of 'before' data) prior to the construction of the pilot to 1.5 per month (based on 6 months of 'after' data) with full ATM including hard shoulder operation. It should also be noted that the accident reductions have been achieved at a speed limit of 50 mph and not the 60 mph speed limit being proposed for the wider roll out of hard shoulder running. It is therefore difficult at this stage to forecast what the impact of hard shoulder running will be on PIAs.

3.22. Both D3M+HSR and D4M will have MIDAS and Controlled Motorway (CM). MIDAS has been shown to achieve a 13% reduction in personal injury accidents (PIAs) and CM a further 15% reduction. A factor affecting any difference in the safety effects of MIDAS and CM on a D3M+HSR compared with a D4M is likely to be differences in the hours of operation of CM on the two layouts. CM will be in operation for slightly more hours with D3M+HSR than for D4M accounted for by the hours when traffic volumes are such that traffic would be travelling between 60 and 70mph with D4M but with D3M+HSR, CM would be switched on restricting speeds to 60mph. However, such hours will be a small proportion of the total. Furthermore, the estimated 15% reduction in PIAs attributable to CM has been derived from its application to a D4M and not a D3M+HS. In the absence of a greater weight of outturn data from the application of CM and variable speed limits, it has been assumed that CM applied to a D3M+HSR and D4M have the same effect on PIAs.

Reliability

3.23. A robust assessment of journey time reliability requires data about incident (including accident) rates and their durations with hard shoulder running compared to widening. Whilst some data on incident rates and durations have emerged from the M42 ATM pilot, they are insufficient to provide the basis for a robust assessment. Therefore, it has been assumed that incident rates and durations are the same for both D3M+HSR and D4M. Accordingly, the same factor has been applied for additional reliability benefits in both cases.

4. Business Case methodology and results

4.1. The Department's National Transport Model (NTM) was used to model the traffic, speeds and emissions effects of the four scenarios explained in chapter 6 of the main report. These outputs were then further analysed to provide monetary valuations of impacts such as time savings or changes in emissions, with the single year estimates scaled to lifetime benefits using capitalisation factors. This is an approach that has been used in previous work and means that using scheme cost estimates, the benefit cost ratio can be calculated.

4.2. This annex provides details on each of these steps and provides a breakdown of the NTM results.

The National Transport Model

4.3. The National Transport Model (NTM) is a highly disaggregated multi-modal model of land-based transport in Great Britain (GB)[3]. It comprises six modes - car driver, car passenger, rail, bus, walk and cycle – and has two main objectives:

[3] Although, the NTM is a model of land-based transport in Great Britain, forecasts are generally presented at the England level. Domestic air travel is not currently modelled. However, it is worth noting that only around 1% of total distance travelled within Great Britain is by air.

- to produce forecasts in a future year of the main transport indicators - traffic, congestion, pollution and public transport patronage;

- to provide a policy and scenario testing tool by estimating the impact of a transport policy scenario or a change in forecasting assumption.

4.4. The NTM combines a wealth of information taken from a range of sources. It uses data of both a time-series nature to reflect differences across time to inform projections, and cross sectional data to capture the diversity of factors that, at any time, determine travel patterns of people in Great Britain. The model also has a 'welfare module' which aims to appraise the overall impact of one modelled scenario against another.

4.5. Further details on the NTM can be found on the Department's website.[4]

The modelled scenarios

4.6. As mentioned in chapter 6 of the main report, the modelling assumptions used in this analysis are the same as those used in the Department's 2007 Forecasts paper[5] in all respects other than the length of the strategic network assumed upgraded by 2015. As described in chapter 6, four scenarios were modelled.

4.7. The reference case assumed that an additional 1402 Lane Kms of capacity would be provided on the strategic network by 2015. This figure is made up of 744 Lane Km which are currently under construction or have been built since the base year of 2003, 358 Lane Km of Motorway widening and hard shoulder running taken as committed and 300 Lane Km of upgrades from schemes in the HA's major scheme programme occurring on the all purpose trunk road network.

4.8. The Planned Motorway Widening scenario included the following schemes which together added a further 433 Lane Km of capacity. In the Equivalent Hard Shoulder scenario, these schemes were modelled as Hard Shoulder Running instead of full widening.

Figure 3: Planned Motorway Widening Scenario

Road Name	Scheme Description
M1	J30 to J31 Widening
M1	J32 to J34S Widening

[4] See http://www.dft.gov.uk/pgr/economics/ntm/
[5] http://www.dft.gov.uk/pgr/roads/roadpricing/researchtrafficcongestion

M1	J34 to J37 Widening
M1	J37 to J39 Widening
M1	J39 to J42 Widening
M1	J19/M6 Improvement
M60	J13 to J15 Widening
M62	J25 to J27 Widening
M62	J27 to J28 Widening
M1	J21 to J30 Widening (Phase 2)
M6	J11a to J19 Widening

4.9. The Priority HSR scenario involved the implementation of hard shoulder running in both directions on 397 Km of the motorway network. The individual links were identified as discussed in chapter 5 of the main report and paragraphs 3.1 to 3.7 above and grouped into the following schemes.

