

# Economic, Environmental and Social Impacts of Changes in Maintenance Spend on the Scottish Trunk Road Network



# Economic, Environmental and Social Impact of Changes in Maintenance Spend on the Scottish Trunk Road Network

**Transport Research Laboratory** 

**C C Parkman and T Bradbury** 

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## Contents

Exe	ecutive s	ummary		i		
1	Introduction					
2	Existing	Existing knowledge of impacts (Literature Review)				
3	Transpo	Transport Scotland road network				
	3.1	Extent o	of network	6		
	3.2	3.2 Amount of travel				
	3.3 Accident trends					
	3.4	Budgets				
	3.5	Paveme	nt condition trends	11		
	3.6	Mainten	ance Schemes	12		
4	Predicte	ed networ	k conditions	16		
	4.1	Paveme	nt analysis	16		
		4.1.1	Overview	16		
		4.1.2	Scenario 1: Maintain current spend	19		
		4.1.3	Scenario 2: 20% reduction in budget	19		
		4.1.4	Scenario 3: 40% reduction in budget	20		
		4.1.5	Issues from the pavement condition analyses	20		
	4.2	Structur	res maintenance	22		
5	Method	ology		24		
	5.1 Overview					
	5.2	5.2 Focus of the study				
	5.3	Analyse	s and results	24		
6	Refinin	g the scen	arios: A subjective assessment	26		
	6.1	Overview				
	6.2	.2 Assessment approach				
	6.3	Assessment results				
	6.4	Conclusi	ions on subjective assessment	28		
		6.4.1	Scenario 2: 20% reduction – focus of impacts	28		
		6.4.2	Scenario 3: 40% reduction – focus of impacts	28		
7	Impacts of pavement condition					
	7.1	Literatu	re review	31		
		7.1.1	General impacts and vehicle operating costs	31		
		7.1.2	Travel time based on deteriorating road conditions	32		

		7.1.3	Road safety impact and accidents	33		
	7.2	.2 Overview of analysis				
	7.3	Surface c	conditions and vehicle operating cost	34		
		7.3.1	Translating remaining life into 3m LPV	34		
		7.3.2	Total network travel by condition	36		
		7.3.3	HDM-4 analysis	36		
		7.3.4	Analysis results	38		
	7.4	Surface c	conditions and travel time cost	42		
	7.5 Skid resistance and accident costs			49		
		7.5.1	Methodology	49		
		7.5.2	Analysis results	49		
8	Impacts	of pavem	ent operations	52		
	8.1	Overview	,	52		
	8.2	Pavemen	t roadworks and travel delay costs	52		
		8.2.1	Scheme data	52		
		8.2.2	Treatment durations	52		
		8.2.3	Delay costs	53		
	8.3	Analysis ı	results	53		
9	Impacts	55				
	9.1	55				
	9.2	Major str	uctures and impact on the road user	55		
	9.3	Winter m	56			
		9.3.1	Literature review	56		
		9.3.2	Winter maintenance assessment	57		
	9.4	Lighting o	operations, travel time and accident costs	58		
		9.4.1	Literature review	58		
		9.4.2	Lighting the network	59		
	9.5	Analysis ı	results	59		
10	) Impact on depreciation					
	10.1	Depreciat	tion of vehicles	61		
	10.2	Depreciation of the road network				
11	Impacts on customer satisfaction					
	11.1	Overview				
	11.2	Literature	e review	63		
	11.3	Customer	r satisfaction surveys and potential impacts	64		
12	Impact on carbon footprint 65					
	12.1	Overview	,	65		

	12.2 Analysis results			
		12.2.1	Carbon emissions from maintenance works	66
		12.2.2	Carbon costs from vehicle CO <sub>2</sub> emissions	66
13	Summa	ary of chan	ges and impacts	70
	13.1	Results s	ummary	70
	13.2	Results d	liscussion	70
	13.3	Assumpti	ions and sensitivity	71
		13.3.1	Inflation on maintenance works costs	75
14	Conclus	sions and r	ecommendations	77
Ref	erences			80
Glo	ssary			83
Ack	nowledg	ements		84
Арр	pendix A	Furth	er Details of the Trunk Road Network	85
Арр	pendix B	Subje	ective assessment of maintenance spend	87
Арр	pendix C	Paver	ment Network Model outputs	90
Арр	pendix D	Sumr	mary of key data and assumptions	100
Арр	pendix E	Detai	led annual and cumulative costs	104
Арр	Appendix F Increase in travel time costs			

# **List of Figures**

Figure 3.1 Numbers of accidents by lighting levels9
Figure 3.2 Number of accidents by road surface condition
Figure 3.3 Number of skidding accidents by road surface condition
Figure 3.4 Skid resistance and road surfacing budgets12
Figure 3.5 Pavement condition and maintenance budgets
Figure 3.6 Total length of schemes by road type and year 13
Figure 3.7 Total length of schemes by treatment type and year 14
Figure 3.8 Number of maintenance schemes by road type and year
Figure 3.9 Average scheme length by road type and financial year 15
Figure 4.1 Relationship between RCI and pavement remaining life
Figure 4.2 Scenario budgets17
Figure 4.3 Network length by remaining life (0-40 years) – Starting Condition
Figure 4.4 Network length by remaining life for Scenario 1 19
Figure 4.5 Network length by remaining life for Scenario 2
Figure 4.6 Network length by remaining life for Scenario 3
Figure 7.1 Outline methodology for converting remaining life to 3m LPV
Figure 7.2 Assignment of traffic to network lengths by 3m LPV
Figure 7.3 Variation of vehicle operating costs with road roughness
Figure 7.4 Projected annual vehicle operating costs
Figure 7.5 Motorway annual vehicle operating costs 40
Figure 7.6 Dual APTR annual vehicle operating costs
Figure 7.7 Single APTR annual vehicle operating costs
Figure 7.8 Predicted travel time costs (Scenario 1) 44
Figure 7.9 Predicted travel time costs (Scenario 2) 46
Figure 7.10 Predicted travel time costs (Scenario 3) 46
Figure 8.1 Total annual delay cost for each Scenario54
Figure 12.1 Costs of carbon from maintenance works
Figure 12.2 Carbon costs due to pavement condition for each Scenario

Figure B.1 Allocation of works to budget heads (1)	. 88
Figure B.2 Allocation of works to budget heads (2)	. 89

## **List of Tables**

Table 2.1 Summary of reported economic impact by subject area5
Table 3.1 Summary of Transport Scotland network         6
Table 3.2 Annual traffic carried by the trunk road network (2010)         7
Table 3.3 Percentage of HGV by road type    8
Table 3.4 Summary of recent maintenance budgets         11
Table 4.1 Predicted network remaining life
Table 4.2 Network length by road type         19
Table 4.3 Structures maintenance (spend of £22m/yr)
Table 4.4 Structures maintenance (spend of £22m/yr compared to current spend) 23
Table 6.1 Scenario allocations by asset management objective         27
Table 6.2 Work activities included in each budget head         29
Table 6.3 Budget reductions based on contribution to asset management drivers 30
Table 7.1 Document relevance and coverage matrix
Table 7.2 Coefficients for relationships between RCI and 3m LPV
Table 7.3 HDM-4 vehicle parameters    37
Table 7.4 Projected annual vehicle operating costs    39
Table 7.5 Changes in traffic speed with pavement condition         42
Table 7.6 Reduction in traffic speed (km/h) with change in 3m LPV
Table 7.7 Assumed average traffic speed by road type and vehicle type         43
Table 7.8 Value of time for each vehicle type    45
Table 7.9 Costs of extra travel time (£m) for each Scenario
Table 7.10 Costs of extra travel time compared to Scenario 1 (£m)
Table 7.11 Increase in travel time cost (£m) with change in network condition
Table 7.12 Resurfacings budgets and skid resistance         49
Table 8.1 Breakdown of treatment type by road type    52
Table 8.2 Treatment thicknesses    53
Table 8.3 Delay cost savings
Table 10.1 Depreciation of the trunk road network    62
Table 12.1 Central non-traded price of carbon (2002 prices)       67
Table 12.2 Carbon costs due to maintenance on the pavement network
Table 13.1 Cumulative costs (Undiscounted)
Table 13.2 Cumulative costs (Discounted)    73
Table 13.3 Summary of quantified economic impacts for 20 year analysis period 74

Table D.1 Annual total vehicle km travelled by road type and vehicle type (2008) 100
Table D.2 Traffic growth rate factors from NRTF         100
Table D.3 Percentage of HGV by road type 101
Table D.4 GDP deflator indices 101
Table D.5 Engine fuel efficiency factors    102
Table D.6 Increase in fuel costs    102
Table E.1 Undiscounted annual costs: 2010/11 to 2020/21 105
Table E.2 Undiscounted annual costs: 2021/22 to 2030/31 106
Table E.3 Undiscounted annual costs compared to Base Case: 2010/11 to 2020/21 107
Table E.4 Undiscounted annual costs compared to Base Case: 2021/22 to 2030/31 108
Table E.5 Cumulative undiscounted costs: 2010/11 to 2020/21 109
Table E.6 Cumulative undiscounted costs: 2021/22 to 2030/31 110
Table E.7 Discounted annual costs: 2010/11 to 2020/21 111
Table E.8 Discounted annual costs: 2021/22 to 2030/31 112
Table E.9 Discounted annual costs compared to Base Case: 2010/11 to 2020/21 113
Table E.10 Discounted annual costs compared to Base Case: 2021/22 to 2030/31 114
Table E.11 Cumulative discounted costs: 2010/11 to 2020/21 115
Table E.12 Cumulative discounted costs: 2021/22 to 2030/31 116
Table E.13 Cumulative undiscounted total costs    117
Table E.14 Cumulative discounted total costs         118
Table F.1 Increase in travel time and associated costs for Scenario 1 120
Table F.2 Increase in travel time and associated costs for Scenario 2 121
Table F.3 Increase in travel time and associated costs for Scenario 3

### **Executive summary**

This report summarises the results of a study to assess the **economic, environmental and social impacts of cuts to the roads maintenance budgets** for trunk roads in Scotland. It describes the methodologies adopted, presents the results from the analyses and discusses the conclusions from the results. This study and the associated study for the assessment of impacts of reductions in maintenance funding for local roads in Scotland provided evidence for the National Road Maintenance Review for Scotland conducted by the Scottish Government initiated in 2011.

The study showed that the economic and social disbenefits to Scotland are greater than the savings in maintenance budgets. The net effects of the reduced budgets were decreases in economic welfare of  $\pm 107$ m and  $\pm 78$ m (Net Present Value at 2002 prices) for the overall maintenance funding reductions of 20% and 40% respectively.

This study examined the effects of different levels of maintenance funding for the Transport Scotland **trunk road network**, excluding the portion of the network managed as DBFO concessions, between 2010 and 2030. A brief literature review was undertaken to identify and incorporate similar analyses into this study but a fuller literature review was undertaken in the study for local roads. The study for local roads also included some sensitivity analyses that were applicable for both trunk and local roads.

**Three funding scenarios** were considered in the study. These all considered constant levels of spend through the first 10 years of the period. The first assumed the spending level in 2009/10 continued and the other scenarios assumed the 2009/10 level of funding was reduced by 20 percent and 40 percent. The first scenario assumed the constant (2009/10) funding also continued for the last 10 years of the analysis period. For the two scenarios with reduced funding, during years 10 to 15 of the analysis period, the funding was restored uniformly to the 2009/10 level and from years 15 to 20, the funding was assumed to increase by 2.5% per year. The results of all the analyses are shown at 2002 prices. The study examined the amount of maintenance undertaken on the road network, assuming standard national growth rates in traffic flow, and assessed the impacts of reducing the current funding in terms of changes in network condition, accident rates, vehicle operating costs, vehicle depreciation, road user journey time, global (i.e.  $CO_2$ ) emissions and customer satisfaction.

Changes in the level of overall maintenance funding were specified but it was recognised that the overall reductions may not affect all aspects of maintenance equally. A **subjective assessment** was made of the likely distribution of the overall budget reductions across Transport Scotland maintenance activities. From this analysis it was clear that in the period considered in this study it is likely that pavement maintenance will suffer a bigger share of the budget reduction than other maintenance areas. An investigation into the likely effects on different maintenance activities suggested the pavement maintenance budget would be reduced by 44% and 76% for reductions in the overall maintenance budgets of 20 percent and 40 percent respectively.

The budget reduction scenarios mean undiscounted **pavement maintenance funding reductions** over 20 years of £304m and £674m (£266m and £568m discounted back to the base year) for the overall 20 percent and 40 percent budget reductions respectively.

For the analyses used in this study, during the first 10 years of the analysis period, maintenance on Motorways was given a higher priority than maintenance on the All Purpose Trunk Roads. Using this strategy the condition of Motorways continued to

improve for all the budget levels considered but overall there is a **worsening in network pavement condition** and with Scenario 3 (40% cut in the overall maintenance budget) the percentage of the network with zero remaining life (i.e. in need of maintenance) was predicted to be 25 percent of the network by 2020 and 29 percent by 2030, compared with 11 percent in 2010.

The ISOHDM model, HDM-4, was used to assess the effects on **vehicle operating costs**, including vehicle depreciation, of changes in network condition resulting from the reduction in maintenance funding. Using typical UK vehicle types in HDM-4, it was estimated that in 2030 there will be an increase in undiscounted vehicle operating costs of approximately £1,200m per year compared with the current level, for the scenario which retains the current level of maintenance spend (i.e. Scenario 1). The results of the analyses show there will be bigger increases following cuts in the maintenance budget. With a 40 percent overall budget reduction the vehicle operating costs were predicted to be £1,241m per year more in 2030 than the costs in 2010.

Using the results of a brief study carried out some years ago into the effects of pavement condition on traffic speed, the **annual undiscounted costs of increased travel time**, by 2030, resulting from the worsening in pavement condition, were estimated to be  $\pounds7m$ ,  $\pounds13m$  and  $\pounds17m$  for the constant level of spend, 20 percent and 40 percent budget reduction scenarios respectively.

A sample of typical maintenance works was used with QUADRO analyses to assess the impacts on road users from changes in the number of maintenance schemes with the reduced maintenance funding. The results show a **reduction in the undiscounted costs of traffic delays to road users at roadworks** of £2m per year, compared with the 2010 level, for all three funding scenarios considered.

For this study, it was considered that safety would continue to have a high priority with reduced maintenance budgets, but carriageway condition would still deteriorate due to the lower maintenance funding and this was predicted to lead to lower levels of skid resistance. The **increase in accidents that accompanies lower skid resistance** was expected to become significant with a 40 percent cut in the maintenance budget and this would lead to increased costs of more than £4m per year by 2020 but reduce back to the 2010 level as the funding increases in 10 years up to 2030.

With the importance to Transport Scotland of road safety, it was recognised that funding of **winter maintenance** would remain a high priority even at the lowest funding level considered (i.e. only a small budget reduction would be applied to winter maintenance if the overall budget is reduced by 40 percent). This study did not therefore include any prediction of the change in accident rates that may arise from a change in the level of funding of winter maintenance. Other studies have considered the overall disruption caused by inadequate levels of winter maintenance but it was not possible, in this study, to reliably predict any effect on the total road user travel time that may result from changes in levels of winter maintenance due to cuts in the overall maintenance budget.

For **structures**, a Transport Scotland study in 2010 examined the effects of changes in the level of maintenance funding. The budget reductions in that study (the biggest reduction was 15 percent) were less than the overall cuts examined in this study but represented the likely effect on structures maintenance following the subjective review of the current maintenance budget. This reduction in funding was not expected to lead to bridge closures but would increase the amount of routine maintenance required in the absence of the renewals maintenance and may introduce difficulties for the 4 Operating

Companies in future years. The effect on road users of this change in funding was not assessed as it was expected the reductions would have only a small impact.

Maintenance operations contribute to the carbon footprint of the road network in a number of ways. This study considered the changes in levels of carbon dioxide emissions from production and use of asphalt materials, the disruption to road users caused by road maintenance and the  $CO_2$  from changes in fuel consumption on rougher pavement surfaces. The analysis showed a predicted increase in the **undiscounted costs of carbon emissions** of £139m per year in 2030 if the current level of maintenance funding is retained. With the 20 percent and 40 percent cuts in maintenance funding, that increase was predicted to be reduced by £3m and £15m respectively.

The effect of maintenance budget reductions for **street lighting** was examined by comparing the reduced energy costs and the increase in the number of traffic accidents that may result from lower lighting levels. The overall savings identified were small but it was recognised that bigger savings may be possible at specific locations. The overall increase in undiscounted total accident cost was estimated to be £2.0m over the analysis period for savings in the Transport Scotland energy bill of £12m (for Scenario 3, the 40% reduction in the overall maintenance budget).

Studies by Transport Scotland since 2008 of **road user perceptions** of trunk roads in Scotland showed that the condition of the road surface is a general concern for road users. It is therefore expected that, with the predicted worsening in network condition, users will continue to have the same level or more concern about pavement condition.

The study showed that with the overall deterioration in network condition the **undiscounted total non-works costs were predicted to increase** by approximately  $\pounds$ 1,336m per year by 2030 for each of the three funding scenarios. Over the analysis period, the discounted non-works cost for the 20 percent funding reduction scenario was predicted to be  $\pounds$ 107m less than the scenario with constant maintenance funding but  $\pounds$ 80b less for the 40 percent funding reduction. The overall increases in undiscounted non-works costs, over the constant level of funding scenario, were predicted to be  $\pounds$ 569m and  $\pounds$ 986m for the 20 percent and 40 percent overall maintenance funding reduction scenarios respectively. The increases in discounted costs were  $\pounds$ 373m and  $\pounds$ 647m for the two Scenarios respectively. Those increases exceeded the savings to Transport Scotland from reduced maintenance costs over the analysis period so the net effect is an increase in the total transport cost with reduced maintenance budgets.

For the two funding reduction Scenarios, the biggest change in non-works costs relative to the base case was in **vehicle operating costs due to changes in road surface condition.** In year 2030 the undiscounted overall non-works costs were predicted to be  $\pounds$ 154m higher for the Scenario with a 40% overall reduction in the maintenance budget, than for the Scenario with the current level of maintenance funding.

Using results from the Transport Scotland asset valuation model to estimate the value of the trunk road network and the year on year depreciation of the asset, the effects on the road network asset value caused by the different levels of maintenance funding showed the worsening condition would be reflected in a lower asset value by 2030. At the end of the analysis period, compared to the value when the 2010 level of spend is retained, there was little **change in the asset value** with the 20 percent reduction in maintenance funding and a reduction of £44m in the undiscounted asset value for the 40 percent funding reduction. With a 40 percent reduction, the decrease in undiscounted asset value in 2030, compared to 2010, was predicted to be more than £530m.

## **1** Introduction

The road network in Scotland is the largest and most valuable community asset in Scotland and the trunk roads comprise the strategic routes that play a key role in the economic performance of Scotland.

In 2011, Audit Scotland highlighted that the overall maintenance backlog on the roads in Scotland was  $\pounds$ 2.25 billion of which approximately a third related to the trunk road network (Audit Scotland, 2011). The report included a central recommendation for the Scottish Government to take forward a national review of "how the road network is managed and maintained, with a view to stimulating service redesign and increasing the pace of examining the potential for shared services."

In response to this report, The Scottish Government set up a National Road Maintenance Review to look at how the trunk road and local road networks in Scotland are managed and maintained.

The Review was taken forward by Transport Scotland in partnership with the Convention of Scottish Local Authorities (CoSLA), the Society of Local Authority Chief Executives (SOLACE), Society of Chief Officers of Transportation in Scotland (SCOTS) and the Scottish Road Works Commissioner under the guidance of a Steering Group. The Steering Group was supported by four Working Groups drawn from Steering Group member organisations as well as invited stakeholders. This study and an associated study for local roads were commissioned to provide evidence of the effects of different levels of road maintenance funding for the Wider Economic Issues, Impacts, Costs and Benefits Working Group (WG4).

The aim of the study was to investigate the effects of changes in road maintenance funding between 2010 and 2030. Three scenarios have been considered in the study:

- Scenario 1 (Base case): Constant annual level of maintenance spend (2010/11 funding level continues) for 20 years
- Scenario 2: Reduction in the annual maintenance spend in Scenario 1 by 20% (starting 2010/11) for the first 10 years. Return the annual spend to current 2010/11 levels using annual uniform increases, between 2020 and 2025. From 2026, increase annual funding by 2.5% per year
- Scenario 3: Reduction in the annual maintenance spend in Scenario 1 by 40% (starting 2010/11) for the first 10 years. Return the maintenance budget to current 2010/11 levels using annual uniform increases, between 2020 and 2025. From 2026, increase annual funding by 2.5% per year

Transport Scotland has described a wide range of possible impacts that may be considered as part of the review. These cover all aspects of maintenance and operations spend. The study considered the current internationally available evidence, analysed potential changes in the amount of maintenance undertaken on the trunk road network and where possible estimated the changes in overall costs. Changes in cost arise from various aspects and this study has assessed:

- Changes in Transport Scotland maintenance budgets and asset values;
- Changes in accident rates;
- Vehicle operating costs and vehicle depreciation;

- Changes in journey time;
- Global (i.e. CO<sub>2</sub>) emissions; and
- Customer satisfaction.

Inevitably there are interactions between these effects that will affect the overall impacts caused by changes in maintenance funding. For the purposes of this study each effect was considered independently.

The effects of the different levels of pavement maintenance funding were based on the predicted pavement condition from the Transport Scotland Pavement Network Model. For the study, using data from the Transport Scotland asset database, the model was used to predict the network condition for 2013, 2017, 2020, 2025 and 2030 for each funding Scenario. The effects on network condition in intervening years were derived by interpolation. The model expresses pavement condition as the Road Condition Index (RCI). To use the outputs from the model in other analyses (e.g. vehicle operating costs in HDM-4 (Watanatada, Harral, Paterson, Dhareshwar, Bhandari, & Tsunokawa, 1987) and studies on the effect on traffic of deteriorating pavement condition) RCI values were converted into International Roughness Index (IRI) and 3m Longitudinal Profile Variance.

In line with the Scottish Transport Appraisal Guidance (STAG) (Transport Scotland, 2011b) (Transport Scotland, 2011b) (Transport Scotland, 2011b)requirements, the results of all the analyses given in this report are given in 2002 prices to enable comparison with different studies over time. Real increases were assumed for the costs of vehicle fuel and road user time in line with this guidance, consistent with standard UK guidance (Transport Scotland, 2011b) (Transport Scotland, 2011b) and (Department for Transport, 2011), costs of maintenance works and carbon emissions. The effects of discounting all future costs at the annual Treasury Test Discount Rate were considered. The analyses included an estimate of traffic growth during the analysis period. As part of the analysis of the impacts on local roads (Transport Scotland, 2012), the sensitivity of the results to real changes in maintenance works costs was examined.

Little information was available for non-pavement assets. Although it was expected that some maintenance reductions would be applied in the technology areas (e.g. signs and ITS), the effects of those reductions have not been quantified in this study.

For this analysis, the portion of the network managed as DBFO concessions has been excluded. The study describes the potential effects of reducing the maintenance budget on the part of the network managed directly by Transport Scotland with no changes to the DBFO concession agreements.

The report:

- Describes the results from available literature covering the aspects of the study;
- Summarises the information available on the current status and operation of the network; and
- Explains the approach adopted for, and the results of, each of the relevant analyses that have been carried out into the effects of changes in the level of maintenance funding.

The associated study for local roads (Transport Scotland, 2012) has provided the same sorts of information to the National Road Maintenance Review and a Summary Report (Transport Scotland, 2011a)(Transport Scotland, 2011a) combines the results from this

report and the local road study to provide an overview of the impact for the entire Scottish road network.

## 2 Existing knowledge of impacts (Literature Review)

The challenge of identifying the economic impacts of maintenance investment is not new and Road Administrations around the world have sought to understand and justify their road maintenance programmes in terms of total transport cost for many years. However, until recently it has taken a secondary focus in most road economic research to the understanding of the economics of the initial road transport choice (e.g. the choice between route X or route Y) to ensure appropriate capital investment. There has been increasing work in this area in recent years as greater focus is applied to the efficacy of maintenance and operational investment.

The impact on a Road Administration of changes in road maintenance is the change in both operational and renewal budgets and also the overall capital asset value. The latter is based on the depreciation of the asset as it deteriorates and is often (e.g. by Transport Scotland) related to the asset condition through the use of road condition information (for the valuation model at Transport Scotland, this is the remaining life from pavement strength data).

The impact on the *road user* of changes in road maintenance falls into two broad areas. The first is the consequence of carrying out roadworks and operations, which affects the travelling public in terms of changes in travel time (e.g. queuing at roadworks or due to reduced winter service), accident rates (e.g. accidents at roadworks) and vehicle operating costs (e.g. fuel consumption). The second area of impact is the consequential change in road conditions (e.g. skid resistance and ride quality) which has follow-on effects on vehicle operating costs and other road user effects (e.g. road accidents) in the longer term.

Where available, at the start of each aspect of the analysis in this study, the report includes a brief overview of the latest research in the relevant topic area before a more detailed explanation of the analysis for this study.

Table 2.1 summarises the relative availability of literature on the various impacts of road maintenance, primarily those associated with the quantitative analysis. A fuller literature review of the wider impacts of changes in maintenance funding has been undertaken as part of the review of the impacts from the study for local roads given by (Transport Scotland, 2012).

	Economic impact				
Area of operation	Vehicle Operating Cost	Travel time	Accidents		
Road surface conditions (general)	Н	L	М		
Road surface conditions (skid)	L	L	Н		
Street lighting	L	L	М		
Winter operations	L	М	М		
Structures conditions	L	L	L		
ITS activities	L	L	L		
Road furniture (general)	L	L	L		

 Table 2.1 Summary of reported economic impact by subject area

Notes 1. Based on the literature review and knowledge of research on the topic.

2. H – Relevant literature available. M – Some literature but not widely reported or very locally specific. L – Limited literature for use in this study.

## **3** Transport Scotland road network

### 3.1 Extent of network

Transport Scotland is responsible for the management and maintenance of the trunk road network in Scotland. The trunk road network comprises route corridors that are considered to be of strategic importance to the economic stability and growth and social wellbeing of Scotland. Data representing the extent, condition and operation of the road network is stored in the Transport Scotland asset database. This has been a primary source of data for this study. A summary of the key data shows:

- 3,007 route kilometres of Motorways and All Purpose Trunk Roads (APTRs);
- 1,891 bridges and 2,614 other structures including 1620 culverts and retaining walls; and
- £17.4 billion asset value, the highest value national asset in Scotland.

Further details on the extent of the network are provided in Appendix A and are summarised in Table 3.1.

Asset Type	Quantity	Asset Type	Quantity	
Carriageway		Structures		
Motorway	268 km	Bridges	1,891 no.	
Dual carriageway APTR	492 km	Culverts	721 no.	
Single carriageway APTR	2,247 km	Retaining walls	899 no.	
Barriers	3,437 km	Lighting points	20,622 no.	
Signs	52,275 no.	Longitudinal road markings	11,086 km	

#### Table 3.1 Summary of Transport Scotland network

*Source:* Transport Scotland asset database. (NB. Route lengths do not match exactly the lengths given by Scottish Transport Statistics but match the lengths used in the network condition analyses))

### 3.2 Amount of travel

The trunk road network carries over 35% of all traffic and over 60% of all Heavy Good Vehicle (HGV) traffic in Scotland, whilst being less than 10% of the total length of the Scottish road network.

At the time of analysis, the most recent traffic data (2008) for the Transport Scotland road network, excluding DBFO roads, was extracted from the Transport Scotland asset database. In the asset database, the network is broken into network sections. For each network section, the Annual Average Daily Flow (AADF), for all lanes, was calculated and multiplied by the section length and 365 to derive the annual vehicle km travelled for each vehicle type. The total distance travelled, in 2008, summarised by road type, used in this study is shown in Appendix D. The traffic carried by the trunk road network in

2010, given by Scottish Transport Statistics<sup>1</sup>, is shown in Table 3.2. For the 20 years represented in this study (2010 - 2030) the growth in annual distance travelled was assumed to match the growth in the number of vehicles given by the National Road Traffic Forecasts (see Appendix D).

For this study, the traffic data in the asset database was aggregated by:

- Cars = Light vehicles
- LGV = Vans (Rigid 2-axle)
- OGV1 = Rigid 3-axle + Articulated 3-axle
- OGV2 = Rigid 4-axle + Articulated 4, 5 and 6-axle
- PSV = Buses

	Traffic (Million vehicle kilometres)					
Road Type	Cars	2 wheel motor vehicles	Buses	Light Goods Vehicles (LGV)	Heavy Goods Vehicles (HGV)	All motor vehicles
Major roads						
Motorways	4,825	28	55	832	764	6,504
Trunk A roads – urban <sup>1</sup>	739	4	8	129	65	945
Trunk A roads – rural <sup>1</sup>	6,679	65	86	1,152	785	8,767
All major local roads	12,243	97	149	2,113	1,614	16,216

#### Table 3.2 Annual traffic carried by the trunk road network (2010)

Note: 1. Scottish Transport Statistics uses the Department for Transport classification of urban and rural roads which is based on population. The classification used here is based on built up/non-built up areas.

Summarising the data by Light and Heavy Goods Vehicles (including PSVs) allowed the percentage of HGVs to be calculated for each road type, shown in Table 3.3.

Travel time information has also been derived from information available from the Transport Scotland website (Transport Scotland, 2006). Two statistics are noted for 2006 (most recent available):

- Additional time spent travelling attributable to congestion was estimated as 9,780,000 hours; and
- Average time lost due to congestion, per vehicle km travelled, was 5.87 seconds.

<sup>&</sup>lt;sup>1</sup> Further details on the trunk road network are available at

http://www.transportscotland.gov.uk/strategy-and-research/publications-and-consultations/j205779-00.htm

Road Type	HGV
Motorway	24%
Dual APTR	15%
Single APTR	13%

#### Table 3.3 Percentage of HGV by road type

#### 3.3 Accident trends

Accident data available in the Transport Scotland asset database at the time of the analysis for 2005<sup>2</sup> to 2010 was analysed. At the time of analysis, only partial data was available for 2010. The analysis focused on determining the number of accidents that occurred under different surface conditions (e.g. wet/damp) and the number of accidents that occurred by the prevailing light condition (e.g. Darkness: No street lighting). The accident data has not been normalised for changes in the level of traffic with time.

Figure 3.1 shows the number of accidents, of all severities, by the prevailing light conditions on all road types. A qualitative assessment of the data in Figure 3.1 showed no clear year on year trend in the number of accidents due to different prevailing light conditions. This is as expected as there have been no significant changes in recent years to the length of the network that is illuminated. Of particular interest is the number of accidents that occur in darkness where the street lights are present and lit. The analysis described in Section 9.4 demonstrates that these accidents are expected to increase if street lighting is turned off, with a corresponding economic impact due to the additional accidents on the network.

<sup>&</sup>lt;sup>2</sup> Accident causality data has been recorded since 2005.



Figure 3.1 Numbers of accidents by lighting levels

Figure 3.2 shows the number of accidents by the pavement surface condition recorded at the accident site. A qualitative assessment of this data showed no clear year on year trend in the number of accidents on roads with wet or damp surfaces.

Figure 3.3 shows the number of skidding accidents by the surface condition that was recorded at the accident site. By restricting the data to skidding accidents only it was seen that there has been an overall reduction in the number of 'wet/damp' accidents since 2005, which is consistent with an overall improvement in the network skid resistance shown by the SCRIM data reported in Section 3.5. Further analysis described in Section 7.5 demonstrated the economic impact that budget cuts may have on 'wet/damp' skidding accidents.



Figure 3.2 Number of accidents by road surface condition

### 3.4 Budgets

Table 3.4 shows the maintenance funding allocations by key activities from 2005/06 to 2010/11.

Each budget head is a summary of a number of work series codes in use by Transport Scotland. These are explained in more detail in Section 6 and are shown in the detailed breakdowns included in Appendix B. The budget heads are self-explanatory, with the exception of the 'Minor Improvements', which includes not only capital but also operating costs to fund the on-going ITS expansion, as well as other investigations, studies and minor projects.

Maintenance funding is a combination of the funding allocated directly to each of the 4 Operating Companies (OCs) used to manage the network and funding directly from head office for items which are most effectively managed on a national basis.



Figure 3.3 Number of skidding accidents by road surface condition

Budget Head	Actual Spend (£m)					
	05/06	06/07	07/08	08/09	09/10	10/11
Inventory, Inspection and Testing AND Routine and Cyclic Maintenance	65	85	79	72	75	69
Structural Maintenance – carriageway	39	56	62	43	56	52
Structural Maintenance – structures	28	25	22	23	22	25
Minor Improvements	26	34	38	34	42	24
Miscellaneous3	3	3	3	4	5	4
DBFO Payments	30	35	42	40	38	46
Total	191	238	246	215	238	220

Table 3.4 Summary of recent maintenance budgets

### **3.5 Pavement condition trends**

Past and current pavement condition data (rutting, longitudinal profile variance, skid resistance and residual life) was extracted from the asset database. Both the pavement condition data and the relevant previous budget activity spends (indexed to 2010 prices) have been examined for trends in the variation of each. Comparisons of relevant

<sup>&</sup>lt;sup>3</sup> Includes other activities such as traffic counts, Motorway telephones and compensation payments

indicators can give a network level view of the degree to which maintenance has impacted on the pavement asset. This approach has been used in this analysis as part of more detailed investigations.

Figure 3.4 shows the road surfacing budgets and skid resistance. The graph shows that surfacing investment has fluctuated, with generally higher investment levels 5-10 years ago than in the most recent 5 years, and skid resistance has improved over the last 10 years.



Figure 3.4 Skid resistance and road surfacing budgets

Figure 3.5 shows road strengthening budgets, structural condition (represented by pavement residual life), rut depth and ride quality (represented by 3m longitudinal profile variance (LPV)). The graph shows that structural road maintenance investment increased to a peak about 7 years ago, and has since been reducing. Until five years ago, conditions showed improvement but have since either remained constant or deteriorated.

### 3.6 Maintenance Schemes

Maintenance scheme data was downloaded from the asset database and aggregated to show the total length of schemes by road type and by treatment type for each of the financial years that scheme data was available. Only those schemes with a valid completion date in the database were included in the analysis to ensure any incomplete or schemes that were not implemented have been excluded. Note that the scheme data used does not include patching works. Scheme data since 2002/03 has been used in this analysis.



Figure 3.6 shows the total length of schemes by road type for each financial year and Figure 3.7 shows the total length of schemes by treatment type for each financial year.

Figure 3.5 Pavement condition and maintenance budgets



Figure 3.6 Total length of schemes by road type and year



Figure 3.7 Total length of schemes by treatment type and year

The number of schemes on each road type (Motorway, dual APTR and single APTR) was also calculated from the same dataset and is shown in Figure 3.8. An analysis of the average (mean) scheme length shows no clear trend, with the average length being between 500m and 900m for all road types and years (Figure 3.9).



Figure 3.8 Number of maintenance schemes by road type and year



Figure 3.9 Average scheme length by road type and financial year

## 4 Predicted network conditions

#### 4.1 Pavement analysis

#### 4.1.1 Overview

In recent years, WDM Ltd has provided estimated projections of pavement condition based on specified budget levels, using the Transport Scotland network level pavement model. It was agreed that results from this model should form the basis of the investigations in this study into changes in road conditions based on reduced budgets.

The model describes the network condition in terms of a Road Condition Index (RCI<sup>4</sup>) derived from the survey data for the network. Future condition is estimated by transforming the RCI data into estimated remaining lives and a combination of the treatments applied and the annual shift (reduction) in remaining life.

Remaining life in the model is derived from the RCI using a polynomial relationship developed from engineering experience as illustrated in Figure 4.1 and Equation 1.



$$RCI = 0.048 RL2 - 4.3383 RL + 98.384$$
(1)

Where RL = Remaining Life (years)

Figure 4.1 Relationship between RCI and pavement remaining life

<sup>&</sup>lt;sup>4</sup> Note that this is not the current standard UK RCI but an earlier version of the Index

WDM provided outputs from the model runs for use in this study based on the funding levels described by the three scenarios given in Section 1.

Scenario 1 represents continuation of the 2010 maintenance funding for all of the 20 years analysis period, Scenarios 2 and 3 represent budget reductions for 10 years followed by restoration of the budgets to the 2010 level over 5 years in equal annual steps. For these 2 scenarios there is an annual 2.5 percent increase in the budgets for the last 5 years of the period. These are illustrated in Figure 4.2.



Figure 4.2 Scenario budgets

The effect of Scenario 3 is to suffer a bigger cut in maintenance budget for 10 years and therefore, in the following 5 years, to have a higher rate of funding increase than Scenario 2, so the budget is restored to the 2010 level in year 15 for both Scenarios 2 and 3. The annual budgets for Scenarios 2 and 3 in the last 5 years of the analysis period are the same but the network condition is different because of the pattern of funding in the first 10 years.

Over the first 10 years the effect was more deterioration in network condition with Scenario 3 than with Scenario 2. Although the rate of increase in budget was higher in the next 5 years, the budget was still lower with Scenario 3 than with the other scenarios and network condition remains worse for Scenario 3 than Scenario 1 or 2 through the analysis period. Table 4.1 shows the percentage of the network in bands of remaining life for each of the scenarios at key points in the analysis period.

The results from the analyses included the length of network by remaining life, in a range from 0 to 50 years for 2010, 2013, 2017, 2020, 2025 and 2030. The output results from the model, as provided by WDM Ltd, are given in Appendix C.

The results were broken down into three road types: Motorway, dual carriageway APTRs and single carriageway APTRs.

Figure 4.3 shows the condition of the network in 2010, by network length and road type. This is the starting condition for the three funding Scenarios. In addition to the pavement lengths shown in Figure 4.3, there is approximately 2000 lane-km of the network with a remaining life of 50 years (i.e. in good condition). This represents around a third of the total network length and will not require maintenance during the 20 years considered in this study.