Figure 4: Priority HSR scenario

Road Name	Scheme Description
M1	J15-17 and J18-19 HSR
M1	J24-25 HSR
M1	J28-35a HSR (excludes J31-32 link)
M1	J40-42 HSR
M3	J2 to J4a HSR
M3	J11 to J14 HSR
M4	J3-4, 5-8/9 HSR
M4	J10-12 HSR
M4	J19-20 HSR
M5	J16-17 HSR
M5	J4a-6 HSR
M6	J2-4 HSR
M6	J5-8W HSR
M6	J11-14 HSR
M6	J15-19 HSR
M6	J21a-24 HSR
M23	J8 to J10 HSR
M27	J5-7, J8-9, J10-11 HSR
M60	J27-J4 HSR
M60	J8-9, J10-12 HSR
M60	J19 to 24 D3 and D4 HSR
M60	J24 to 25 HSR
M62	J10-12 HSR
M62	J18-20 HSR
M62	J25-28 and J29-30 HSR
M56	M60 to J2/3 merge Dual 3 HSR
M56	J6-7 HSR
M20	J3-5 HSR

4.10. The majority of the schemes involved the implementation of hard shoulder running on 3 lane motorways (providing a fourth lane at congested times) however, some links - on the M60 J19-24 scheme and on the first M56 scheme - hard shoulder running was on two lane motorway sections.

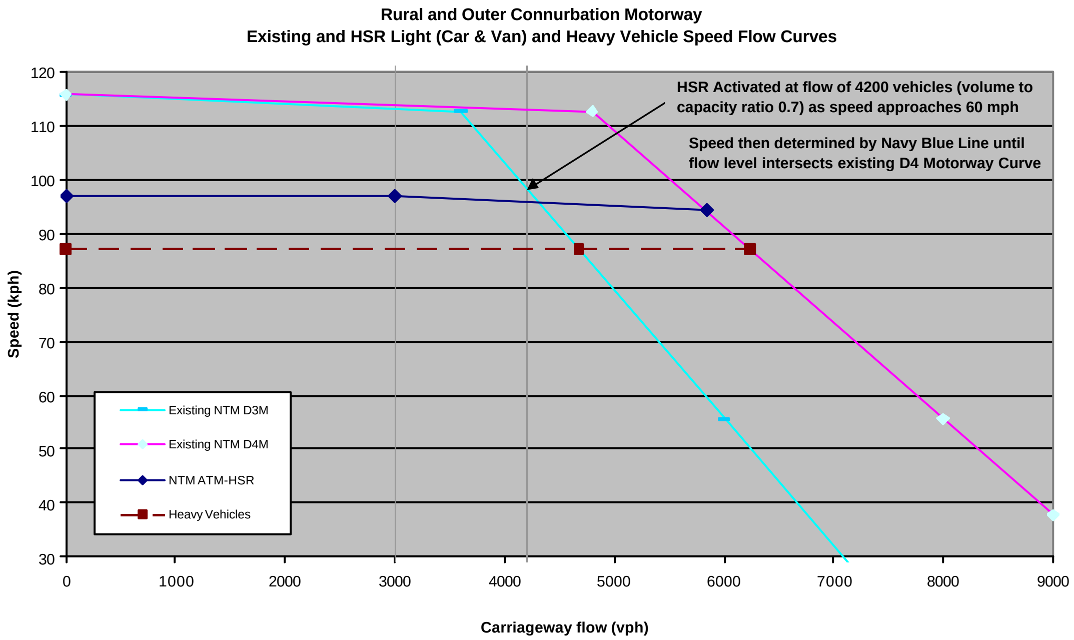
Modelling hard shoulder running

4.11. Modelling road traffic with a road capacity constraint is an advanced area of transport modelling. Transport models can forecast the likely demand for road space and then confront this with the supply, primarily determined by the type and length of available roads. As demand rises, initially the traffic growth is accommodated without too much congestion, with traffic flowing at or near the speed limit. But as capacity is reached, delays become more marked. In strategic transport models, this effect is estimated using curves that map the speed of traffic with flow levels, these being different for different types of roads. Increased capacity reduces congestion for a given flow and this is modelled by changing the speed-flow relationship recognising that the fall off in speed as traffic increases will occur at a higher flow level.

4.12. Modelling hard shoulder running does not fundamentally differ from this, but there have been some particular challenges. For an individual road link with an ATM intervention, there may be several speed-flow relationships possible. This will be because the different ATM regimes could involve a different number of lanes in operation, different speed limits and - potentially - quite sophisticated lane-by-lane rules (e.g. HGVs in particular lanes). In the current work, the focus has been on the regimes where the hard shoulder is opened for all traffic rather than the most sophisticated uses of ATM.

4.13. The motorway speed flow curves used to model hard shoulder running are shown in figure 5 below. As flows on a link increase the speed declines as shown by the light blue line which is for a dual 3 lane motorway. When the flow reaches a figure of 4200 vehicles, and the speed is approximately 60 mph, the model allows use of the hard shoulder and increases the capacity of the link. In normal circumstances such an increase in capacity would result in speeds increasing to those shown by the pink line (for D4M) however, with hard shoulder running the speed is maintained at approximately 60 mph and then declines gradually as flows increase until it meets the existing dual 4 lane motorway curve at a flow of approximately 5800 vehicles per hour. This is shown by the dark blue line. For flows in excess of this figure the vehicle speeds decline as if the link were a normal 4 lane motorway.

Figure 5: Motorway speed flow curves for hard shoulder running



4.14. The NTM can thus simulate the opening and closing of lanes on particular motorway links. In doing so the model assumes that the hard shoulder is able to provide the same capacity of a normal motorway lane (2000 vehicles per hour). A different rate of traffic growth has been applied in each of the modelled regions. However, when that growth is applied to existing traffic levels and then confronted with the available motorway capacity, congestion on individual links will trigger a switch in regime. In particular, at the most congested times and directions, on the most congested links, hard shoulder running will be simulated to switch on.

4.15. Models inevitably have to simplify the likely manner in which hard shoulder running would operate. However, in these NTM modelling runs, many of the most important features of the hard shoulder running option are captured:

- It operates only on links where it is proposed to fit the ATM equipment - different for the different packages being considered
- It operates only for the required time periods on a link-by-link basis where the switching on is determined by traffic flows reaching a defined level (4200 vehicles per hour for a dual 3 lane motorway), in the particular direction of travel
- Once on, speed limits on the link are changed and the added capacity of the additional lane means that flows can be accommodated with less impact on speeds
- Even when on, congestion eventually begins to rise again as flow increases utilise the additional road space.

4.16. The traffic impact of the operation of hard shoulder running can be seen in the main traffic and congestion results of the different scenarios which are presented in figure 6 below. The results here are for England and are presented as percentage changes from the base year of 2003. The Priority HSR scenario is shown to approximately halve the reference case forecast increase in congestion on the motorway network without any significant increase in traffic levels.

Figure 6: Traffic impacts of hard shoulder running

			Scenario			
Road Type	Time Period	Data Item	Reference Case	Planned Widening	Equivalent HSR	Priority HSR
Motorway	Off-Peak	Congestion s/vkm	79%	57%	71%	57%
		Traffic Bvk	28%	28%	28%	27%
		Speed	-0.2%	0.1%	-0.1%	0.1%
	Peak Hours	Congestion s/vkm	83%	56%	58%	41%
		Traffic Bvk	24%	24%	24%	25%
		Speed	-7.5%	-5.0%	-5.2%	-3.5%
	Inter-Peak and Weekends	Congestion s/vkm	110%	68%	77%	56%
		Traffic Bvk	28%	28%	28%	28%
		Speed	-3.9%	-2.2%	-2.6%	-1.7%
	All Periods	Congestion s/vkm	91%	59%	64%	46%
		Traffic Bvk	27%	27%	27%	27%
		Speed	-4.1%	-2.5%	-2.7%	-1.8%
Major	All Periods	Congestion s/vkm	24%	24%	24%	24%
		Traffic Bvk	20%	20%	20%	20%
		Speed	-4.0%	-4.0%	-4.0%	-4.0%
Minor	All Periods	Congestion s/vkm	19%	19%	19%	19%
		Traffic Bvk	18%	18%	18%	18%
		Speed	-3.3%	-3.3%	-3.3%	-3.3%
All Roads	Congestion s/vkm		22%	21%	21%	21%
All Roads	Traffic Bvk		21%	21%	21%	21%
All Roads	Speed		-2.9%	-2.7%	-2.7%	-2.6%

s/vkm = average delay (seconds per vehicle kilometre)
Bvk = billion vehicle kilometres[6]

4.17. Whilst, with respect to the reference case, there has been a very slight increase in national traffic levels in all the scenarios of up to 0.1% in the Planned and Equivalent scenarios and 0.2% in the Priority HSR case as discussed in chapter 6 of the main report, these increases are below the level of accuracy reported here.