Analysis Year	Sconaria	Remaining Life (% of network)					
	Scenario	Less than 1 yr	1-5 yrs	6-10 yrs	11-20 yrs		
2010	Scenario 1	11.32	11.87	11.30	17.75		
	Scenario 2	11.32	11.87	11.30	17.75		
	Scenario 3	11.32	11.87	11.30	17.75		
2020	Scenario 1	18.24	5.89	8.88	17.63		
	Scenario 2	22.54	7.00	9.17	13.60		
	Scenario 3	25.17	7.17	9.33	13.51		
2025	Scenario 1	17.53	5.76	9.49	14.77		
	Scenario 2	23.66	7.09	7.44	11.55		
	Scenario 3	27.68	7.31	7.40	11.41		
2030	Scenario 1	17.34	6.30	7.95	13.21		
	Scenario 2	23.52	5.53	6.18	10.45		
	Scenario 3	29.01	5.55	6.14	10.20		

Table 4.1	Predicted	network	remaining	life
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Figure 4.3 Network length by remaining life (0-40 years) – Starting Condition

The total network length used for the analysis (provided from the WDM Ltd analysis) is shown in Table 4.2 (note these lengths do not represent the full network, see Table 3.1). These lengths do not include roads operated as DBFO concessions or roundabouts, but do include slip roads. The proportion of each road type in different condition bands was used as the basis for all the economic analyses and calculations presented in this report unless noted otherwise.

Road Type	Route (km)	Carriageway (km)	Lane 1 (km)	
Motorway	rway 268 537		537	
Dual APTR	492	983	983	
Single APTR 2,247		2,247	4,494	
TOTAL	3,007	3,766	6,013	

#### Table 4.2 Network length by road type

#### 4.1.2 Scenario 1: Maintain current spend

Figure 4.4 shows the percentage of the network by remaining life assuming the current spending level continues. For presentational clarity, pavements with a remaining life of longer than 25 years have been removed. These pavements include a large proportion of the network with a remaining life of at least 50 years as noted earlier.



Figure 4.4 Network length by remaining life for Scenario 1

#### 4.1.3 Scenario 2: 20% reduction in budget

Figure 4.5 shows the percentage of the network by remaining life for each year assuming the funding levels described for Scenario 2. The results confirm that more of

the network is in poor condition after 10 years (i.e. in 2020) than if the current spending level is maintained.

#### 4.1.4 Scenario 3: 40% reduction in budget

Figure 4.6 shows the percentage of the network by remaining life for each year assuming the funding levels described for Scenario 3. The results confirm that more of the network is in poor condition after 10 years (i.e. in 2020) compared to the condition shown for Scenario 1 or Scenario 2.



Figure 4.5 Network length by remaining life for Scenario 2

#### 4.1.5 Issues from the pavement condition analyses

Based on a review of the analyses outputs and the assumptions used in the model, the following points have been identified as having a significant impact on the use of the outputs for this study:

- Figure 4.3 shows the distribution of network condition by remaining life (in years). It shows that there is considerable variation with life. The model uses this information as its basis for projecting the annual change in condition (each year, the remaining life on a length of road decreases by one year). Outputs showing the projected condition will continue to reflect this level of variation in future years;
- The largest part of the network (33% of network in 2010) comes from roads in excellent condition (remaining life equal to 50 years or more). The second largest part of the network (11% of network in 2010) comes from roads at the other extreme in the worst condition (remaining life of 0 years or less). These two

proportions of the network have a significant influence on the network conditions predicted by the model over time;

 If deteriorating pavement conditions do not impact on economic outcomes until they reach some threshold between the above two extremes of condition, then significant economic changes will not be projected to occur until those roads currently in excellent condition reach this threshold. At such a time, the projected economic impact may show a sudden step change and then continue to increase;



Figure 4.6 Network length by remaining life for Scenario 3

- In the Pavement Network Model, the mix of different treatments applied by the model is based on the proportion of different treatments required in year 1 of the analysis. This is because there is data available for year 1 at the individual defect level (e.g. cracking, rutting) which allows the different treatment requirements to be modelled. In future years, because the only parameter projected into the future is the remaining life (and the corresponding RCI value), there is no ability to prescribe treatments based on individual treatment types and so the modelled approach is to continue to apply future treatments in the proportion of the treatment types to meet the requirements for year 1. In reality, a Road Administration might choose to limit the application of more expensive treatments under reduced funding scenarios but the model does not attempt to address this refinement.
- At the current level of pavements budget, the model predicts that the condition of Motorways will improve but this is offset by deterioration in single carriageway roads. Even with a 20% reduction in pavement budgets, the condition of the Motorway network is projected to improve during the first 10 years of the analysis period. For years 10 to 20 of the analysis, the higher priority for maintenance

funding for Motorways was removed and budget allocated simply on the basis of the condition of parts of the network.

The implication of these points is considered in the relevant Sections in this report.

#### 4.2 Structures maintenance

In an assessment of the effects of changes in funding for structures maintenance, Transport Scotland assumed three budget options and compared these with the current budget level ( $\pounds 26m$  for 2010/11):

- Desirable (£51m per year). Needed to clear the backlog of defects over 10 years, maintains asset value and ensures optimal safety and minimal disruption;
- Essential (£38m per year). Clears the backlog (requires more than 10 years), maintains asset value, and delivers reasonable safety and levels of disruption; and
- Minimum (£22m per year). Backlog increases, asset value reduces and risks of safety (accidents) and disruption are increased.

The Transport Scotland assessment included no quantification of the customer or economic impacts caused by the different budget levels. For this study, which considered budgets less than the current spending levels, the minimum budget level option in the Transport Scotland assessment was the only relevant case.

Table 4.3 summarises the results for that budget level. In Table 4.4 the values in Table 4.3 are expressed as percentage changes compared with the current activity spends.

Unlike carriageway maintenance, structures maintenance and renewal shows more pronounced potential variation in budget from year to year due to the discrete packages of work which are either included or excluded, and the substantial investments often associated with those packages. Hence the budgets for Replacement, Strengthening and Major Schemes show significant year to year variation between 2011/12 and 2015/16.

The key result from the Transport Scotland report is the expected increase in routine maintenance required to maintain the structures stock. The increase is more than offset by the very significant reduction in capital (major schemes) investment on the network. Routine maintenance is carried out as a lump sum item by the Operating Companies (OCs) while the renewals maintenance is undertaken as specifically funded works.

Activity	Annual Budget (£k)						Total
Activity	10/11	11/12	12/13	13/14	14/15	15/16	Total
Replacement Strengthening and Major Schemes	15,822	12,823	19,035	6,447	3,577	9,234	66,938
OC Lump Sums	1,364	1,364	2,000	2,000	2,000	2,000	10,728
OC Residual Bridge Strengthening	1,967	7,269	1,892	2,022	20	100	13,270
OC Maintenance	6,025	5,000	5,000	5,000	5,000	5,000	31,025
M8 Bridge Maintenance Strategy	300					10,000	10,300
TOTAL	25,478	26,456	27,927	15,469	10,597	26,334	132,261
Rounded Average Annual	25,478	21,357	21,357	21,357	21,357	21,357	132,261

### Table 4.4 Structures maintenance (spend of £22m/yr compared to current spend)

Activity	10/11	Difference compared with 2010/11 budget (%)					Total
	(£K)	11/12	12/13	13/14	14/15	15/16	
Replacement Strengthening and Major Schemes	15,822	-21	17	-60	-78	-43	-37
OC Lump Sums	1,364	0	47	47	47	47	37
OC Residual Bridge Strengthening	1,967	270	-4	3	-99	-95	15
OC Maintenance	6,025	-17	-17	-17	-17	-17	-17
M8 Bridge Maintenance Strategy	300	-100	-100	-100	-100	3,233	567
TOTAL	25,478	2	8	-40	-59	2	
Rounded Average Annual	25,478	-18	-18	-18	-18	-18	

## 5 Methodology

#### 5.1 Overview

The following approach was adopted for the analyses in this study:

- Review literature and Transport Scotland information with a focus on areas which, from experience, have most significant impact in terms of network condition, operations and economics;
- Use results of the literature review to confirm key aspects within the budget levels to be tested for economic impact;
- Refine the budget scenarios from the overall '20% reduction' and '40% reduction' of the total maintenance and operational budget, based on asset management principles, to arrive at more realistic estimates of budget reductions in key spending categories; and
- Conduct analyses and report results.

#### 5.2 Focus of the study

There is a wide range of activities included in road operations and maintenance budgets so there were a number of aspects that needed to be assessed in this study to identify the overall economic, environmental and social impacts of changes in levels of maintenance funding. Therefore, for this brief analysis a number of significant assumptions needed to be made. The approach adopted was limited by both the extent of these assumptions and the level of current knowledge of the specific subject area. The key assumptions and parameter values adopted for the analyses in this study are further described in Appendix D.

The general principle adopted was to focus on variations to those activities which either have a significant impact on budget, or a significant impact on economic consequence, or both.

The economic, environmental and social impacts of changes in maintenance funding and, hence, asset condition, were considered in four general areas. First, the possible impacts on travel in terms of potential lost journeys, delayed journeys and the results of these in terms of lost education, working hours etc. Second, the possible impacts on road user safety, in terms of the costs of accidents. Third, the possible impacts on vehicle operating costs in terms of fuel consumption, vehicle maintenance and commercial crew time. Fourth, the potential impacts on carbon emissions. Fifth, the impacts on the residual value of the asset which changes with the amount of funding invested in the asset.

#### 5.3 Analyses and results

Based on the data available, it was not feasible to carry out all the potential economic analyses. The analyses therefore focused on those for which there was sufficient suitable data. The following analyses were carried out:

• Test impact of different funding levels in terms of long term road surface conditions and the subsequent impact on vehicle operating costs, travel time costs and accident costs;
- Test impact of different funding levels in terms of changes to pavement operations and the subsequent impact on road user travel time costs due to delays at roadworks;
- Test impact of different funding levels in terms of other road maintenance and operations (specifically structures, winter maintenance and lighting) and where possible identify any economic impacts;
- Assess impact on overall asset value and depreciation;
- Assess the impact on potential feedback from customers; and
- Translate the identified effects into the impact on the carbon footprint of the road network.

Sections 7 to 12 describe each of these analyses. Section 13 uses the results from the analyses to form an overall view of the economic impact. Section 14 then provides the key conclusions and recommendations.

Note that in Sections 7 to 12, all results which are derived from results of the pavement model analyses undertaken with the Transport Scotland model (i.e. pavement conditions and their impact on vehicle operating costs and travel speeds, roadworks delay costs and carbon footprint) are summarised based on the 3 pavement maintenance budget scenarios.

Section 6 describes how the effect of the Scenarios 2 and 3 budget reductions may lead to a higher cut in the pavement maintenance budget. The results of the analysis of overall 20% and 40% cuts to pavement budgets are therefore factored up in Sections 13 and 14 to reflect the proportionately larger reductions expected when the overall budgets are reduced by 20% or 40% (i.e. Scenarios 2 and 3).

All other analyses in Sections 7 to 12 (for pavement skid resistance conditions, lighting and winter maintenance and operations) are reported based on the estimated reductions to the relevant budgets. Therefore, no further adjustment is needed to these results for the summaries in Sections 13 and14.

# 6 Refining the scenarios: A subjective assessment

# 6.1 Overview

Road maintenance and operational budgets cover numerous activities within any Road Administration, each of which has a different focus in terms of its relative contribution to the overall corporate objectives. For example, the objective of maintaining directional road signs is primarily to enable reliable and predictable travel for the road user, whereas the objective of maintaining road median barriers is to enable safe travel for the road user. Identifying how best to minimise the impact of any road operational and maintenance budget reductions requires a view on the relative importance of each of the various objectives and the contribution made to those objectives by the different maintenance activities.

A Road Administration sets out its objectives in a Corporate Plan and linking those objectives to each operational activity is achieved by developing levels of service for each activity. However, there is no straightforward way of directly linking levels of service with levels of activity. The New Zealand Transport Agency, in its most recent unpublished draft Asset Management Plan, has attempted a very preliminary and transparent approach to assist with this refinement to its budget planning.

For this study, a similar approach has been adopted so that the impact of the budget scenarios to be tested (overall 20% and 40% reductions) is refined, with each activity delivering proportional contributions to the overall reduction depending on its contribution to the Transport Scotland stated objectives for asset management.

# 6.2 Assessment approach

In Transport Scotland's Road Asset Management Plan (RAMP) (Transport Scotland, 2007b) (Transport Scotland, 2007b), a number of asset management drivers, or objectives, are stated. These are *safety*, *accessibility*, *reliability*, *condition*, *sustainability*, *value for money* and *customer care*. Each activity will contribute to one or more of these objectives in different proportions. Using these objectives, the approach adopted for this study was:

- For each activity in the road operations and maintenance budget, a subjective assessment was made of which objective(s) the activity contributes towards, and the relative balance of the contribution. For example, it might be postulated that maintenance of road markings and reflector studs is carried out 90% for safety and 10% for customer care;
- The activity spend was proportioned by each of the drivers (e.g. in the above example, 90% of the current road marking and reflector studs budget would be allocated to safety and 10% would be allocated to customer care);
- Each activity was summarised so that the total budget was shown as a summation of allocations to each of the asset management objectives;
- When reductions were applied, a view was taken on which asset management objective should be challenged. In this study, for example, for Scenario 2, 10% of the reduction is attributed to the condition objective notional allocation and 5% to each of the sustainability and customer care notional allocations;

- The 10% of the overall budget being taken out of the condition objective represents a significantly higher proportional reduction on the condition objective allocation in itself (in this case, 10/30 or 33% see Table 6.1). The proportional reduction required from each notional allocation was assessed for all objectives and budget heads;
- All reductions were apportioned at the total budget level through each activity and the new budgets available for each activity determined for the overall budget levels throughout the analysis period.

In this way, various activities were reduced by different amounts depending on their contribution to the various objectives and the relative importance assigned to each.

# 6.3 Assessment results

In reviewing the objectives, it was decided that *Value for Money* is a principal driver for all activities and that, with the information available, it was not possible to discriminate between the *Value for Money* contributions for different activities. For this reason, *Value for Money* was excluded as an objective from the analysis and was therefore not considered as a criterion for reducing the allocations. The resulting allocations derived for the Scenario 1 (current expenditure) and Scenarios 2 and 3 for reduced funding are shown in Table 6.1.

	Contribution to overall budget by asset management objective							
Scenario	Safety	Access	Reliability	Condition	Sustainability	Customer care	TOTAL	
Scenario 1	36%	4%	12%	30%	6%	12%	100%	
Scenario 2	36%	4%	12%	20%	1%	7%	80%	
Scenario 3	36%	4%	7%	13%	0%	0%	60%	

Table 6.1 Scenario allocations by asset management objective

The rationale of the above reductions was that *safety*, *accessibility* and *reliability* are all primary customer impacts and should be protected from cuts as long as possible. The assumption made was that at significant budget reductions, value for money in terms of delivering solutions which minimise long term whole of life costs (through *condition* and *sustainability*) or softer customer care outcomes (e.g. appearance of the network maintained by landscaping or graffiti removal) will have to be sacrificed to deliver the primary customer impacts.

Therefore, for Scenario 2 (a 20% overall budget reduction for the first 10 years), the reductions were applied to *condition*, *sustainability* and *customer care* only. At the more significant 40% reduction (for the first 10 years) for Scenario 3, funding for each of *condition*, *sustainability* and *customer care* activities were further reduced and sustainability and customer care were removed completely (these aspects would feed

into the overall objectives but budgets would not be allocated for these sole purposes). Some reductions to the other primary customer care objectives were also required and this was achieved by challenging the *reliability* objective.

The results of apportioning the budget reductions are shown in Table 6.2 and Table 6.3 and in more detail in Appendix B. Table 6.2 shows the work activities assumed to contribute to each budget head and Table 6.3 shows how the budget in each of the heads change for each Scenario.

# 6.4 Conclusions on subjective assessment

The process provided more immediate clarity on where the real impacts would be felt if overall budget reductions were applied as in Scenarios 2 and 3.

At a 20% total budget reduction, the analysis showed that structural maintenance of pavements, at only 56% of its original budget, would be most adversely affected. This would be further accentuated at the 40% total budget reduction in which the budget would be reduced to 24% of the current level.

# 6.4.1 Scenario 2: 20% reduction – focus of impacts

For Scenario 2, those activities most adversely affected (i.e. reductions of 40% or more on the current budget in each of the first 10 years for the specific activity) were:

- Overlay and reconstruction. Road users would experience a significant decrease in road conditions over time.
- Graffiti removal and landscape planting. Customers would see significant deterioration in aesthetics.
- Traffic counts. The ability to manage the asset and plan for the future would be reduced with less information available to support maintenance decisions and performance reporting.
- Payments and claims. Transport Scotland would need to take a stronger view when answering claims from customers and contractors.

# 6.4.2 Scenario 3: 40% reduction – focus of impacts

For Scenario 3, those activities most adversely affected (i.e. reductions of 70% or more on the current budget in each of the first 10 years for the specific activity) were the same as for Scenario 2, but showed more significant changes. As well as the activities affected in Scenario 2, which would all reduce to 40%, or less, of the current allocations, there would be significant reductions in routine and cyclic budgets. The impact would be felt strongly even in some very sensitive areas of activity. For example, maintenance of noise barriers, fences and screens would be reduced to 60% of their current allocations.

The outcome of this process has been used in each of the following more detailed analyses to refine the assessed impact of the cuts in overall budget on the specific activities.

Budget Heads and Descriptions of Works									
Inventory, inspection, testing, routine and	Inventory, inspection, testing, routine and cyclic activity								
Cyclic Maintenance (Monthly Lump Sum)	Road and lighting and electrical work								
Patching Flexible Roads	New footways and cycle tracks								
Patching Concrete Roads	Graffiti removal								
Maintenance of footways and cycle tracks	Technical surveys and investigations								
Raising and replacing of existing kerbs	Winter maintenance (monthly Lump Sums)								
Maintenance of safety fence	Emergencies								
Maintenance of pedestrian guard rails	Routine Services (Lump Sum)								
Maintenance of road traffic signals, signs and bollards	Electricity charges								
Retaining wall under 1.5m	Changes in scope of operations								
Remedial earthworks to embankments and cuttings	General Expenditure								
Drainage and culverts under 2m	DCP Monthly Sum								
Road markings and reflector studs	Damages >£5,000								
Fences, walls, screens and noise barriers	Damage repair & cost recovery service <=£10,000								
Landscape and planting	Payment for damage repair >£10,000								
Pedestrian crossings and furniture	Claims for additional payment - not accepted by Director								
Miscellaneous									
Traffic counts									
Structural maintenance – pavements									
Reconstruction	Surface Dressing								
Overlay	Provision of Special Anti Skid Treatment								
Resurfacing									
Structural maintenance – structures									
Bridges and Culverts 2 metres and over, retaining wall over 1.5 metres and other structures	Principal and General Inspections (Monthly Lump Sum)								
Bridge Strengthening	Structural Assessment								
Major Bridges	Special Investigations								
Silane Treatment	General Expenditure - Bridges								
Protective Coatings to Steel Structures									
Minor improvements									
Individual Accident and Prevention Schemes	Individual Improvement Schemes								

# Table 6.2 Work activities included in each budget head

# Table 6.3 Budget reductions based on contribution to asset managementdrivers

Budget Head	Proposed new budget head spend as percentage of current budget head spend				
budget nead	Scenario 2: Overall 20% cut	Scenario 3: Overall 40% cut			
Inventory, inspection, testing, routine and cyclic activity	87	72			
Miscellaneous	88	71			
Structural maintenance – pavements	56	24			
Structural maintenance – structures	96	86			
Minor improvements	93	75			
Total overall budget	80	60			

# 7 Impacts of pavement condition

# 7.1 Literature review

As part of the study for local roads, related to this study, a review of literature of the wider impacts of changes in maintenance funding was carried out and reported (Transport Scotland, 2012) (Transport Scotland, 2012) (Transport Scotland, 2012) (Transport Scotland, 2012). (Transport Scotland, 2012) (Transport Scotland, 2012). To illustrate the extent of that review, Table 7.1 shows the document relevance matrix developed from the literature review undertaken in the study for local roads.