4.18. The results for motorways have been disaggregated by time period to illustrate the impacts of hard shoulder running mentioned above. In off peak periods, when the hard shoulder would not be

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[6] Details of the measurement of congestion and the Strategic Network PSA Congestion Target on the are on the DfT website http://www.dft.gov.uk/pgr/statistics/datatablespublications/roadstraffic/speedscongestion/congestiononthestrategicroad5359

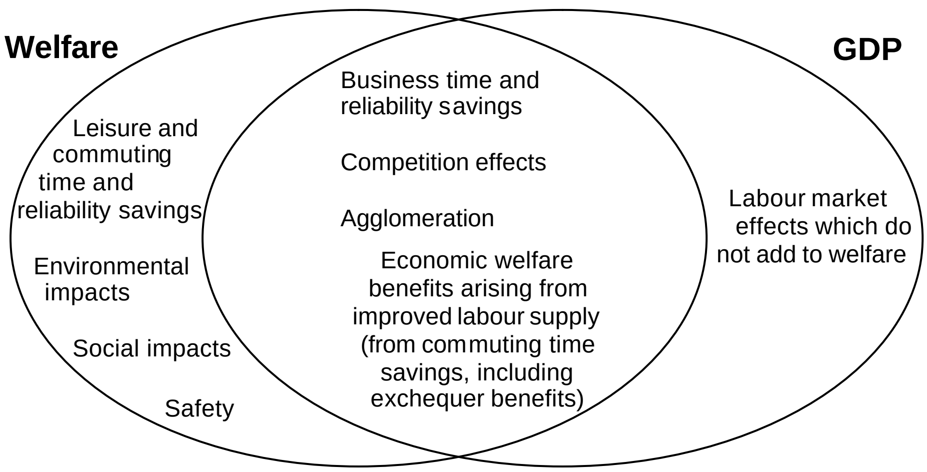
expected to be in operation, the congestion impacts shown in the Equivalent HSR scenario are similar to those in the reference case. In peak periods however, when the hard shoulder would be expected to be operational, the Equivalent HSR scenario delivers 93% of the congestion benefits that are attributed to the full widening scenario. During the Monday to Friday Inter-peak period and at weekends, the hard shoulder will be operational at fewer locations and here the Equivalent HSR scenario delivers 78% of the congestion benefits of the full widening scenario. Overall, the Equivalent HSR scenario delivers 84% of the congestion benefits of the full widening scenario and this is reflected in the very similar levels of time savings benefits shown in the following detailed welfare results.

Welfare and Wider Economic Benefits

4.19. Transport appraisals generally look at the wider well-being of people in the UK; their 'welfare'. This is the best measure of the benefits of a transport intervention since it includes the impact on everyone – including leisure users as well as environmental and social impacts.

4.20. It is right that this broad definition of benefits is used in transport appraisal and decision making. The Eddington transport study also looked at the wider economic benefits of transport considering impacts of transport on labour markets and agglomeration, which have resulting welfare and productivity benefits. The productivity impacts can be seen as a sub-set of welfare and it is the impacts that count as welfare that are incorporated within the scheme appraisal of costs and benefits. Figure 7 below gives a representation of what the two measures address.

Figure 7: Welfare and productivity impacts



Although labour market effects can contribute to GDP, many are already captured in time and money savings for business and commuters.

4.21. The measurement of wider economic benefits of transport policy is relatively new territory. Guidance for the Transport Innovation Fund included new approaches which enable this calculation and set out productivity impacts which have previously been omitted.

4.22. In order to assess the wider economic benefits of the interventions considered here, the results of both the NTM and appraisals have been 'retrofitted'. This process used evidence from a variety of sources.

4.23. The retrofitted estimates provide a high level view of wider economic benefits of particular types of policy intervention. This can provide useful insights for a study which aims to set a more strategic framework for interventions which support the economy.

4.24. However, the high level picture (by its nature) will not provide a precise assessment of the impacts of a particular scheme. This will depend on the specific scheme, the nature of travel on that link, and on the type of improvement it provides.

Calculating the benefit-cost ratio

4.25. At the centre of a value for money (VfM) analysis lies the Benefit Cost Ratio (BCR). The BCR compares a large proportion of the benefits of a particular scheme with its costs and the ratio therefore can give a good indication of the Value for Money it provides. The formula used to calculate the BCR is given as:

$$BCR = \frac{(\text{Welfare - Welfare}_{TP} + \text{WEB}) \times CF - \text{Landscape}}{\text{CC} + (\text{RC - Welfare}_{TP}) \times CF}$$

where CC is the construction costs, RC is the running costs and TP indicates the transport providers. Some of the impacts considered in the ratio - the landscape impacts and construction costs - are incurred before scheme opening. However, for other aspects we need to model the stream of future impacts over the full appraisal period. This is done by taking the welfare outputs for a single year from the NTM's welfare module and then applying a capitalisation factor, which uplifts the estimates to represent the current value of the full future impacts. A capitalisation factor (CF) of 51 is used to give the lifetime benefits over 60 years.[7]

4.26. All monetary values are at market prices. This means that the construction costs incorporate a factor of 1.209 to convert from the factor basis on which they are originally calculated[8]. In the analysis, transport provider welfare is primarily the revenues received by

[7] This factor is based on a 32% growth of traffic post 2015 and derived from analysis of previous appraisals by the HA. It is derived by dividing lifetime benefits by opening year benefits.
[8] Construction costs are usually quoted in factor prices while benefits are measured in market prices.

Government through indirect taxation. Changes in fares received also form part of this.

Sensitivity to capitalisation factors

4.27. The capitalisation factor is a relatively blunt means to convert the single year estimates into a present value. The factor has been derived from a number of studies where the future impacts were carefully modelled. These studies found that different kinds of benefits and costs might grow differently over time resulting in impact specific factors. Vehicle operating costs for example are likely to fall in real terms while time benefits are expected to grow with incomes.

4.28. The factor of 51 used here comes from applying traffic and income growth as well as discounting[9] to the opening year benefits and dividing 60 years' benefits by those from the opening year. This is the correct factor to use for time benefits. Taking out the effect of traffic growth brings the factor down to 44, the value appropriate for emissions and running costs. Highways Agency analysis recommends a capitalisation factor of 33 for vehicle operating costs. As most of that would be fuel, the same factor would apply to the effects on tax receipts.

4.29. Figure 8 below indicates how sensitive the benefit cost ratio is to different assumptions on the capitalisation factor. The changes in the table are quite small suggesting that while the single factor is blunt, it does not change the picture greatly if more disaggregated factors are applied.

Figure 8: Effect of applying individual capitalisation factors on BCRs

	Planned Widening	Equivalent HSR	Priority HSR
BCR - single capitalisation factor	2.3	7.6	6.8
BCR - differential capitalisation factors	2.9	8.6	7.9

Costing the Priority HSR package

4.30. The identified priority links described in chapter 5 of the main report were grouped into logical schemes and costed on this basis, using the design assumptions described at paragraph 3.6 above. In preparing the scheme cost estimates, the team investigated the following factors and adjusted the cost estimates accordingly:

[9] 3.5% p.a. for the first 30 years, 3% thereafter

- whether the existing hard shoulder was continuous and what would be required to make it continuous
- any other location-specific physical or other barriers to hard shoulder running

4.31. The cost estimates were made using a base year of 2004 (using M42 scheme prices) crudely uplifted using historical RPI figures to arrive at an estimate of current prices. No separate risk assessment was undertaken. Risk allowance was assumed to be 25% of scheme costs and P10, P50 and P90 figures were determined from this.

4.32. All indicative scheme cost estimates were then added together and averaged, coming to an average cost of around £4m per kilometre.

4.33. A 40% optimism bias[10] uplift was applied to the £4m figure bringing the cost to £5.6 per kilometre (2004 prices). Indicative operating costs per km were also factored in, as follows:

[10] For technology projects, 40% optimism bias is at lower end of values recommended in WebTAG. This was used because the M42 experience provides satisfactory costing models.

Area	Specific Item	Caveats	Assumed Per KM Annual figure
Back office costs of supervising ATM operation, including RCC costs	Provision of operators	Placing a per Km figure on this generally is extremely difficult as it is dependant on how much ATM one RCC has to operate. The figure shown is an average cost derived from rough analysis of requirements assuming that all of the schemes suggested within R21 data are implemented. In practice, early schemes will incur greater costs and later schemes less.	£ 7,391
Service costs associated with ATM including Traffic Officer Costs	Provision of Traffic Officers	As per operator costs, difficult to ascertain per Km cost. Analysis undertaken in similar way.	£ 9,483
	Provision of vehicles		£ 1,545
Utility and other direct input costs associated with ATM (Electricity to run the system, maintenance costs etc)	Electricity payments	Generic information obtained from energy procurment is that an average value for a KWh is 8p - this is subject to regional fluctuations. A crude assumption of equipment utilisation and approximate operational loads on the M42 pilot, generated the assumed annual charge shown. This was simply divided by 13Km to achieve the per Km figure.	£ 5,748
	Maintenance of communication and technology elements		£ 28,846
	HADECS Maintenance	Costs are likely to be proportional to the number of sites rather than per Km. This depends on number of links rather than scheme length, but for simplicity, annual costs have been divided by 13Km (which, therefor, assumes junctions are spaced similarly to the pilot).	£ 38,000
	Police Monitoring of HADECS system & Enforcement	Based on raising a certain number of NIPs every month and, therefore, not length dependant (although will be police 'area' dependant). Assume that average RCC has (end game) 50Km of ATM over which NIPs must be raised.	£ 1,440

4.34. The overall costs of hard shoulder running were then compared to the benefits from the NTM Welfare Module in order to produce an indicative benefit cost ratio for the Equivalent and Priority Hard Shoulder Running scenarios, alongside the widening scenario. The detailed benefits are given in the tables below.