		Impacts											
Environment Activity/ Assets							Safe	ety	Economy (transport economic efficiency)	Accessibilit inclu	y and social Ision		
		Noise and vibration	Global air quality	Biodiversity	Visual amenity	Cultural	Landscape	Physical fitness	Accidents	Security	Vehicle operating cost	Community accessibility	Comparative accessibility
		1	2	3	4	5	6	7	8	9	10	11	12
A	Pavement	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
в	Structures	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
с	Footway	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
D	Cycleway	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Ε	Lighting	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
F	Drainage	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
G	Pedestrians	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12
н	Cyclists	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12
J	Street cleaning	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12
N	otes:	Nun	ber of ref	ferences (≥5)					Number of r	eferences	s (2 to 4)		
	Number of references (1) White cell = no reference												

#### Table 7.1 Document relevance and coverage matrix

*Source:* (Transport Scotland, 2012) (Transport Scotland, 2012) (Transport Scotland, 2012) (Transport Scotland, 2012) (Transport Scotland, 2012)

# 7.1.1 General impacts and vehicle operating costs

In general, for countries where roads have historically been built and maintained to deliver smooth travel over the life of the pavement, maintenance decision making has focused on parameters other than road roughness (e.g. travel time impact of roadworks, skid resistance). For countries where rougher roads have been more common, the effects of road roughness have been pivotal in the maintenance decision making framework. Countries where roughness has a more significant role in decision making tend to have networks with a significant proportion of the network with roughness greater than 5 or 6 IRI (International Roughness Index).

The World Bank HDM model (Watanatada, Harral, Paterson, Dhareshwar, Bhandari, & Tsunokawa, 1987) (Watanatada, Harral, Paterson, Dhareshwar, Bhandari, & Tsunokawa, 1987) and other models such as the TRL RTIM (Robinson, Hide, Hodges, Rolt, & Abaynayaka, 1975) were originally developed for roads in developing countries and had

a key focus on road roughness impacts on the road user and vehicle operating costs. They have since been upgraded and extended (e.g. the HDM-4 model is used in Eastern Europe and preliminary analyses have been carried out for local roads in England) but the basic conceptual frameworks remain similar. The logic of these models is a link from road condition (predominantly summarised by road roughness) through to road user costs in terms of vehicle operating costs and travel time. These effects are derived albeit at higher levels of roughness than currently experienced on the strategic road networks in the UK using established relationships that, in practice, would be calibrated for the road network under consideration.

Other studies have been carried out elsewhere but the HDM study remains the most widely applicable and reported model for assessing vehicle operating cost changes based on road condition.

Vehicle operating costs are a summation of fuel and engine oil consumption, tyre use, vehicle depreciation and maintenance and repair costs. In terms of modelling impacts of road maintenance, the models depend primarily on road roughness changes as other road conditions (e.g. curvature, rise and fall) will not be affected by changes in maintenance policy, or their impact is second order.

Road roughness does have an effect on vehicle travel speeds in so far as road users will travel at lower speeds on roads which are in a worse condition. The HDM model identified this effect from the studies in the 1970s on experimental road sections in very poor condition and HDM-4 updated the relationships in the 1990s. The model shows variations of between 0.62 and 2.57 km/h reduction in speed per 1 IRI increase in roughness (this is equivalent to changes of around 1.5mm<sup>2</sup> in 3m wavelength Longitudinal Profile Variance, LPV, at base ride quality levels of 4 mm<sup>2</sup> LPV).

# 7.1.2 Travel time based on deteriorating road conditions

Little has been reported on how surface conditions affect travel time. Vehicle drivers may choose to drive more slowly over a surface that has deteriorated than they would over a more even surface. However, it has been postulated that with modern vehicles the effects are reduced and vehicle speeds are maintained but with higher operating costs.

An early study (Cooper, Jordan, & Young, 1980) gathered vehicle speed data for three sites in England due to be resurfaced. At two of the three sites the surface unevenness showed little change before and after resurfacing. At the third site a statistically significantly increase in the traffic mean speed levels was seen following reconstruction of the road. The observed increases in the mean speed after resurfacing were 2 km/h for private cars, 2.3 km/h for light goods vehicles, 2 km/h for medium goods vehicles, and 2.6 km/h for heavy goods vehicles.

The World Road Association report, (PIARC, September, 1987), made the following conclusions about the effect of pavement surface condition on vehicle speed:

- An increase in macrotexture and the lower orders of megatexture generally induces the driver to reduce speed; and
- Increases in megatexture and greater roughness, or the incidence of loose gravel or deep snow or mud, frequently have the effect of inducing the driver to reduce speed to below 50 km/h.

Studies in Sweden by (Linderoth, 1981) and (Wretling, 1996) investigated the relationship between road surface condition and travel speed using a sample of resurfaced roads and a control group. They concluded that there was no evidence of reduced speed due to roughness. (Wretling, 1996) described another Swedish study by (Anund, 1992) that investigated the relationship between surface quality (measured in IRI) and vehicle speed. The results showed that there was a statistically significant speed reduction of 1.6 km/h for passenger cars between 3.00 p.m. and 9.00 a.m. if the rut depth increased by 10 mm, and a reduction of 2.2 km/h for an increase of 1 IRI. The corresponding values during 9.00 a.m. and 3.00 p.m. were 1.9 km/h and 3.0 km/h. For trucks with and without trailers, no significant speed reduction with increased roughness or rut depth was found. The results of those studies support a significant reduction in vehicle speed only when road condition deteriorates beyond some critical level that is rougher than the general level of condition of the trunk road network in Scotland.

# 7.1.3 Road safety impact and accidents

The relationship between skid resistance, site accident risk rating and skidding accident rates is well established in the UK. Many factors influence the rate or risk of accidents, including skid resistance/texture depth, and other road condition factors such as unevenness and ruts (Wilde & Viner, 2001).

An investigation by (Viner, Sinhal, & Parry, 2005) provided comparative friction data over a wide range of surfaces, with a range of skid resistance and texture characteristics. The data also showed that higher risk sites have higher proportions of accidents above a Sideway-Force Coefficient (SFC) of 0.35 than is the case for low risk category sites.

The research also confirmed the necessity of maintaining an adequate level of texture depth to ensure good high-speed friction and the data showed that a texture of at least 0.7mm Sensor Measured Texture Depth (SMTD) was desirable. The results also demonstrated the declining benefits of continuing to increase the texture depth above an adequate level of approximately 1.25mm SMTD.

A large-scale study of the link between skid resistance and personal injury accidents, based on 1000km of road network (Rogers & Gargett, 1991), confirmed the different levels of accident risk for different types of road site and the increase in risk for sites with lower skid resistance.

In general, summarised by (Viner, Sinhal, & Parry, 2005), it has been found that for Motorways, the overall trend with skid resistance is very flat except for the lowest levels of skid resistance. For dual carriageways the results showed there is a statistically significant trend for accident risk to increase at locations with lower skid resistance. For single carriageway non-event sections, the trend was both stronger and more significant and the trend was stronger when considering only wet or skidding accidents. The trend for single carriageway non-event sections showed a continuous increase in accident risk with decreasing skid resistance.

In summary, the literature supports the conclusion that lower skid resistance tends to correlate with an increased accident rates.

# 7.2 Overview of analysis

Based on the broad experience of the economic impacts of road maintenance noted in Section 7.1 the main impacts to be considered in this study were assessed to be:

- Test any impacts of changes in road surface conditions (summarised by ride quality or road roughness) on vehicle operating costs using the HDM-4 framework;
- Test any impact of changes in road conditions (summarised by ride quality or road roughness) on travel time based on the most relevant UK study (Cooper, Jordan, & Young, 1980);
- Test any impacts of changes in road conditions in terms of skid resistance based on UK models relating skid resistance to accidents.

The following Sections describe each of these analyses.

#### 7.3 Surface conditions and vehicle operating cost

To derive vehicle operating costs from the HDM-4 relationships it is necessary to translate pavement condition (remaining life) into IRI. This was achieved by translating remaining life into 3m LPV and then, a further conversion from 3m LPV to IRI.

#### 7.3.1 Translating remaining life into 3m LPV

Many of the economic impacts (i.e. carbon emissions, vehicle operating costs and travel time) are driven by pavement roughness. As noted earlier, the projected pavement condition data for various pavement budget scenarios was given as the length of network for each road type (Motorway, dual APTR and single APTR) by remaining life: ranging from 0 to 50 years. Figure 7.1 shows the steps taken to translate the projected remaining life data to 3m LPV.

In order to develop a relationship between remaining life and 3m LPV, condition data for 300 sections, 10m in length, of each road type (Motorway, dual APTR, single APTR) were extracted from the Transport Scotland database. Using the methodology for calculating RCI from 10m condition data (Transport Scotland, 2007a) the RCI for each section was calculated. A more recent RCI calculation methodology was available for Transport Scotland but an earlier version used for the Transport Scotland pavement model was considered sufficiently reliable for this study.

From the RCI value for each 10m length a linear regression between RCI and 3m LPV data provided relationships (for each road type independently) suitable for use in this study. It should be noted that since RCI and 3m LPV are not independent variables this methodology was not adopted to prove a statistical correlation, but did yield the simple linear conversion shown in Equation 2 to translate RCI data for each of the different road types to 3m LPV. Some outlier data points were removed from the analysis (i.e. 3m LPV > 40mm<sup>2</sup>) to improve the correlation.

$$LPV3m = A (RCI) + B$$
 (2)

Table 7.2 shows the parameter values for the relationship, including the correlation coefficient, between 3m LPV and RCI for each road type.

Road Type	Α	В	R2
Motorway	0.0396	0.7506	0.6087
Dual and Single APTR	0.0397	0.8083	0.3085

Table 7.2 Coefficients for relationships between RCI and 3m LPV



Figure 7.1 Outline methodology for converting remaining life to 3m LPV

The remaining life data from the projected network condition was converted to RCI using the relationship shown in Equation 1. The RCI data was further converted to 3m LPV using the relationships shown in Equation 2. Note that the R<sup>2</sup> value from the analysis for only single carriageways was particularly poor so the relationship derived for dual carriageway APTRs was used for all APTRs.

# 7.3.2 Total network travel by condition

To assign the traffic to the network it was assumed that the traffic is distributed evenly over the different lengths of the network in different levels of 3m LPV (i.e. there is no significant avoidance by road users of roads in poor condition or attraction of roads in good condition). This assumption was necessary as the projected condition data does not represent the actual' network (i.e. the projected condition data does not show route information for the lengths of the network in each remaining life condition band). To undertake a more detailed analysis the condition would need to be projected using the actual road network and associated condition data.

Figure 7.2 sets out the steps taken to determine the vehicle km travelled by each vehicle type over the different levels of 3m LPV.

To use IRI in the economic relationships in HDM-4, a further conversion was required to convert the 3m LPV data to IRI. A provisional transformation has been derived in the European FILTER study (Alonso, 2001) and is provided in Appendix D with other default parameters used in this study.



Figure 7.2 Assignment of traffic to network lengths by 3m LPV

# 7.3.3 HDM-4 analysis

The HDM-45 model includes modules to calculate vehicle operating costs (VOCs) and vehicle emissions and was considered to be an appropriate tool for this analysis.

<sup>&</sup>lt;sup>5</sup> The analysis used HDM-4 version 2.

Typically HDM-4 is not used in the UK as the road network is, by international standards, relatively smooth and vehicle operating costs are not sensitive to roughness until the pavement has an IRI of around 4 or 5. Based on this threshold it is only the worst parts, in terms of longitudinal profile variance, of the Scottish trunk road network that will have any impact on vehicle operating costs.

A set of notional 1km road lengths were modelled in HDM-4, using IRI values ranging from 2 to 5.5 in increments of IRI 0.5. All of the modelled road lengths were of asphalt construction, had a width of 7.5m, a Rise and Fall of 10m/km and a curvature of 15 degrees/km. A further set of 3 lengths were modelled with a surface dressing wearing course to investigate the sensitivity of the model outputs to the different material type. No significant changes in the results of the economic analysis were found due to the change in surfacing type and as a result only one surfacing type has been used in this analysis.

Five vehicle types were defined for use in the model (car; light goods vehicle; passenger service vehicle; rigid HGV; and articulated HGV) and appropriate economic data for each vehicle type, based on published data and consultation with TRL experts and the outputs from the literature review. The parameters used for each vehicle type are shown in Table 7.3. For this study, the Rigid 3-axle HGV was assumed to represent OGV1 vehicles and the Articulated HGV to represent OGV2 vehicles.

Parameter	Car	Light Goods (LGV)	Rigid HGV	Articulated HGV	Passenger Service Vehicle (PSV)
Passenger car equivalent	1	1	1.4	1.8	1.5
No. of wheels	4	4	8	12	6
No. of axles	2	2	3	5	2
Tyre type	Radial ply	Radial ply	Radial ply	Radial ply	Radial ply
Tyre Retread cost (%)	20	30	50	50	50
Annual kilometres	10000	20500	60000	60000	45000
Working hours	700	2250	3500	3500	4000
Average life (yrs)	14	9	10	10	10
Private use (%)	100	0	0	0	0
Passengers (persons)	1	0	0	0	50
Work related passenger trips (%)	75	0	0	0	75
Operating weight (t)	1	2.5	23	44	7.5
New vehicle cost (£)	13600	18000	40000	56000	36000
Replacement tyre cost (£)	36	64	200	336	200
Fuel cost (£ per litre)	0.46	0.48	0.48	0.48	0.48
Lubricating oil cost (£ per litre)	4	12	4	4	4

#### Table 7.3 HDM-4 vehicle parameters

*Note: Costs are economic costs at 2002 prices* 

HDM-4 was run for each of the vehicles travelling over each of the 1km lengths to evaluate the economic costs associated with each vehicle type.

To take account of vehicle engine efficiency improvements and predicted real growth in the resource cost of fuel, the fuel costs in the HDM-4 outputs were replaced with values calculated from:

- The amount of fuel used given in the outputs from the HDM-4 modelling, modified for each year of the analysis based on the assumed vehicle fuel efficiency improvements given in STAG (Transport Scotland, 2011b) (Transport Scotland, 2011b) and webTAG unit 3.5.6 (Department for Transport, 2011).
- The resource cost of fuel based on the vehicle type, taking into account the proportion of the vehicle type using petrol or diesel and the growth forecast for the resource costs of petrol and diesel given in (Transport Scotland, 2011b) (Transport Scotland, 2011b) and webTAG unit 3.5.6. (Department for Transport, 2011)



The outputs from these analyses for 2010 are shown in Figure 7.3.

Figure 7.3 Variation of vehicle operating costs with road roughness

#### 7.3.4 Analysis results

For each year of the analysis period for each of the three pavement budget scenarios the vehicle km travelled by IRI for each vehicle type and road type, derived using the methodology described in Sections 7.3.1 and 7.3.2, was multiplied by the economic costs per 1000 vehicle km figures for each of the IRI bands used in the HDM-4 analysis described in Section 7.3.3. Parts of the network with an IRI greater than 5.5 were assigned an IRI of 5.5 and parts of the network with an IRI value less than 2 were

assigned an IRI of 2. All other parts of the network were rounded to the nearest 0.5 IRI. The results of the analysis are summarised in Table 7.4.

Figure 7.4 shows for the key years in the funding scenarios, that the difference in annual vehicle operating costs between Scenario 1 and the 2 budget reduction Scenarios increases while funding is reduced (i.e. to 2020) and while funding is restored (i.e. to 2025) but the difference then reduces as the funding continues to grow. However, the vehicle operating costs remain higher than for Scenario 1 as the network is in poorer condition for Scenarios 2 and 3.

Figure 7.5 to Figure 7.7 show the variation of annual vehicle operating costs by the different road types for the key years in the funding scenarios. Appendix E contains the results for each year of the analysis.

In summary, these show that for Scenarios 2 and 3, the vehicle operating costs are higher than for Scenario 1 for all 3 road types. By 2030, the vehicle operating costs on Motorways for Scenario 3 are lower than for Scenario 1 and Scenario 2. The increases in vehicle operating costs over the analysis period are similar for all 3 scenarios.

Scenario	Vehicle Operating Costs (£b)									
Scenario	2010	2013	2017	2020	2025	2030				
Scenario 1	4.2941	4.4461	4.7233	4.9050	5.1802	5.4857				
Scenario 2	4.2941	4.4570	4.7489	4.9423	5.2199	5.5164				
Scenario 3	4.2941	4.4640	4.7659	4.9673	5.2467	5.5354				

 Table 7.4 Projected annual vehicle operating costs



Figure 7.4 Projected annual vehicle operating costs



Figure 7.5 Motorway annual vehicle operating costs



Figure 7.6 Dual APTR annual vehicle operating costs



Figure 7.7 Single APTR annual vehicle operating costs

# 7.4 Surface conditions and travel time cost

The earlier TRL study (Cooper, Jordan, & Young, 1980) demonstrated that on newly surfaced roads with a good ride quality, expressed by longitudinal profile variance, drivers travel faster than on roads with a comparably poorer longitudinal profile variance (e.g. pavements in need of maintenance). The results of this research were used as the basis of an estimate of the impact on journey time during normal running that would result from the levels of condition predicted for the different pavement budget scenarios. The analysis used the number of vehicle kilometres travelled over the carriageway lengths defined by different levels of 3m LPV condition derived for the analysis in Section 7.3.

The TRL study (Cooper, Jordan, & Young, 1980) showed the average traffic speed increased when a new surface was provided for a road pavement. Conversely, the average traffic speed can be assumed to have reduced between the provision of a new surface and the time for that surface to be replaced.

Table 7.5 shows the assumed average traffic speed changes between new and worn out pavements for the different vehicle types as identified by (Cooper, Jordan, & Young, 1980). For the purposes of this analysis the change in traffic speed for PSV is assumed to be the same as that for OGV1.

The changes in speed shown in Table 7.5 were assumed to vary linearly with changes in 3m LPV (see Table 7.6).

The traffic data available in the asset database did not include a breakdown between cars and Light Goods Vehicles (LGVs). To enable both of these vehicle types to be used in this part of the analysis, the Rigid 2 axle flow was assumed for LGVs.

For the purposes of this analysis, a representative base speed (when the pavements are in new condition) for each vehicle and road type combination was assumed (see Table 7.7).

Vehicle Type	Change in Traffic Speed (km/h)
Car	2.00
Light Goods Vehicle (LGV)	2.30
PSV	2.00
Other Goods Vehicle 1 (OGV1)	2.00
Other Goods Vehicle 2 (OGV2)	2.60

Table 7.5 Changes in traffic speed with pavement condition

Vehicle				3	8m LPV	′ (mm²	)			
Туре	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Car	0.00	0.22	0.44	0.67	0.89	1.11	1.33	1.56	1.78	2.00
LGV	0.00	0.26	0.51	0.77	1.02	1.28	1.53	1.79	2.04	2.30
PSV	0.00	0.22	0.44	0.67	0.89	1.11	1.33	1.56	1.78	2.00
OGV1	0.00	0.22	0.44	0.67	0.89	1.11	1.33	1.56	1.78	2.00
OGV2	0.00	0.29	0.58	0.87	1.16	1.44	1.73	2.02	2.31	2.60

Table 7.6 Reduction in traffic speed (km/h) with change in 3m LPV

The travel time for the vehicle kilometres travelled (by vehicle type) on the predicted condition (represented by 3m LPV) less the time travelled on an as new surface was assumed to represent the extra delay caused by the levels of predicted condition. The delay time per vehicle type with the value of time for the vehicle type (see Table 7.8) as given by QUADRO (Highways Agency, 2009) at 2002 prices, was used to give the extra cost of travel time that would be caused by the predicted levels of condition on the network.

Figure 7.8, Figure 7.9 and Figure 7.10 show the effect of the predicted pavement condition on the travel time costs across the network for each of the levels of maintenance budget considered for each road type.

		Vehicle Type								
Road Type	Car (km/h)	LGV (km/h)	PSV (km/h)	OGV1 (km/h)	OGV2 (km/h)					
Motorway	105	105	105	90	90					
Dual	105	90	90	70	70					
Single	90	72	70	56	56					

 Table 7.7 Assumed average traffic speed by road type and vehicle type

Note: Traffic speed for new pavement surface

Table 7.9 summarises the extra costs of travel time associated with the predicted network condition (compared to travel on a network in new condition) through the analysis period. The costs were calculated using the pavement condition predicted for 2010, 2013, 2017, 2020, 2025 and 2030 with costs interpolated for other years.

The effect of assuming different average traffic speeds to those shown in Table 7.7 was also investigated. Although the changes in speed raised or lowered the level of delay, the

pattern of behaviour was unaffected. Appendix E shows the breakdown of the increases in travel time and costs by road type.

Table 7.10 shows the increase in travel time costs from the reduction in pavement budgets compared to the costs expected with the current level of funding for pavements.

Table 7.11 shows the cumulative increases through the analysis period compared with the costs expected from the current level of maintenance funding.



Figure 7.8 Predicted travel time costs (Scenario 1)

Year	Car	LGV	PSV	Rigid 3 axle	Articulated
2011	8.71	9.66	59.43	8.47	8.47
2012	8.78	9.75	59.89	8.55	8.55
2013	8.91	9.92	60.75	8.70	8.70
2014	9.07	10.13	61.82	8.89	8.89
2015	9.23	10.35	62.91	9.09	9.09
2016	9.39	10.56	63.98	9.28	9.28
2017	9.55	10.77	65.03	9.47	9.47
2018	9.69	10.95	65.91	9.62	9.62
2019	9.82	11.13	66.80	9.79	9.79
2020	9.96	11.31	67.70	9.95	9.95
2021	10.09	11.49	68.62	10.12	10.12
2022	10.23	11.68	69.54	10.28	10.28
2023	10.37	11.87	70.48	10.46	10.46
2024	10.52	12.07	71.43	10.63	10.63
2025	10.66	12.26	72.40	10.81	10.81
2026	10.81	12.46	73.37	10.99	10.99
2027	10.96	12.67	74.36	11.17	11.17
2028	11.11	12.87	75.37	11.36	11.36
2029	11.27	13.08	76.38	11.55	11.55
2030	11.42	13.30	77.41	11.74	11.74

Table 7.8 Value of time for each vehicle type

*Note:* Values taken from QUADRO. These do not match directly the values given by STAG and webtag guidance (2002 prices)



Figure 7.9 Predicted travel time costs (Scenario 2)



Figure 7.10 Predicted travel time costs (Scenario 3)

Year	Scenario 1: Current Budget	Scenario 2: 20% Budget Cut	Scenario 3: 40% Budget Cut
2011	21.2	21.7	22.0
2012	21.4	22.3	22.9
2013	21.5	23.0	23.8
2014	21.9	23.9	25.1
2015	22.3	24.8	26.4
2016	22.7	25.7	27.6
2017	23.1	26.6	28.9
2018	23.4	27.5	30.1
2019	23.7	28.4	31.4
2020	24.0	29.3	32.7
2021	24.4	29.9	33.5
2022	24.8	30.5	34.2
2023	25.2	31.1	35.0
2024	25.5	31.7	35.8
2025	25.9	32.3	36.5
2026	26.4	32.6	36.8
2027	26.9	33.0	37.1
2028	27.3	33.3	37.4
2029	27.8	33.6	37.6
2030	28.2	34.0	37.9

 Table 7.9 Costs of extra travel time (£m) for each Scenario

Year	Scenario 1	Scenario 2	Scenario 3
2011	0.0	0.5	0.8
2012	0.0	0.9	1.5
2013	0.0	1.4	2.3
2014	0.0	1.9	3.2
2015	0.0	2.5	4.0
2016	0.0	3.0	4.9
2017	0.0	3.5	5.8
2018	0.0	4.1	6.8
2019	0.0	4.7	7.7
2020	0.0	5.2	8.7
2021	0.0	5.5	9.1
2022	0.0	5.7	9.5
2023	0.0	5.9	9.8
2024	0.0	6.1	10.2
2025	0.0	6.4	10.6
2026	0.0	6.2	10.4
2027	0.0	6.1	10.2
2028	0.0	6.0	10.0
2029	0.0	5.9	9.9
2030	0.0	5.7	9.7

Table 7.10 Costs of extra travel time compared to Scenario 1 (£m)

*Note: Extra cost = Costs with reduced budget – Costs with current pavement budget* 

# Table 7.11 Increase in travel time cost (£m) with change in network condition

Year	Scenario 1	Scenario 2	Scenario 3
2010	0.000	0.000	0.000
2013	0.000	1.764	1.309
2017	0.000	7.649	5.936
2020	0.000	14.241	11.469
2025	0.000	57.352	94.865
2030	0.000	87.320	145.114

# 7.5 Skid resistance and accident costs

#### 7.5.1 Methodology

Earlier studies have shown that provision of good skid resistance reduces the risk of accidents on a road network (Parry & Viner, 2005) and (Kennedy & Donbavand, 2008). Using skid resistance data from the asset database, skid resistance over time has been compared with the historic road resurfacing investment (see Figure 3.4).

Based on this analysis, a preliminary assessment of the potential impact of reduced resurfacing budgets on road accidents has been made by:

- Developing a relationship between skid resistance and resurfacing investment;
- Reviewing trends in accidents (total, and wet weather) on the network and assessing the base number of accidents which could be affected by the level of skid resistance;
- Using information from an earlier study (Coyle & Viner, 2009) to identify accident models for the UK trunk road network based on skid resistance.

Section 7.5.2 summarises the results of the above analysis.

#### 7.5.2 Analysis results

#### 7.5.2.1 Step 1: Relationship between skid resistance and surfacing investment

Figure 3.4 shows skid resistance has improved across the network over the last 10 years. It improved most markedly between 2001/02 and 2005/06, since when it has remained relatively constant (if slightly improving). The indexed surfacing budgets during this time, also shown in Figure 3.4 have fluctuated without any strong trend. However, it can be concluded that the average annual budgets between 2001/02 and 2004/05 were higher than during the more recent period. This postulation is demonstrated in Table 7.12.

Itom	4 year period average annual value1		
	2001/02 to 2004/05	2005/06 to 2008/09	
Resurfacing budget <sup>2</sup> indexed to 2010/11 (£m)	17.8	12.7	
	2002/03 to 2005/06	2006/07 to 2009/10	
Annual reduction of percentage of network with negative SCRIM deficiency (% of network)	~(60-20)/60 in 4 years = 16%	Constant (0%)	

#### Table 7.12 Resurfacings budgets and skid resistance

*Notes: 1. The four year period for SCRIM condition data is one year later than the budget data, to make allowance for a lag effect between condition and maintenance work.* 

2. The indexed summation of the 4 Operating Company spends on pavement surfacing treatments.

From Table 7.12 it has been postulated:

- At an annual budget (Operating Company component) for resurfacing of around £12.7m, the percentage of the network with negative SCRIM deficiency can only be held at the current level of around 20%;
- At an annual budget (Operating Company component) for resurfacing of around £17.8m, the percentage of the network with negative SCRIM deficiency reduced by approximately 16% per year.

From the analysis, it is possible that with further budget reductions, current levels of skid resistance could be maintained. For example, there could be further efficiencies that could be achieved even within the existing budgets. Similarly, it is not certain that improvements in skid resistance between 2002/03 and 2005/06 are attributable only to budget changes. However, based on the available information these statistics have been used to derive a first estimate of potential impacts of the proposed budget cuts.

A linear relationship as shown in Equation 3 has been derived:

$$APR = 3.2 * OCB - 40.6 \tag{3}$$

Where

APR = Annual percentage reduction in percentage of the network with negative SCRIM deficiency;

OCB = Annual surfacing budget for the 4 Operating Companies (£m)

From the subjective assessment of the funding scenarios (described in Section 6 and Appendix B) the following has been assumed for the funding of surfacing maintenance:

- Scenario 2 (20% budget reduction) will allocate around £13m to the 4 Operating Companies for the first 10 years of the analysis period;
- Scenario 3 (40% budget reduction) will allocate around £9.6m to the 4 Operating Companies for the first 10 years of the analysis period

Using Equation 3, Scenario 2 would lead to skid resistance levels remaining broadly constant, but for Scenario 3 the percentage of the network with negative SCRIM deficiency would increase by 10% of the current percentage per year.

# 7.5.2.2 Step 2: Accident trends attributable to skid resistance

From a more detailed review of the accident data shown in Section 3.3, a rounded average of the last 5 years of available data (2005 to 2009 inclusive) was calculated. From the number of accidents that occurred only during wet or damp conditions, which are the conditions in which skid resistance becomes a key driver of the number of accidents, the data analysis showed that:

- The number of fatal accidents on all trunk roads in wet/damp conditions has varied from 11 to 21 per year, with an average of around 15; and
- The number of accidents of all severity has varied between 340 and 440 per year, with an average of around 380.

Impacts of Maintenance on the Trunk Road Network in Scotland

#### 7.5.2.3 Step 3: UK trunk road model application

Using models proposed in the most recent unpublished TRL study (Coyle and Viner, 2009) and a number of related assumptions, an estimate of the increase in the number of accidents due to increases in negative SCRIM deficiency values was made:

- **Step 3.1.** Network characterised into two populations of positive SCRIM deficiency and negative SCRIM deficiency. Characteristic values of SFC were assigned to the two populations. From the model proposed by Coyle and Viner (2009), the relative change in accident risk was predicted for the two populations;
- **Step 3.2.** For the current condition of the network, the risk model was applied to the two different populations to generate a total number of accidents equal to the current skid related number of accidents derived in Step 2;
- **Step 3.3.** The calculated accident risks were used to predict changes in the total number of accidents based on the predicted changes in skid resistance derived in Step 1.

For Step 3.1, the mid-range was assumed for the data described in Section 4 of the study, and was used with equal contributions from the different curves postulated in Figure 6 of the (Coyle & Viner, 2009) report. These assumptions suggest accident risk increases by a factor of 12.5/7.5 = 66% when moving from the population with a positive SCRIM deficiency to the population with a negative SCRIM deficiency.

For Step 3.2, two models for the number of accidents were considered. First, the total number of all wet road related accidents (fatal, severe and slight) and second, the total number of fatal accidents.

The results of the analysis (Step 3.3) show that:

- For Scenario 1 (current budget) and Scenario 2 (20% budget reduction), throughout the analysis period there is no increase in the predicted number of accidents as no change in skid resistance occurs. There is, therefore, no cost impact of the funding reduction in Scenario 2;
- For Scenario 3 (40% budget reduction), the percentage of the network with negative skid deficiency was predicted to increase from the current 20% to around 45% during the first 10 years of the analysis while only the lower budget is available. This would result in a predicted increase in the number of all severity accidents from the current figure of around 380 per year to around 440 in 2019/20. Over the next 5 years, as the budget is restored to the 2010 level, the number of accidents also returns to the 2010 level and is retained at that level for the last 5 years of the analysis period. Similarly, the number of fatal accidents was predicted to increase from the current figure of around 15 per year to around 17 in 2019/20. This would represent an increase in annual undiscounted accident costs from the current figures of around £23m to around £26m by 2019/20 before returning to £23m in 2029/30. The total effect is an increase in the cost of skidding accidents of £29m (undiscounted) over the analysis period.

# 8 Impacts of pavement operations

#### 8.1 Overview

The impact of pavement maintenance operations on travel time has been assessed using the current UK approach for assessing road maintenance. The Highways Agency Pavement Management System (HAPMS) includes a module to evaluate the whole life costs of different pavement maintenance options, known as SWEEP (Software for the Whole-life Economic Evaluation of Pavements). The SWEEP model adopts current parameter values to assess the impact of works in terms of the costs of delays to road users under different traffic management arrangements at maintenance sites.

The analysis approach was applicable for this study, subject to the input values being based on the typical range of works operations undertaken on the Scottish trunk road network. This Section sets out the background to this analysis and the results obtained for the Scottish trunk road network.

#### 8.2 Pavement roadworks and travel delay costs

#### 8.2.1 Scheme data

Scheme data based on the estimated area of work (m<sup>2</sup>) was obtained for each treatment type for the last 10 years. The breakdown of treatment type by road type was calculated using the historic scheme data obtained from the asset database, as shown in Table 8.1. This allowed the maintenance work to be broken down by road type.

Treatment Type	Motorway	Dual APTR	Single APTR
Reconstruction	47.1%	32.4%	20.5%
Strengthening	15.3%	13.4%	71.3%
Surface treatment	2.5%	2.9%	94.6%
Total	21.0%	16.3%	62.7%

 Table 8.1 Breakdown of treatment type by road type

For the analysis of the cost of delays to road users, the quantity of maintenance work was split into notional schemes. The analysis in Section 3.6 shows that the average length of scheme is between 500m and 900m for all road types and years. To account for tapers in and out of the works a notional scheme length of 1500m was selected for dual APTRs and Motorways. A notional scheme length of 500m was selected for Single APTRs.

#### 8.2.2 Treatment durations

To estimate the delays to road users it was necessary to assess the duration of each notional scheme (i.e. the number of days/nights of traffic disruption). The default

treatment output rates in SWEEP were used to estimate the duration of work for the notional schemes.

Table 8.2 shows the treatment thicknesses assumed in the analysis.

Treatment Type	Treatment Thickness (mm)
Reconstruction	300
Strengthening	100
Surface treatment	30

#### **Table 8.2 Treatment thicknesses**

To calculate the duration of the maintenance work it was assumed that one lane within the notional scheme length is closed at any one time. Using the scheme length, the area treated (assuming the width of a lane is 3.65m) was calculated and using the output rates, the duration (in hours) was obtained.

# 8.2.3 Delay costs

QUeues And Delays at ROadworks (QUADRO) is a Department for Transport (Highways Agency, 2009) sponsored computer program which estimates the effects of roadworks in terms of time, vehicle operating and accident costs on the users of the road. Individual roadworks can be combined to produce the total cost of maintaining the road over time. For this analysis, the delay cost for each day of each notional scheme was calculated. The total delay cost per scheme was calculated by multiplying the duration (as described in Section 8.2.2) by the delay cost per day. The total cumulative delay cost of all notional schemes gave the total delay cost for each year of each scenario.

# 8.3 Analysis results

For each of the three scenarios, the total delay cost per year was calculated using the methodology described in Section 8.2. Over the first 10 years of the analysis (i.e. while budgets were reduced in Scenarios 2 and 3), for a 20% reduction in pavement budgets (Scenario 2), the total delay cost savings (relative to Scenario 1) ranged from 19% to 34%. For a 40% reduction in pavement budgets, the total delay cost savings (relative to Scenario 1) ranged from 27% to 39%. The overall delay cost savings relative to the costs of delays to road users that would be incurred over the first 10 years of the analysis, with the current budget level, are shown in Table 8.3. In the second 10 years of the analysis, as budgets increase and the amount of maintenance increases in Scenarios 2 and 3, the differences between the scenarios is removed.

Figure 8.1 shows the total annual undiscounted delay costs for each scenario over the 20 year period.

The results of the analysis show the reductions in pavements budgets would lead to reductions in the amount of work and hence less disruption to traffic on the network. The

annual variation in delay costs shown in Figure 8.1 arises as the number of notional schemes on each road type changed over the analysis period.

Scenario	Average Annual Delay Cost Saving Compared to Scenario 1
Scenario 2	26%
Scenario 3	33%





Figure 8.1 Total annual delay cost for each Scenario

# 9 Impacts of other maintenance operations

# 9.1 Overview

As noted in Section 2, there has been much less quantitative reporting on the economic impacts from budget reductions for non-pavement operations. This part of the study has focused on three key areas of budget spend and potential impact:

- Structures maintenance;
- Winter maintenance; and
- Street lighting.

# 9.2 Major structures and impact on the road user

Spend on major structures represents a significant proportion of the Transport Scotland budgets ( $\pounds$ 26m for 2010/11). The issues surrounding structural maintenance of structures which differentiate the asset group from the other road assets are:

- Design/economic lives. Design lives of major structures are significantly longer than the lives achieved for other assets and it is not uncommon for structures to be in service well beyond the original predicted design lives. Tools for the prediction of the impact of variation in year on year maintenance budgets are much less developed than for pavements and forecasts of the effects of future maintenance budgets are less reliable.
- Risk. The risk associated with structures can be significant. If structures are found to be unsafe, there is a significant potential impact in terms of both accidents and route availability which is significantly higher than the impact from most other assets.
- Cost per unit of asset. Major structures, when they do require maintenance, often require very significant amounts of investment and combined with the issues of risk and design life, this can lead to large changes to maintenance budgets, sometimes at short notice, when defects are identified.

Section 4.2 summarised an assessment by Transport Scotland of the effects of potential future structures maintenance budgets. The assessment provided subjective comments on the economic impacts of the assumed budgets, but no quantitative economic analysis had been undertaken.

The nature of trafficking the network with or without the availability of structures is very specific to the routes containing those structures. It is therefore much less appropriate to scale up generic conclusions on the effects of maintenance budget changes seen on other networks. Any analysis of the effects of maintenance budget changes on the structures stock on the Scottish trunk road network would need analysis to include elements of risk assessment and specific technical analyses of the structures most at risk.

Development of tools, or the use of existing tools, to undertake such an analysis was beyond the scope of this study.

# 9.3 Winter maintenance and travel delay and accident costs

#### 9.3.1 Literature review

There have been limited studies into quantifying the economic benefits of winter road maintenance under specific weather conditions. Such studies have tended to assume uniform road and weather conditions regardless of local variables, which can introduce particular consequences, apart from any changes in winter maintenance policy and funding levels. Inevitably, any realistic forecast of the effects of winter maintenance funding is dependent on reliable forecasts of the future weather conditions on the network. Studies into the effects on journey time are particularly unreliable while studies into the effects of winter maintenance on the number of accidents may be more relevant.

An American study (Hanbali & Kuemmel, 1992) concluded that significant reductions in accidents were observed after salt/salt-abrasive mixes had been spread. The average reduction in accident rates was 87% and 78% for two lane single carriageways and dual carriageways, respectively.

A study in 2006, (Fu, Perchanok, Moreno, & Shah, 2006) investigated the relationship between road safety in Canada and various weather and maintenance factors, including air temperature, total precipitation, and the type and amount of maintenance operations. They concluded that anti-icing, pre-wet salting with ploughing and sanding have statistically significant effects on reducing the number of accidents. Both temperature and precipitation were found to have a significant effect on the number of crashes. However, later research (Usmana, Fua, & Miranda-Morenob, 2010) has pointed out limitations which mean the earlier (Fu, Perchanok, Moreno, & Shah, 2006) research may not be directly applicable for quantifying the safety benefit of winter road maintenance of other highways or maintenance routes.