NTM Welfare Results

Benefits from Widening											
£m 2006	Car			Bus	Rail	Freight	All Modes			Total	
Transport Users	Business	Commuter	Leisure				Business	Commuter	Leisure	2015	60yrs
Time Saving	101	28	102	0	2	65	102	29	103	298	15,195
Reliability benefits	26	7	26	0	n/a	11	26	7	26	71	3,604
VoC and Other Charges	3	-4	-8	n/a	n/a	-16	3	-4	-8	-25	-1,292
Net user benefit	130	32	121	0	2	59	130	32	121	343	17,507
(PT Operator)	0	0	0	0	0	0	0	0	0	0	4
Transport Providers											
Other Revenues (inc. fares)	0	0	0	-7	-3	0	0	-1	-9	-10	-498
Indirect Tax impact	4	2	5	1	1	17	4	2	6	30	1,535
Infrastructure costs	0	0	0	0	0	0	0	0	0	0	-25
Net transport provider benefit	4	2	5	-6	-3	17	4	1	-2	20	1,012
Previously Omitted Wider Economic Benefits											
Agglomeration	20	5	n/a	0	0	6	20	5	n/a	32	1,616
Competition	13	n/a	n/a	0	0	6	13	n/a	n/a	19	968
Labour market benefits	96	6	n/a	0	0	2	96	6	n/a	105	5,350
Net Wider Economic Benefits	130	12	n/a	0	0	14	130	12	n/a	156	7,934
								previously ommitted		82	4,186
Externalities											
	All Car										
Accident benefits	-7	0	0	0	n/a	0	0	0	0	-7	-378
Local air pollution	-3	0	0	0	0	-4	0	0	0	-7	-382
Noise	-1	0	0	0	0	0	0	0	0	-1	-35
Climate change	-5	0	0	0	0	-3	0	0	0	-7	-375
Net external benefit	-15	0	0	0	0	-7	0	0	0	-23	-1,169
								Landscape costs			-487
Total benefit	**419**			**-6**	**0**	**83**	**264**	**45**	**119**	**422**	**21,053**

Benefits from Equivalent HSR											
£m 2006	Car			Bus	Rail	Freight	All Modes			Total	
Transport Users	**Business**	**Commuter**	**Leisure**				**Business**	**Commuter**	**Leisure**	**2015**	**60yrs**
Time Saving	93	26	94	0	2	63	94	27	95	278	14,202
Reliability benefits	24	7	25	0	n/a	10	24	7	25	66	3,349
VoC and Other Charges	3	-4	-7	n/a	n/a	-14	3	-4	-7	-23	-1,152
Net user benefit	120	29	112	0	2	59	120	30	113	322	16,399
(PT Operator)	0	0	0	0	0	0	0	0	0	0	5
Transport Providers											
Revenues (inc. fares)	0	0	0	-6	-3	0	0	-1	-8	-9	-467
Indirect Tax impact	4	2	4	1	1	16	4	2	6	28	1,406
Infrastructure costs	0	0	0	0	0	0	0	0	0	0	-24
Net transport provider benefit	4	2	4	-5	-3	16	4	1	-2	18	915
Previously Omitted Wider Economic Benefits											
Agglomeration	19	5	n/a	0	0	6	19	5	n/a	30	1,512
Competition	12	n/a	n/a	0	0	6	12	n/a	n/a	18	914
Labour market benefits	89	6	n/a	0	0	2	89	6	n/a	97	4,952
Net Wider Economic Benefits	120	11	n/a	0	0	14	120	11	n/a	145	7,379
									previously ommitted	78	3,956
Externalities											
	All Car										
Accident benefits	-7	0	0	0	n/a	0	0	0	0	-7	-349
Local air pollution	-3	0	0	0	0	-4	0	0	0	-6	-323
Noise	-1	0	0	0	0	0	0	0	0	-1	-33
Climate change	-4	0	0	0	0	-3	0	0	0	-7	-336
Net external benefit	-14	0	0	0	0	-7	0	0	0	-20	-1,041
Total benefit	**388**			**-5**	**-1**	**82**	**244**	**42**	**110**	**397**	**20,233**