Nordic countries have conducted extensive research on issues related to winter road safety and road maintenance (Wallman, Wretling, & Oberg, 1997). The findings in general are consistent, showing that winter weather increases the risk of accidents and that application of winter maintenance measures lowers the accident risk. Another Nordic study showed that winter maintenance activity is not enough to maintain traffic safety completely and that other actions, such as increasing driver awareness of slipperiness hazards, are required in combination.

The Winter Resilience Review for the Department for Transport (Quarmby, Smith, & Green, 2010) looked at the economic benefits of winter maintenance in terms of:

- Lost economic output if people cannot get to work;
- Personal time lost due to travel delays and lost journeys;
- Additional road vehicle collisions; and
- Personal and health service costs of slips, trips and falls causing personal injury.

The analysis showed on average there was an annual benefit of around £1 billion from adequate winter maintenance funding during a 'hard' winter in England. The cost to highway authorities in England of providing winter service has been estimated to be around £160 million per year. However, the study did not include any further information on impacts of any incremental changes to budgets.

In summary, the literary evidence supports a strong case for investing in winter maintenance both economically and socially, with a significantly positive cost-benefit ratio on the side of 'benefit'. This supports the approach taken in the subjective assessment described in Section 6 and Appendix B in which the spend on winter maintenance was to a large degree protected in the budget reductions.

#### 9.3.2 Winter maintenance assessment

#### 9.3.2.1 Safety impact

This study has assessed the order of magnitude of the impact of potential budget reductions on road accidents in winter on the Scottish trunk road network.

It was assumed that the number of accidents in winter is greater than in summer due to poorer light conditions and more unsafe surface conditions due to water, snow and ice. The data provided by Transport Scotland for a Swedish study, which showed the variation in accidents during last 5 years by winter/summer, suggested around:

- 30 more fatal accidents per year in winter than in summer
- 500 more accidents of any severity per year in winter than in summer

At typical UK accident cost rates, this puts the value at between  $\pm 35m$  and  $\pm 50m$  per year.

The current winter maintenance funding allocation for trunk roads by Transport Scotland is around  $\pounds$ 8m per year. Given that winter maintenance has such an important impact on road safety and journey reliability, the subjective assessment in Section 6 supports this and shows that the budgets would be 97% and 89% of the existing winter budgets, for the funding Scenarios 2 and 3 respectively.

For this study, the information and analysis tools could not quantify any impact at the 97% or 89% funding level so the impacts from Scenarios 2 and 3 are uncertain. Whilst the risk of accidents might go up with reduced winter maintenance, the amount of travel will reduce if fewer roads are kept open, so that this in turn will potentially reduce the number of accidents.

It has therefore been concluded that it is not possible to reliably quantify the safety impact of variations to winter maintenance activities for the levels of overall budget reduction considered in this study.

# 9.3.2.2 Travel time impact

The Winter Resilience Review (Quarmby, Smith, & Green, 2010) concluded that the major economic impact of lack of winter maintenance is in terms of lost trips and extended travel time. It was recognised that salting and gritting budgets lead directly to the availability of the network, in so far as every tonne of salt for a given length of road could keep that length of road open for a given length of time under assumed conditions. Any reduction in the salting budgets could therefore directly translate into a reduction in the number of day-km that the roads are kept free of ice. The effects the reduced salting has on vehicle speeds is again subject to levels of traffic flow, time of day and prevailing weather conditions.

However, as for the safety analysis in Section 9.3.2.1, given that the scenarios considered in this study include reductions to the winter maintenance budget of only

11% in the worst case (Scenario 3), and even this would probably be subject to considerable internal debate and political pressure, no further analysis has been progressed.

#### 9.3.2.3 Analysis results

The overall conclusion is that winter maintenance variation will be limited for either of the analysis scenarios, so there will be no resulting economic impact to consider in this study.

# 9.4 Lighting operations, travel time and accident costs

#### 9.4.1 Literature review

Recent research on lighting costs, technologies and accident statistics has started to change attitudes and assumptions about changes in lighting policies. As well as any economic efficiency drivers, the reduction of lighting energy use is also required by a number of related EU Directives and Statutory Instruments such as the CRC Energy Efficiency Scheme (first sales of allowances was due to be held in April 2011), Energy Related Products Directive (requiring the environmental performance of products throughout their life-cycle to be considered), and the Green Public Procurement Directive.

A TRL study in 2005, (Crabb, Beaumont, Steele, Darley, & Burtwell, 2005), found that the visibility of a small target and reaction times to peripheral objects were not significantly altered either by switching to white light or by a reduction in luminance (by electronic dimming) from full to half the luminous output for Ceramic Metal Halide (CMH) or High pressure Sodium (HPS) lights. This supports later research that has questioned the global applicability of the traditional 30% accident reduction figure used to justify the introduction of night-time lighting on a stretch of road (Crabb, Crinson, Beaumont, & Walter, 2009). As a result of this and other research, the Highways Agency in England now recommends the use of a figure of 10% for the reduction in the number of accidents when calculating the cost-benefit ratio for lighting on the English trunk road network.

The TRL cost analyses (Crabb, Beaumont, Steele, Darley, & Burtwell, 2005) showed that a 22% energy saving can be achieved though the adoption of a dimming strategy. This requires the use of white light (utilisation of lower wattage lamps) and dimming to half the full light output for half of lighting hours at time of low traffic flow. Later, it was also shown (Crabb, Beaumont, & Webster, 2009) that switching from HPS lighting to CMH provides an improvement factor (in energy use) of 1.8.

In Street Lighting – Invest to Save (Institution of Lighting Engineers, 2006) it was suggested that the indirect benefits of street lighting are more than the direct cost of powering the lights and suitable alternatives can be used to reduce energy costs. The use of lower switch on/off lighting levels for some lamp types can save up to the equivalent of a month's energy requirement (per lamp) every 4 years (i.e. around 2%). Reduced traffic route lighting can also provide significant savings. There is also reinforced support for the use of "white light" (lamps with a colour rendering index greater than 60).

In order to implement new strategies, such as dimming, the current infrastructure may require adaptation. In a further TRL study, (Crabb, Beaumont, & Webster, 2009) it was

shown that the cost of new elements required to upgrade to controllable lamps was balanced by the saving in electricity in a 30 year whole life cost analysis. It was further commented that as the electricity price increases, the return would be achieved in a shorter period.

In 2011, Local Highway Authorities trialled part-night lighting schemes (e.g. Leicestershire, Gloucestershire, Wokingham, Essex, Devon) and the Institute of Lighting Engineers has issued a briefing note for decision-makers with responsibility for public realm lighting (Institution of Lighting Engineers, 2010) recommending that street lighting should not be turned off. The recommendations also included the consideration of dropping a lighting class, changing to 'white light' (e.g. BS5489 (British Standards Institution, 2003)) allows a drop of one lighting S class by using white light), adopting new technology (electronic control gear replacing old magnetic gear can immediately save 10% of energy, or the use of LED lighting), dimming of lighting on traffic routes when traffic flow is low, retaining lighting uniformity (i.e. not switching off alternate lamps), and switching off lights in rural locations only after all parties have been consulted and the majority agree with the proposed curfew times.

# 9.4.2 Lighting the network

Based on the results described in the available literature, a simple approach of assuming that should a 100% reduction in street lighting ever be implemented (i.e. turning off all electricity to all lights), then the accident rate on lit routes would increase by 10% (using the current Highways Agency cost-benefit recommendation in reverse). A subjective assessment as part of this study suggests that for a 20% total budget cut (Scenario 2), electricity charges would be reduced by 15% and at the 40% reduction in the total maintenance budget (Scenario 3), the charges would be reduced by 35%, from the current  $\pounds$ 3.3m per year for the Scottish trunk road network.

Using the accident statistics from the asset database and filtered by those accidents occurring on sections of lit road between 2005 and 2009 inclusive, the average number of all accidents on those roads was 141 and 2.2 of these were fatal.

Assuming a 10% increase in accidents on those roads where lights would be switched off, and assuming that the accidents and electricity charges are equally distributed across the street lighting asset, this equates to a potential economic disbenefit of  $\pounds$ 0.1m per year with the Scenario 2 funding reduction (with savings in the Transport Scotland energy costs of  $\pounds$ 0.5m per year) or  $\pounds$ 0.2m per year with the Scenario 3 funding reduction (with savings in the Transport Scotland energy costs of  $\pounds$ 1.1m per year).

It was recognised that this could be a significant underestimate of the disbenefit, as the 10% figure recommended for use by the Highways Agency is based on new schemes to be considered now and the benefits are probably less clear than those provided by some of the existing sites where street lights are already in place. However, if the earlier 30% figure is used this would still only produce a disbenefit of between £0.75m and £1.5m per year (i.e. similar to the saving in the Transport Scotland street lighting energy costs).

# 9.5 Analysis results

The review suggests further work could usefully assess the increased risk to structures of changes in maintenance budget levels. However, because cuts in maintenance of

structures and many of the other non-pavement maintenance operations have such a significant impact on road safety, it is likely that if cuts to the maintenance budget are needed these would be aimed primarily at pavement maintenance, as assumed in the subjective assessment (Section 6).

Closer monitoring of structures may enable the structures budget to be better targeted but this is unlikely to lead to significant savings and there would be a strong aim to maintain structures to prevent any bridge closures. For the trunk road network, the traffic delay costs that would result from any such closures are likely to out-weigh the short term maintenance savings.

Some savings may be possible on winter maintenance but climate is the main determinant of the amount of money spent on this aspect of maintenance. It is not a reliable position to expect year on year savings from winter maintenance as a bad winter would upset the budget planning process. Spend on winter maintenance was preserved in the subjective analysis described in Section 6.

Street lighting offers the potential for some savings but the overall impact is unclear when accidents and other related benefits (e.g. security) are included in the analysis. There is not a large scope for maintenance savings in this area but bigger savings may be made at specific locations.

Overall, the increase in undiscounted accident costs could be  $\pounds 2.0m$  over the analysis period for savings in the Transport Scotland energy bill of  $\pounds 12m$  (for Scenario 3, the 40% reduction in the overall maintenance budget).
# **10** Impact on depreciation

#### **10.1** Depreciation of vehicles

The impact on vehicle depreciation has been considered based on the assumption that a network in worse condition will result in more wear and tear on vehicles and therefore higher rates of vehicle depreciation.

Generally in studies of the effects of changing pavement condition, the cost of vehicle depreciation is subsumed within the overall vehicle operation costs as it is usually considered a relatively small contribution to the overall level of those costs. The ISOHDM study on road user effects (Bennett & Greenwood, 2004) included the development of models specifically for depreciation based on various international studies, supplementing these with realistic assumptions where the appropriate research data did not exist. The models showed that up to roughness levels of 5 IRI (equivalent to 5.5 mm<sup>2</sup> 3m LPV) there is no significant change in vehicle depreciation for any vehicle type.

Based on the projected pavement conditions used in this study, for the proposed budget levels, it was concluded that any changes in vehicle depreciation due to changes in investment levels on the network would be negligible.

#### **10.2** Depreciation of the road network

If renewal investment in the asset is less than the annual depreciation of the asset, then under current assumptions in asset valuation methodologies, the overall asset value will depreciate over time. Whilst there might be debate over the exact figure to be used for the asset value and its variation over time as conditions vary, it is clear from the analyses in this study that the asset value will decline with any of the three budget scenarios (as the total amount of the network requiring renewal according to current standards is shown to increase over time).

In addition to the Transport Scotland Pavement Network Model, WDM Ltd provides estimates of the asset value for the trunk road pavement network for Transport Scotland. Using this method, WDM assessed the change in asset value for the predicted levels of pavement condition. Table 10.1 shows the undiscounted depreciation of the pavements in the trunk road network based on the predicted network condition for each Scenario. The analysis by WDM Ltd produced the depreciation for the Base Case and Scenarios 2 and 3.

The depreciation values have been reported with the other impacts from reductions in maintenance funding to give an indication of the likely effects of the predicted changes in network condition. With the uncertainty in how the asset value feeds into the maintenance decision making process, the asset value has not been included in the reported overall impact in Section 13.

The overall asset value of the road network is made up from the value of all assets on the network. Table 10.1 includes only the depreciation of the road pavements.

Cumulative discounted1 costs (£m 20022 Prices)	Scenario 1 (Base Case)	Scenario 2	Scenario 3
Based on 20% and 40%	budget reductions		
Reduction in pavement asset value	-487	-489	-531
Difference compared to Base Case	Base Case	-2	-44

#### Table 10.1 Depreciation of the trunk road network

## **11** Impacts on customer satisfaction

#### **11.1** Overview

Transport Scotland carried out road user satisfaction surveys in 2007, 2009 and 2010. However, many questions changed between 2007 and 2009 so the two surveys which are most comparable are the most recent 2009 and 2010 surveys. As part of this study the feedback received from these surveys was reviewed and interpretations have been made based on an understanding of road user surveys identified in the literature survey.

#### **11.2** Literature review

A recent study (Ramdas, Thomas, Lehman, & Young, 2007) showed that user requirements and levels of acceptability of the surface condition of paved surfaces are influenced by more than just the condition of the surface. Other effects include media reports, experience in other parts of the country, or other countries, and non-condition related factors (e.g. congestion, traffic management measures such as speed humps).

That study concluded that the two main condition factors that influenced user opinions and satisfaction were 'safety' and 'ride comfort'. Sudden unexpected bumps were classed as unacceptable. It was observed that users expect to not notice the road surface they travel on. In general, any condition aspect that caused them to react to the surface condition and took their attention away from driving was construed as unsafe and unacceptable. User requirements were mainly centred on the need for safe surfaces (i.e. level with good grip) with no unexpected or sudden changes in ride quality. Comparison between user perceptions and engineering data showed that the condition parameters related to ride quality (i.e. 3m LPV, 10m LPV and the bump measure from SCANNER surveys) aligned well with user perceptions of poor ride quality. The other condition aspect that affected ride quality was poor or failed patches. The RCI was high on most roads which users perceived to be in unacceptable condition.

Road user participants in that study showed a good level of understanding of issues related to highway management, including the types of defects commonly encountered, maintenance treatments used and also the budgetary constraints under which highway authorities often operate. It was found that expectations could be managed if users understand the constraints associated with the current maintenance budget and Road Administration objectives. Road closures for maintenance were acceptable if they meant the road surfaces would be repaired to a high standard with good quality materials and would last for many years.

A similar study (Benbow, Nesnas, & Wright, 2006) found that the LPV wavelengths that cause users most discomfort are those in the range of 1-5m. Wavelengths of 5-10m had a much smaller effect and higher wavelengths had no effect. IRI values did not correlate with the user perception as well as 3m LPV.

In summary, if user expectations are managed with additional knowledge of why decisions have been made and how these decisions will not put road user safety at risk, user satisfaction can be kept at an acceptable level.

#### **11.3** Customer satisfaction surveys and potential impacts

From the subjective assessment described in Section 6, the main effect of the lower maintenance budgets that users will see will be reduced roadworks, deteriorating network conditions in the longer term, and possible reductions in operations such as less maintenance to keep street lights operational. The subjective assessment made limited cuts to operations which maintain route reliability, accessibility and safety.

From the results of the 2010 survey by Transport Scotland, it is clear that the area of most concern for road users on the Scottish trunk road network is the general condition of the road surface. The key observation in the report is that with the significant reductions in the pavement budgets, this concern is likely to increase.

# **12** Impact on carbon footprint

#### 12.1 Overview

A key component of the total carbon emissions in the UK is the emission from vehicle exhausts. It is known that pavement condition can affect this by changes in the rate of fuel consumption of vehicles but the direct correlation is unclear because of the wide range of related variables which also have an effect. Existing research on changes in fuel consumption has been described in Section 7. There has also been research into quantifying the impacts of roadworks in terms of congestion and delays to travel times as noted in Section 8.

In the extreme cases of increased closures on the network and reduced accessibility due to potentially higher risks being taken managing the assets (e.g. bridges requiring closure), there would be a severe impact on journeys from trips not made as well as longer alternative routes. This may lead to both reduction and increases in emissions.

This Section describes the investigations undertaken into the various sources of emissions.

#### **12.2** Analysis results

Based on a qualitative assessment of the impact on  $CO_2$  emissions resulting from cuts in pavement maintenance it has been concluded that:

- (i) As long term pavement conditions deteriorate, road roughness increases and predictions based on fuel consumption and therefore CO<sub>2</sub> emissions will increase;
- (ii) As long term pavement conditions deteriorate, travel speeds will be reduced and fuel consumption will decrease, countering the effect in (i);
- (iii)As the number of roadworks interventions reduces with reduced funding, the amount of travel disruption will be reduced and emissions resulting from maintenance activities and due to vehicle idling and queuing will decrease; and
- (iv)As risks on the network increase, the chance of unforeseen closures increases and these would lead to increased queuing and  $CO_2$  emissions.

A quantitative analysis was carried out to demonstrate the first 3 of these effects. Since data on unplanned (emergency) maintenance works was not available the fourth effect could not be assessed.

The quantitative assessment included consideration of the following contributors to the  $CO_2$  produced on the Transport Scotland trunk road network (excluding DBFO roads):

- Embodied carbon in the asphalt used in planned maintenance works;
- Change in carbon emissions from vehicles due to the presence of traffic management required during the planned maintenance on the network; and
- Change in fuel consumption and associated carbon emissions from vehicles using the network due to changes in the pavement surface condition (i.e. increased pavement roughness).

The first two components of the analysis are dependent on the level of maintenance carried out on the network under the different funding scenarios and build upon the analyses carried out to calculate the increase in user delay costs through roadwork sites set out in Section 8. The third component of the analysis builds on the vehicle operating cost analysis reported in Section 7 and uses the outputs from the HDM-4 emissions model and the projected change in network condition to calculate the change in vehicle emissions. Each component of the analysis is described in detail in Sections 12.2.1 and 12.2.2.

#### 12.2.1 Carbon emissions from maintenance works

Using the areas of treatment derived from the scheme information in the Transport Scotland asset database, and used in the assessment of roadworks in Section 8, the total volume of material was estimated for each of the years in the analysis using the notional treatment thicknesses shown in Table 8.2.

Based on work carried out by TRL, as part of the development of the asPECT lifecycle carbon assessment tool (British Standards Institution, 2008a), (British Standards Institution, 2008b), a generic figure for the embodied  $CO_2$  equivalents in a tonne of asphalt, using an asphalt density of  $2.3t/m^3$ , the mass of embodied  $CO_2$  per cubic metre of asphalt is 104kg  $CO_2/m^3$ . This figure was used to convert the volumes of asphalt material to weight of  $CO_2$  and the cost of the carbon monetised using the non-traded carbon costs given in STAG (Transport Scotland, 2011b) (Transport Scotland, 2011b) and webTAG (Department for Transport, 2011) shown in Table 12.1.

During maintenance, traffic management and temporary speed restrictions delay vehicles travelling through the maintenance site. The QUeues And Delays at ROadworks (QUADRO) model (Highways Agency, 2009) generates costs for the difference in vehicle carbon emissions due to the delayed vehicles compared with normal flow conditions. Using the delay methodology from Section 8 the carbon costs for the traffic management arrangements assumed for the maintenance works were aggregated over the analysis period. QUADRO uses a cost base of 2002 for all costs so the carbon costs were updated using RPI to 2010 values.

The carbon costs from the maintenance works and the vehicle emissions due to delays at roadworks sites were combined and the undiscounted costs from the analysis are shown in Table 12.2 and Figure 12.1.

The reduction in maintenance works due to the lower maintenance budgets delivers a small saving in  $CO_2$  costs. It should be noted that closures on Motorways and dual APTRs can actually reduce carbon emissions since the reduction in vehicle speed increases fuel efficiency.

#### **12.2.2** Carbon costs from vehicle CO<sub>2</sub> emissions

Using the projected IRI condition from Section 7.3 and the outputs from the HDM-4 emissions model using the same notional network lengths and default vehicles as used in the vehicle operating cost analysis, the total mass of carbon was calculated from the mass of  $CO_2$  produced and monetised using the factors in Table 12.1. The undiscounted costs from the analysis are shown in Figure 12.2.

The results demonstrate that the carbon costs decrease as budgets are reduced and the network condition deteriorates. The effect is relatively small, but larger in magnitude than the savings in carbon costs from the reduced maintenance works programmes. Carbon costs reduce as the network deteriorates because HDM-4 predicts reductions in vehicle speeds as the network becomes rougher.

Carbo Non	n Costs Central -Traded Price
Year	(£/Tonne)
2011	158.87
2012	161.25
2013	163.67
2014	166.13
2015	168.62
2016	171.15
2017	173.71
2018	176.32
2019	178.97
2020	181.65
2021	184.68
2022	187.70
2023	190.73
2024	193.76
2025	196.79
2026	199.81
2027	202.84
2028	205.87
2029	208.90
2030	211.92

## Table 12.1 Central non-traded price of carbon (2002 prices)

Vear	Car	bon costs by Scena	ario (£m)
Tear	Scenario 1	Scenario 2	Scenario 3
2011	1.231	0.841	0.557
2012	1.276	0.855	0.567
2013	1.284	0.865	0.575
2014	1.303	0.881	0.586
2015	1.256	0.850	0.551
2016	1.316	0.880	0.577
2017	1.302	0.873	0.565
2018	1.312	0.880	0.566
2019	1.335	0.898	0.580
2020	1.330	0.896	0.574
2021	1.385	1.028	0.777
2022	1.390	1.110	0.923
2023	1.409	1.205	1.084
2024	1.447	1.317	1.262
2025	1.444	1.406	1.420
2026	1.472	1.466	1.480
2027	1.487	1.520	1.535
2028	1.531	1.592	1.603
2029	1.585	1.668	1.676
2030	1.612	1.733	1.740

#### Table 12.2 Carbon costs due to maintenance on the pavement network



Figure 12.1 Costs of carbon from maintenance works



Figure 12.2 Carbon costs due to pavement condition for each Scenario

# **13** Summary of changes and impacts

#### **13.1** Results summary

The overall results from this study are presented in **Error! Reference source not** found. and **Error! Reference source not found.**.

**Error! Reference source not found.** shows the cumulative undiscounted costs of each of the impacts for each Scenario at each of the key time steps in the funding Scenarios. **Error! Reference source not found.** shows those costs discounted over the analysis period. Appendix F shows the annual costs for each Scenario.

Table 13.3 summarises the overall effects caused by Scenario 2 (20% overall maintenance budget reduction) and Scenario 3 (overall 40% maintenance budget reduction) compared to Scenario 1 (maintain the 2010 maintenance budget), the Base Case.

#### **13.2** Results discussion

The overall outcome from the study is that compared with the effect of maintaining the 2010 maintenance budget for 20 years, for the funding Scenarios analysed, the vehicle operating costs were predicted to increase. There is little overall change in the other costs to society considered in this study so to see the net socio-economic effect, the increase in vehicle operating costs should be compared with the reduction in maintenance works costs to Transport Scotland. For the levels of budget reduction considered in this study, the increase in vehicle operating costs more than offsets the reduction in the direct Transport Scotland costs, so the net effect is a reduction in economic welfare.

These results do not include the change in residual value of the network for the different scenarios. The residual value can be considered analogous to the asset value. For the scenarios representing budget reductions over the first 10 years of the analysis period (i.e. Scenario 2, a 20% reduction in the overall maintenance budget, and Scenario 3, a 40% reduction in the overall maintenance budget), compared with the effect of maintaining the 2010 level of maintenance funding (i.e. Scenario 1), there was little change in the asset value for Scenario 2 but with Scenario 3, the reduction in asset value was predicted to be approximately half the net increase in total transport cost.

For the scenarios for budget reductions, the changes in road user costs relative to the base case are most significant for the changes in vehicle operating costs due to changes in surface condition (e.g. in year 2020/21 an annual difference of  $\pounds$ 62m undiscounted between the costs expected if the current level of maintenance funding was continued and the level that has been predicted after a 40% budget reduction in the maintenance budget). In year 2030/31, after the period of restoring and increasing the annual budgets, for Scenario 3, the undiscounted vehicle operating costs were still  $\pounds$ 49m higher than in the Base Case.

The effect of discounting the future costs changed the effects as the distribution of costs through the analysis period was not uniform over the 20 years analysis period. For the discounted costs, the Net Present Value for the economic analysis showed an overall increase in the total transport cost compared to the Base Case but the increase was smaller for Scenario 3 (i.e. a 40% reduction in the overall maintenance budget) than for Scenario 2 (i.e. 20% reduction in the overall maintenance budget).

The results of the analyses are heavily dependent on the pavement conditions predicted by the pavement network model. The model shows an improvement in Motorway condition over time at the expense of deterioration in single carriageway APTRs while funding was reduced. Changes in the distribution of funding to road types may change the effects shown in this analysis for vehicle operating costs.

#### **13.3** Assumptions and sensitivity

During this study it was clear that little information was available for non-pavement assets. The results of the analyses are therefore shown for the effects derived from the analysis of pavement condition. Better information on the non-pavement assets would enable more reliable predictions of the effects of cuts in the overall maintenance budget. For example, although it was expected that some maintenance budget reductions would be applied in the technology areas (e.g. signs and ITS), the effects of those reductions could not be quantified in this study.

The effects of the different levels of pavement maintenance funding were based on the predicted pavement condition from the Transport Scotland pavement network model. For the study, using data from the Transport Scotland asset database, the model was used to predict the network condition for 2013, 2017, 2020, 2025 and 2030 for each funding Scenario. Assessing the effects on network condition in intervening years by interpolation was considered sufficiently reliable for this analysis.

Based on the Pavement Network Model outputs and the transformations of the analysis parameters described in this report, some issues about the analyses undertaken have been identified.

- No change to vehicle operating costs is predicted by the HDM-4 model until the remaining life of a road pavement reduces to around 7 years;
- No change to average traffic speed is predicted by the analysis until the remaining life of a road pavement reduces to between 30 and 35 years;
- Reducing the amount of maintenance work reduces the number of interventions on the network and so, in the short-term, delivers a benefit to the road user in terms of travel time (i.e. less disruption at roadworks).

The analysis assumed traffic growth and increases in the value of time, increases in the cost of vehicle fuel and improvements in vehicle engine efficiency in line with STAG (Transport Scotland, 2011b) (Transport Scotland, 2011b) and webtag guidance (Department for Transport, 2011) and summarised in Appendix D.

The Pavement Network Model expresses pavement condition as the Road Condition Index (RCI). To use the outputs from the model in other analyses (e.g. vehicle operating costs in HDM-4 and studies on the effect on traffic of deteriorating pavement condition) RCI values were converted into International Roughness Index (IRI) and 3m Longitudinal Profile Variance. There are no established transformations for these conversions so simple relationships were developed specifically for these analyses.

Itom	Year											
Item	2010/11	13/14	17/18	20/21	25/26	30/31						
Total Agency (works) Costs (£m)												
Scenario 1: Base case	141	566	1,132	1,556	2,263	2,970						
Scenario 2: 20% cut	114	455	910	1,252	1,904	2,666						
Scenario 3: 40% cut	85	341	683	939	1,534	2,296						
Vehicle operating costs due to surface of	condition de	terioratio	n (£m)									
Scenario 1: Vehicle operating costs	4,294	17,480	35,958	50,491	75,842	102,659						
Scenario 2: Vehicle operating costs	4,294	17,502	36,060	50,693	76,237	103,226						
Scenario 3: Vehicle operating costs	4,294	17,516	36,127	50,827	76,502	103,602						
Increase in travel time costs due to sur	face condition	ons (£m)										
Scenario 1: Travel time costs	21	85	175	246	372	509						
Scenario 2: Travel time costs	21	88	189	274	430	596						
Scenario 3: Travel time costs	21	90	198	292	467	654						
Skid resistance analysis (£m)	1											
Scenario 1: Accident costs	23	91	181	249	363	476						
Scenario 2: Accidents costs	23	91	181	249	363	476						
Scenario 3: Accident costs	23	92	191	270	391	505						
Delay costs at (carriageway) roadworks	s (£m)											
Scenario 1: Delay costs	9	35	68	89	126	162						
Scenario 2: Delay costs	9	27	50	65	95	130						
Scenario 3: Delay costs	9	23	41	52	79	114						
Lighting analysis (£m)	1											
Scenario 1: Lighting accident costs	8	34	67	93	135	177						
Scenario 2: Lighting accident costs	8	34	68	93	136	178						
Scenario 3: Lighting accident costs	8	34	69	94	137	179						
CO <sub>2</sub> Emissions (£m)	1											
Scenario 1: CO <sub>2</sub> costs	320	1,322	2,753	3,893	5,919	8,135						
Scenario 2: CO <sub>2</sub> costs	320	1,319	2,742	3,873	5,881	8,081						
Scenario 3: CO <sub>2</sub> costs	319	1,317	2,735	3,860	5,858	8,050						

## Table 13.1 Cumulative costs (Undiscounted)

Itom	Year											
Item	2010/11	13/14	17/18	20/21	25/26	30/31						
Total Agency (works) Costs (£m)		-										
Scenario 1: Base case	141	538	1,006	1,318	1,770	2,152						
Scenario 2: 20% cut	114	433	810	1,060	1,476	1,886						
Scenario 3: 40% cut	85	324	607	795	1,174	1,584						
Vehicle operating costs due to surface of	ondition de	terioratio	n (£m)									
Scenario 1: Vehicle operating costs	4,294	16,605	31,899	42,563	58,780	73,223						
Scenario 2: Vehicle operating costs	4,294	16,625	31,985	42,723	59,063	73,599						
Scenario 3: Vehicle operating costs	4,294	16,638	32,041	42,829	59,252	73,848						
Increase in travel time costs due to sur	face condition	ons (£m)										
Scenario 1: Travel time costs	21	81	155	208	288	362						
Scenario 2: Travel time costs	21	84	167	229	329	419						
Scenario 3: Travel time costs	21	85	174	244	355	456						
Skid resistance analysis (£m)	1											
Scenario 1: Accident costs	23	86	161	211	284	345						
Scenario 2: Accidents costs	23	86	161	211	284	345						
Scenario 3: Accident costs	23	88	169	227	305	366						
Delay costs at (carriageway) roadworks	s (£m)											
Scenario 1: Delay costs	9	34	61	76	100	119						
Scenario 2: Delay costs	9	26	45	56	75	94						
Scenario 3: Delay costs	9	22	37	45	62	81						
Lighting analysis (£m)												
Scenario 1: Lighting accident costs	8	32	60	78	105	128						
Scenario 2: Lighting accident costs	8	32	60	79	106	129						
Scenario 3: Lighting accident costs	8	33	61	80	107	130						
CO <sub>2</sub> Emissions (£m)												
Scenario 1: CO <sub>2</sub> costs	320	1,256	2,440	3,276	4,572	5,765						
Scenario 2: CO <sub>2</sub> costs	320	1,253	2,430	3,260	4,544	5,729						
Scenario 3: CO <sub>2</sub> costs	319	1,251	2,424	3,250	4,528	5,707						

## Table 13.2 Cumulative costs (Discounted)

Cumulative costs <sup>1</sup>	Un	ndiscounted <sup>3</sup>		Discounted <sup>3</sup>						
(£m 2002 <sup>2</sup> Prices)	Scenario 1 (Base Case)	Scenario 2	Scenario 3	Scenario 1 (Base Case)	Scenario 2	Scenario 3				
Financial Costs to Transport Scotla	nd									
Maintenance works	2,970	-304	-674	2,152	-266	-568				
Impacts on Society										
Vehicle operating costs	102,659	+567	+943	73,223	+376	+625				
Travel time (surface condition related)	509	+87	+145	362	+57	+94				
Accidents (skid related)	476	0	+29	345	0	+21				
Delays (through roadworks)	162	-28	-48	119	-25	-38				
Lighting (accidents)	177	+1	+2	128	+1	+2				
C0 <sub>2</sub> Emissions	8,135	-54	-85	5,765	-36	-58				
Overall (non-works) impact	112,118	+569	+986	79,942	+373	+646				
Economic analysis										
						[				
Works costs reduction	Base Case	304	674	Base Case	266	568				
Increase in non-works costs	Base Case	569	986	Base Case	373	646				
Net Present Value <sup>4</sup>	Base Case	-265	-312	Base Case	-107	-78				

Table 13.3 Summary of quantified economic impacts for 20 year analysis period

(1) Annual discount rate = 3.5%.

(2) 2002 prices are 2010 prices factored by 0.81.

(2) Loss prices are zero prices decored by order.
(3) Scenario 2 (20% reduction) and Scenario 3 (40% reduction) figures are shown as differences compared to Scenario 1 (2010/11 funding retained).
(4) Negative NPV shows an overall increase in cost (i.e. non-works costs increase more than the reduction in maintenance expenditure).

The Pavement Network Model applies maintenance to lengths in the network in worst condition (remaining life 0 years) and restores them to a remaining life of between 10 and 50 years depending on the maintenance treatment. Therefore, all roads which are restored to a remaining life of 50 years (by reconstruction or strengthening) do not contribute to the analysis again in the period to 2030. For the analyses undertaken for this study, this amounted to around 60% of the treatments applied in the first 10 years of the analysis for Scenario 3 (a 40% cut in the total maintenance budget), so even if the analysis period was lengthened, these maintained roads would have no economic impact on road user costs for the next 15 to 20 years (vehicle operating costs based on condition) or for 40 to 45 years (vehicle speed costs).

The Pavement Network Model applies maintenance treatments in all years in the same proportion as used for year 1. This assumption is reasonable when budgets are not subject to big changes but for the budget reductions considered in this study, the types and proportions of pavement maintenance treatments applied over the first 10 years of the analysis period may change during the period (e.g. more of the lower cost treatments may be applied).

For the first 10 years of the analysis period, in line with existing Transport Scotland policy, the Model applied a higher priority to maintenance of Motorways. For the second 10 years of the analysis period, an equal priority was given to all three road types (Motorways, dual APTRs and single APTRs).

The subjective assessment used in this study for the reduction in overall budget was aimed at maintaining the service to road users on the network. Transport Scotland has a programme of improvements in the provision of road user information. No effect of reducing that element of expenditure, to preserve the maintenance budget was included in this study.

All the analyses undertaken for this study have adopted single values for the many parameters needed in each part of the analysis. No sensitivity to the selected values has been undertaken in this study but a simple analysis of the effects of alternative parameter values may provide a more reliable guide to the possible effects of reducing spend on the different aspects of maintenance. In particular, changing the assumptions made in the pavement network model, that determine the predicted network condition, and the assumptions in the subjective assessment to give a revised distribution of maintenance spend, could lead to modified conclusions on the effects of the maintenance cuts.

This study has been aimed at the effects of maintenance cuts over the period to 2020 and the subsequent increase in budgets over the next 10 years. Reducing the maintenance budgets over a longer period, or a different strategy for recovery in budget levels, may show different overall effects to those shown in this study.

#### **13.3.1** Inflation on maintenance works costs

Inflation of road maintenance costs has been up to 8% per annum in recent years, which is higher than general rates of inflation (Audit Scotland, 2011). Even if current maintenance budget levels are maintained, if the same inflationary pressure continues in future, road authorities will be able to buy less maintenance work than they can today for the same level of budget. Road authorities use standard indices to update the value of maintenance work prices each year, to manage the risk of inflation in contract costs.

No prediction of specific road cost indices was available for the 20 years analysis period used in this study as the costs are considered too volatile to predict over the time period. Predictions for broader indices are available for more general construction costs but these are less applicable for road maintenance activities. To overcome the difficulties in predicting future price increases, a more appropriate assessment method was considered to be the use of historic trends of various indices to represent the future potential changes.

The ROCOS index (Road Construction Resource Cost Index) (BCIS, 2011) was compared against the Treasury GDP deflator, Retail Price Index and Consumer Price Index. Since 2000, the average annual differential between ROCOS and the various indices was around 4%, and against the Treasury GDP deflator it was 3.9%. Based on experience of the last 10 years, an annual rate of 4% seemed a reasonable basis on which to test the sensitivity of maintenance works costs.

The assumption was also tested finally against oil price predictions from the Department of Energy and Climate Change (Department of Energy and Climate Change, 2011). There were a range of predictions, ranging from low increases (average prices from 2010 onwards varying from 40-50% below 2008 prices) to high increases (prices rising to 40% above 2008 prices by 2015 and peaking and stabilising at 50% above 2008 prices from 2020 onwards). With the differences in these estimates and difficulties with forecasting, and the fact that prices impact on both inputs (e.g. construction price inflation) and impacts (e.g. vehicle operating costs) it was considered that for the purposes of this study, the 4% figure derived from cost price indices described above, was adopted for sensitivity tests.

The results show that the NPV of each funding reduction Scenario becomes less negative compared to the case with no differential rate for road maintenance costs. The Net Present Value for the Scenario with a 20% funding reduction moves from a net impact on society of £107m to £62m and from £79m to £-44m for the Scenario with a 40% reduction in funding. This result implies that it becomes more attractive to consider reductions to road maintenance budgets if there is high inflation for maintenance works, since the cost of delivering the benefits of road maintenance will increase during the analysis period.

However, with higher inflation for maintenance works costs, it is more beneficial to invest now in maintenance than to defer spending to a time when road authority buying power is reduced (i.e. the case not to reduce the current levels of maintenance budgets is strengthened).

## **14** Conclusions and recommendations

This study has shown there are no established earlier studies that have attempted to assess the overall economic, environmental and social impacts of maintenance budget reductions. Many studies have looked at the effects on future asset condition but not the related external effects.

The overall conclusion from the results of this study is that if Transport Scotland can allow a reduction in its current standards and adopt the lower levels of pavement maintenance funding, then there will be an economic disbenefit to the travelling public, primarily from increased vehicle operating costs.

For the modelling approach and the funding scenarios considered in this study, users experience reduced network performance, with increased costs to Scotland, primarily through vehicle fuel costs.

The effects seen in this analysis depended significantly on the assumptions in the Pavement Network Model on the application of maintenance treatments and continuing the treatment allocation used in year 1 for all future years.

In addition to an economic disbenefit to road users, there is likely to be increased public dissatisfaction with the condition of road network. Customer complaints due to worse surface conditions are likely to increase given recent experience from recent customer satisfaction surveys.

A number of potential impacts have not been assessed in terms of network resilience and risk. Particularly for non pavement aspects, the risks of closures due to unforeseen events will increase as the level of expenditure is reduced and inspection and monitoring budgets are reduced. The risk of large diversions due to higher risk sections of the network becoming more frequently inoperable due to inclement weather could become unacceptable. No estimate has been made of such impacts.