Benefits from Priority HSR											
£m 2006	Car			Bus	Rail	Freight	All Modes			Total	
Transport Users	**Business**	**Commuter**	**Leisure**				**Business**	**Commuter**	**Leisure**	**2015**	**60yrs**
Time Saving	167	50	173	0	4	97	169	51	174	492	25,077
Reliability benefits	43	13	45	0	n/a	16	43	13	45	117	5,990
VoC and Other Charges	5	-6	-12	n/a	n/a	-19	5	-6	-12	-32	-1,624
Net user benefit	216	57	206	0	4	95	217	58	207	577	29,444
(PT Operator)	0	0	0	0	0	0	0	0	0	0	9
Transport Providers											
Revenues (inc. fares)	0	0	0	-11	-6	0	0	-2	-14	-17	-865
Indirect Tax impact	7	3	7	2	1	22	7	4	9	42	2,135
Infrastructure costs	0	0	0	0	0	0	0	0	0	-1	-43
Net transport provider benefit	7	3	7	-10	-5	22	7	1	-5	24	1,226
Previously Omitted Wider Economic Benefits											
Agglomeration	32	9	n/a	0	0	11	32	9	n/a	51	2,619
Competition	22	n/a	n/a	0	0	9	22	n/a	n/a	31	1,592
Labour market benefits	160	11	n/a	0	0	3	160	11	n/a	175	8,934
Net Wider Economic Benefits	214	20	n/a	0	1	23	214	20	n/a	258	13,145
									previously ommitted	136	6,938
Externalities											
	All Car										
Accident benefits	-12	0	0	0	n/a	0	0	0	0	-12	-620
Local air pollution	-4	0	0	0	0	-5	0	0	0	-9	-450
Noise	-1	0	0	0	0	0	0	0	0	-1	-58
Climate change	-7	0	0	0	0	-4	0	0	0	-10	-532
Net external benefit	-23	0	0	0	0	-9	0	0	0	-33	-1,660
Total benefit	**706**			**-10**	**-1**	**131**	**438**	**79**	**202**	**705**	**35,957**

5. Modelling the emissions effects of smoother running: M42 speed/emissions curves

5.1. Chapter 4 of the main report described how hard shoulder running and controlled lower speed limits may improve the flow of traffic and at the same time reduce the emissions from individual vehicles. This section of the annex describes in more detail how this was incorporated into the analysis using results from the M42 pilot.

M42 Pilot

5.2. Transport Research Laboratory (TRL) Emissions and Air Pollution Team has been involved in the assessment of the effects of traffic management on emissions, fuel consumption and air quality for over 30 years. The team was involved in the M42 pilot scheme implementing a toolkit of traffic management technologies and procedures, including hard shoulder running and controlled motorway.

5.3. TRL have analysed the M42 pilot and created average speed emission curves to assess expected changes in driving dynamics associated with the smoother driving. The M42 pilot speed emission curves were derived based on logged trips along the M42 motorway, using an instrumented car and HGV (vehicles equipped to record vehicle and engine speed from the vehicle's on-board electronics and position from a GPS receiver). A number of logged trips were collected before and after the pilot (between M42 junctions 3 to 7), with a range of average speeds. The resulting exhaust emissions over these trips were evaluated using an emissions model (PHEM) for various light-duty and heavy-duty vehicle categories and Euro specification vehicles.

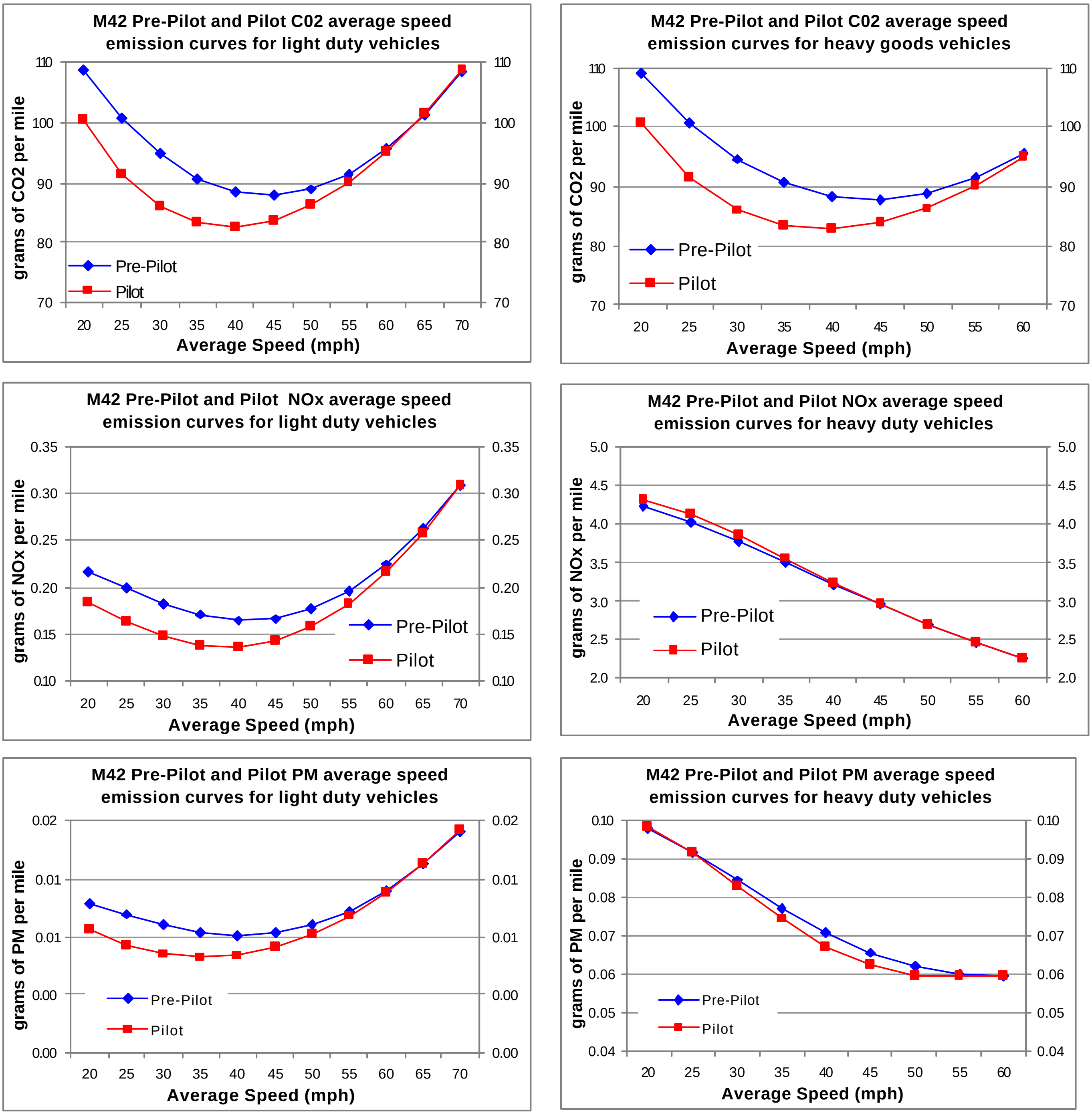
5.4. Fleet compositions were derived from the National Atmospheric Emissions Inventory (NAEI) fleet projections and from DfT traffic statistics. The various emissions were then aggregated to derive fleet weighted averages for light-duty and heavy-duty vehicles, for the years 2005 and 2010, for M42 pre-pilot and pilot conditions. A third order polynomial curve was fitted to the resulting g/hour data to derive emission functions. By dividing this function by the speed, the emissions in g/mph can be obtained.

5.5. Figure 9 below illustrates the grams of carbon dioxide (CO_2), oxides of nitrogen (NO_x) and particulate matter (PM) emitted per mile at different average speeds for light duty and heavy duty vehicles, before and during the pilot. One can see that, in general, regardless of the pilot, emissions per mile fall as average speed increases to 40-50mph where the fuel efficiency of the engine is greatest and then rises as the average speed increases towards 70mph and fuel efficiency falls.

5.6. The gap between the two lines on the chart illustrates the change in emissions associated with the pilot on the M42. It can be seen that for the M42 the benefit was greater at lower speeds, where ordinarily, before the pilot, the traffic would have been subject to stop-start conditions.

5.7. These results were the most robust available to assess the impact of hard shoulder running and controlled lower speed limits of the Equivalent HSR and Priority HSR scenarios covered in this document. The percentage change in emissions at the average speed on the links, as analysed by the National Transport Model, were used to adjust the initial outputs of the NTM.

Figure 9 – M42 average speed emission curves for CO_2, NO_x and PM



5.8. Although these were the most robust data available to assess the impact of hard shoulder running there remain a few areas that require further study:

- These emission functions are based on logged vehicles speeds measured along the M42 between 2003 and 2006. It is not known how generic these emission functions are. Ideally, additional investigations should be carried out if to assess how they are to be optimally applied to other roads into the future.

- In addition, although the approach taken is consistent with a strategic level analysis, the fleet composition was largely based on national statistics and assumptions, which may or may not represent local conditions. Thus for future analysis a more detailed assessment could be made to assess specifically the impact of smoother traffic flow on the fleet compositions for specific schemes into the future.

- The speed emission curves for NO_x and PM from heavy goods vehicles do not follow the normal 'U-shaped' curve one may initially expect - however, this pattern has been confirmed in other results studying NO_x and PM emissions from HGV's. Overall, this did not make a significant impact on the analysis, but may be an area requiring further study when analysing the potential impact of hard shoulder running in the future.

As additional data on the traffic flow impacts of hard shoulder running become available, these relationships should be reviewed to take advantage of richer and larger data sets from a wider range of sites.