The particular conclusions from this study with costs expressed in 2002 prices are:

- From a subjective assessment of the likely distribution of the overall budget reductions across the Transport Scotland maintenance activities it was clear that in the period (2010-2030) considered in this study it is likely that pavement maintenance will suffer a bigger share of the budget reduction than other maintenance areas. The study suggests the pavement maintenance budget would be reduced by 44% and 76% for reductions in the overall maintenance budgets of 20 percent and 40 percent respectively.
- The results from the Transport Scotland Pavement Network Model show the condition of Motorways will continue to improve during the first 10 years of the analysis period when budgets are reduced and before the budgets have started to increase, for all the budget levels considered but overall there is a worsening in network pavement condition with the percentage of the network with zero remaining life (i.e. in need of maintenance) predicted to be 25 percent of the network by 2020, compared with 11 percent in 2010 for Scenario 3. The effect of restoring and increasing the budgets between 2020 and 2030 was to forecast the network continues to deteriorate and there to be 29 percent of the network with zero remaining life in 2030.
- A brief analysis using HDM-4 has shown that by 2020 there will be an increase in undiscounted vehicle operating costs of more than £600m per year compared

with the current level, assuming the current level of maintenance spend is retained. The results also showed there will be further increases if the cuts in the maintenance budget are applied. For the 40 percent budget reduction Scenario, the undiscounted vehicle operating costs were predicted to rise by  $\pounds$ 673m per year by 2020 compared with the costs in 2010 and by  $\pounds$ 1.24 billion by 2030.

- Using the results from a study carried out some years ago into the effects of pavement condition on traffic speed, the annual undiscounted costs of increased travel time, by 2020, resulting from the worsening in pavement condition, were estimated to be £8m and £12m for the 20 percent and 40 percent budget reduction scenarios respectively.
- A QUADRO analysis of a sample of typical maintenance works to assess the impacts on road users from changes in the number of maintenance schemes with the reduced maintenance funding showed in 2030 a reduction in the undiscounted costs of traffic delays to road users at roadworks of 44 percent for the Scenario with a 20 percent cut in overall maintenance budget and a 56 percent reduction for the Scenario with a 40 percent cut in the overall budget. There was still a 20 percent reduction in the annual cost, compared with 2010/11, at the end of the analysis period, after restoration and increase of the maintenance budget.
- Although safety would continue to have a high priority if maintenance budgets are cut, the poorer pavement condition resulting from the reduced maintenance funding was predicted to lead to lower levels of skid resistance. The increase in accidents that may accompany the lower levels of skid resistance for the Scenario with a 40 percent cut in the overall maintenance budget was predicted to be increased undiscounted costs of approximately £40m per year by 2020 but no increase in 2030 following restoration of the maintenance budget.
- With the importance to Transport Scotland of road safety, it was recognised that funding of winter maintenance would remain a high priority even at the lowest funding level considered (i.e. only a small budget reduction would be applied to winter maintenance if the overall maintenance budget is reduced by 40 percent). This study did not therefore predict any change in accident rates that may arise from a change in the level of funding of winter maintenance.
- For structures, a Transport Scotland study in 2010 examined the effects of changes in the level of maintenance funding. The budget reductions (maximum reduction considered was 15 percent) were less than the overall cuts examined in this study but represented the likely effect on the structures maintenance budget following the subjective review of the current overall maintenance budget. This level of funding cut was not expected to lead to bridge closures but would increase the amount of routine maintenance required with the reduction in renewals maintenance. This may introduce difficulties for the 4 Operating Companies in future years. The effect on road users of the change in structures maintenance funding was not assessed as it was expected the reductions would have a small impact.
- Transport Scotland uses condition data from the asset database with an asset valuation model to estimate the depreciation in the value of the trunk road network. The analysis for this study showed that even with retaining the 2010/11 levels of overall maintenance budget, the reduction in the undiscounted trunk road pavement asset value at the end of the 20 years analysis period was

expected to be more than £480m. With the Scenario 2 funding (20 percent reduction in the overall maintenance budget) the effect was to increase the reduction to more than £540m and with the Scenario 3 funding the reduction in asset value by 2030 was expected to be more than £600m.

- Maintenance operations contribute to the carbon footprint of the road network in a number of ways. The analysis in this study showed a predicted increase in the undiscounted costs of carbon emissions of £66m per year in 2020 if the current level of maintenance funding is retained. For the scenarios with 20 percent and 40 percent cuts in overall maintenance funding, the increase was predicted to reduce to £63m and £61m per year respectively. For Scenarios 1, 2 and 3 the increases in the undiscounted costs of carbon by 2030 were predicted to be £139m, £136m and £135m respectively.
- Studies by Transport Scotland since 2008 into the road user perception of the trunk roads in Scotland highlighted a general concern for road users about the condition of the road surface. It is therefore expected that, with the predicted worsening in the overall condition of the network, users will continue to have the same level or more concern about pavement condition.
- For the different funding scenarios, the increases in road user costs relative to the Base Case are most significant for the changes in vehicle operating costs due to changes in surface condition. For Scenario 3, in year 2020/21 there was a predicted annual increase of £62m from the undiscounted costs in 2010/11 but in 2030/31 this was reduced to £49m after improvements in network condition. Changes in all other road user costs were far less significant.
- Overall there would be savings in electricity charges as lighting is reduced but these will be off-set by an increase in the number of accidents and the costs of those accidents. For Scenario 3, (40% reduction in the overall maintenance budget) the savings were not predicted to exceed £1.0m per year.

The overall outcome from the study is that with the predicted deterioration in network condition from the reductions in maintenance funding considered, the total road user costs were predicted to increase and exceed the discounted value of the total saving in the direct Transport Scotland costs, so the net effect was a reduction in the overall economic welfare for both maintenance funding Scenarios that include overall budget reductions, compared to the funding Scenario that retains the 2010/11 level of funding.

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# Glossary

AADF	Annual Average Daily Flow
APTR	All Purpose Trunk Road
СМН	Ceramic Metal Halide
COSLA	Convention of Scottish Local Authorities
dB(A)	A-weighted Decibel (measure of noise)
DCP	Dynamic Cone Penetrometer
DBFO	Design Build Finance Operate
DfT	Department for Transport
ESALF	Equivalent Single Axle Load Factor
HA	Highways Agency
HAPMS	Highways Agency Pavement Management System
HDM	Highway Design and Maintenance Standards Model
HGV	Heavy Goods Vehicle
HPS	High Pressure Sodium
HRA	Hot Rolled Asphalt
IRI	International Roughness Index
ISOHDM	International Study on Highway Development and Management
ITS	Information Technology Services
LGV	Light Goods Vehicle
LPV	Longitudinal Profile Variance (mm <sup>2</sup> ) (reported at 3m, 10m or 30m wavelengths)
OC	Operating Company – there are 4 on the Scottish trunk road network.
OGV	Other Goods Vehicle
PAG	Performance Audit Group
PSV	Public Service Vehicle
QUADRO	Queues and Delays at Roadworks
RAMP	Road Asset Management Plan
RCI	Road Condition Index
RPI	Retail Price Index
RTIM	Road Transport Investment Model
SCANNER	Surface Condition Assessment for the National Network of Roads
SCOTS	Society of Chief Officers of Transportation in Scotland
SCRIM	Sideway-force Coefficient Routine Investigation Machine
SFC	Sideway-Force Coefficient
SMTD	Sensor Measured Texture Depth
SOLACE	Society of Local Authority Chief Executives
STAG	Scottish Transport Appraisal Guidance
SWEEP	Software for the Whole-life Economic Evaluation of Pavements
VOC	Vehicle Operating Cost

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- Members of the Wider Economic Issues, Impacts, Costs and Benefits Working Group

Provision of the network condition and asset depreciation analyses with supporting information from WDM Ltd is also acknowledged.

# Appendix A Further Details of the Trunk Road Network

Table A.1 shows more detail of the assets on the trunk road network in Scotland.

Asset Type	Asset Group	Quantity
	Motorway	268 km
	Dual Carriageway	492 km
	Single Carriageway	2,247 km
Carriagowaya	Hard shoulder	536 km
Carriageways	Lay-by	206 km
	Crossover	19,531
	Central Island	29.5 km
	Central Reserve	1,150 km
Dedectrice & Cycle Escilition	Footway	782 km
Pedestrian & Cycle Facilities	Cycle Facility	21 km
	Road Markings (Hatched)	289 km
	Road Markings (Longitudinal)	11,086 km
Road Markings, Studs and Kerbs	Road Markings (Special)	18,321
	Road Studs	7,864 km
	Kerbs	3,801 km
	Bridge	1,891
	Culvert	721
Structures	Retaining Wall >1.5m	899
Structures	Sign/Signal Gantry	250
	High Mast Light	606
	Footbridge	138
	Lighting point	20,622
Road Lighting	Road Traffic Signs (lit)	5,771
	Bollards (lit)	1,500
Fences, Barriers and Road	Fences and Barriers	1,463 km
Restraint Systems (RRS)	Traffic Control Barriers	58 km
	Safety Fence (RRS)	1,874 km
	Pedestrian Guardrail (RRS)	42 km

Table A.1 Assets on the trunk road network in Scotland

Asset Type	Asset Group	Quantity
	Road Traffic Signs	52,275
	Bollards	49,448
Road Traffic Signs & Signals	Reference Marker Point	6,731
	Road Traffic Signals	1,322
	Pedestrian Crossing	463
	Tree	11,528
Landacanina	Hedge	116 km
Lanuscaping	Verge	5,745 km
	Grass, Bulbs & Wildflower Areas	Unknown
	Balancing Pond	26
	Counterfort Drain	16 km
	Ditch	634 km
	Channel	77 km
Designed	Filter Drain	1514 km
Drainage	Grip	22,775
	Gully	85,703
	Catchpit	3,439
	Manhole	38,950
	Piped Grip	1,077
Geotechnical	Embankment and Cutting	2,177 km
	Variable Message Signs	120
	Communications Cabinet	4,921
Technology Equipment	Detector Loop	4,888
	Emergency Telephone	601
	Ice Sensor	112

# Appendix B Subjective assessment of maintenance spend

Figure B.1 shows the spreadsheet for the allocation of works activities to maintenance budget heads and the distribution of funding to Transport Scotland objectives. This funding represents the funding for the Operating Companies. Further funding of activities, directly by Centre of the organisation, is shown in Figure B.2.

In Figure B.1, the columns on the right-hand side show the allocated budgets after the overall 20% and 40% reductions. The columns headed by the blue box on the left-hand sides of the tables were created as part of the PAG contract function. All other information derived for use in the analysis for this study is shown on the right-hand sides of the tables.

Figure B.2 shows the funding allocation as shown in the Transport Scotland Road Asset Management Plan (RAMP) (Transport Scotland, 2007b) (Transport Scotland, 2007b). The difference between the funding allocated to the Operating Companies and the funding shown in the RAMP is shown distributed between the budget heads. This enable the distribution of the total funding to be shown distributed for the current budget, the 20% cut budget and the 40% cut budget.

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Non-deglet ingrovement blacknest         M         FERRET 12/32         FERR	108	Individual Automation and Prevention Schemes	407	4,707,217.44	4,707,211,81	# T87	100	: II.			1 1	10	4,235.4	100	8.0	1.00	0.5	8.0	470.7	A 580 T	87%	A DECK	
Mill       Advaluating researced (brannal       M.       6.00       6.01	1001	Individual this revenued Schemes	M0	18.665.743.09	15.689.743.89	18,000	45		280		10	100	1.853.4	- 8.0	4 822.4	1 8 8	0.0	8.00	5,005.0	17.841.81	11.16	Townson and	
Diff     Turfle route     HC     P, #3244     P, #3244 <td>100</td> <td>Individual Improvement Schemes</td> <td>MI</td> <td>8.00</td> <td>2.00</td> <td></td> <td>20</td> <td></td> <td>801</td> <td></td> <td>1</td> <td>100</td> <td>8.0</td> <td>1.1</td> <td>8.0</td> <td></td> <td>0.5</td> <td>8.00</td> <td>2.0</td> <td></td> <td></td> <td></td> <td></td>	100	Individual Improvement Schemes	MI	8.00	2.00		20		801		1	100	8.0	1.1	8.0		0.5	8.00	2.0				
Opt.         General Equandary         NC         MC7 (25.12)         State 2 (3.2)         State 2 (3.2)         State 3 (3.2)	aby .	Truths souths	PC .	7.882.84	7.812.01				1	1,100	1 2	-	8.0				1.1	- 24	8.0	1.1	10.00		
201     Biologies and Columba and greet, whan RU     7 211, 224, 17     7, 341, 876, 80     7, 341     7, 341     876, 80     9, 341     3, 348, 84     7, 341     872, 8     8, 8     9, 341 <t< td=""><td>100</td><td>Cont-Anal Experimentary</td><td>ALC: NO</td><td>467.735.43*</td><td>\$15.825.mil</td><td></td><td>34</td><td>200</td><td>20</td><td>10 10</td><td>1 2</td><td></td><td>test</td><td>1011</td><td>100.1</td><td>103.0</td><td>163.2</td><td></td><td></td><td>470.4</td><td>81.5</td><td>and a second</td><td></td></t<>	100	Cont-Anal Experimentary	ALC: NO	467.735.43*	\$15.825.mil		34	200	20	10 10	1 2		test	1011	100.1	103.0	163.2			470.4	81.5	and a second	
Open Standy Strangthening         HI         5.547,825.64         5.848,922.62         6.848,926         5.847,922.64         5.848,922.62         6.848,926         5.36         21         1 <th1< th="">         1         1         &lt;</th1<>	301	Bridges and Coloris 7 matters and mer return	85	7.317.354.17	7.361 676.64	1.040	10	- 100	100	10	1 2		3 april 1	1.672.2	1472.2	The P				T BALL OF	11.0	a trans	
National Integration         No.	101	Bridge Ubanofficiality	81	8.847 ptc 44	5 650 501 04			140	28		1.1		2.875.4	1.697.4	1.1.10					1.000	1005		
Odd         Distant Transmit         Cold	343	Major Bindage	100	4 838 373 54	A 1720, 9450, per		-84		10		1.2		7.065.1	814.4	1004	1012				The state of	10.0	The second second	
Op/Instruction         Number 12 (addings 5)         User 12 (adding 5) <t< td=""><td>304</td><td>Elizia Tradinant</td><td>80</td><td>0.000</td><td>1.00</td><td></td><td></td><td></td><td>1</td><td></td><td>1.2</td><td></td><td></td><td>3.5</td><td></td><td></td><td>1.0</td><td>1.00</td><td></td><td></td><td></td><td></td><td></td></t<>	304	Elizia Tradinant	80	0.000	1.00				1		1.2			3.5			1.0	1.00					
Vinite         Transport         Transport <thtransport< th=""> <thtransport< th=""> <thtran< td=""><td>306</td><td>Furthering Condition in Closed Directioned</td><td>80</td><td>100.057.07</td><td>201.100.77</td><td></td><td>1.40</td><td></td><td></td><td>-</td><td>1.2</td><td></td><td>100.0</td><td></td><td></td><td>145.0</td><td>260.0</td><td></td><td></td><td>100</td><td>12.8</td><td>1000</td><td></td></thtran<></thtransport<></thtransport<>	306	Furthering Condition in Closed Directioned	80	100.057.07	201.100.77		1.40			-	1.2		100.0			145.0	260.0			100	12.8	1000	
NO.         Display A is evented?         NO.         44, 50, 72         47, 484, 47         64         69         70          70         70         70 <td>101</td> <td>Renaulting and Contempt Incom Start Manufactory</td> <td>and the second s</td> <td>1 313 845 19</td> <td>1 126 871 84</td> <td>2 1 and</td> <td>24</td> <td></td> <td>-</td> <td>10</td> <td>1.2</td> <td>1</td> <td>26.8</td> <td></td> <td>240.00</td> <td>134 1</td> <td></td> <td></td> <td>612.0</td> <td>1.100</td> <td>100</td> <td></td> <td></td>	101	Renaulting and Contempt Incom Start Manufactory	and the second s	1 313 845 19	1 126 871 84	2 1 and	24		-	10	1.2	1	26.8		240.00	134 1			612.0	1.100	100		
Visit         Production         Production </td <td></td> <td>The chief has a company and the second second</td> <td>100</td> <td>48, 612 51</td> <td>47,485,47</td> <td></td> <td>100</td> <td>- 13</td> <td></td> <td>1</td> <td>1.2</td> <td></td> <td>122.0</td> <td>- 64</td> <td></td> <td></td> <td>122</td> <td></td> <td></td> <td>700 0</td> <td></td> <td></td> <td></td>		The chief has a company and the second	100	48, 612 51	47,485,47		100	- 13		1	1.2		122.0	- 64			122			700 0			
Optimization         Description         Projection         Proj	100	Resided Incontraction		ALC: 1 10 10 10	107 1 10 17		10				1 2	10	443.4				177.0			100	1.11		
DCP Readles/Leg manuficity         PE         Dot // P         Dot // P <td>400</td> <td>Company Presentations, Bernard</td> <td>100</td> <td>104 104 104</td> <td>24 848 12</td> <td></td> <td>1</td> <td></td> <td>10</td> <td>1 1</td> <td></td> <td>100</td> <td>10.0</td> <td></td> <td></td> <td></td> <td>120</td> <td>1.1</td> <td>1.0.0</td> <td>100</td> <td>1.24</td> <td></td> <td></td>	400	Company Presentations, Bernard	100	104 104 104	24 848 12		1		10	1 1		100	10.0				120	1.1	1.0.0	100	1.24		
Diamages	and the second se	Contract Contractory - December	10 mil	10, 141, 16	11,000 13		-24		1	1.1	1 2	-	100		1.4	11				-			
Normal Damage register 41.000         No	and a	Lour monthly Durin	No.	8.00	0.00	D				10.1	1.2			0.0	0.0	0.00	0.2	0.0	0.0			11	
Literage regist 4 controller part 4 controler part 4 controller part 4 controller part 4 controll	10.5	2.4m while +4.2 (201		8.00	100			- L.			1.2				1.00		1.28						
NOS         Plannet find damage repair v110,000         NC         EV2./05.1         EV2./05.1 <td>100 A</td> <td>Damage repair &amp; cold recovery particle KTD,</td> <td>100 g</td> <td>13,340.25</td> <td>18,081.01</td> <td>.18</td> <td></td> <td>- 12</td> <td>144</td> <td></td> <td>1.1</td> <td>194</td> <td></td> <td></td> <td></td> <td>0.00</td> <td>1.00</td> <td></td> <td>8.0</td> <td>18.2</td> <td></td> <td>1.1</td> <td></td>	100 A	Damage repair & cold recovery particle KTD,	100 g	13,340.25	18,081.01	.18		- 12	144		1.1	194				0.00	1.00		8.0	18.2		1.1	
NOT         Classifier of antificing parment - net accepted in the section of antificing parment - net accepted in the section of antificing parment - net accepted in the section of antificing parment - net accepted in the section of antificing parment - net accepted in the section of antificing parment - net accepted in the section of antificing parment - net accepted in the section of accepted in the sectin the sectin the section of accepted in the section of accepted	805	Payment for damage repair v610,000	80	892,678-31	812,82817	613		- 11			- B	1.001	4.0	4.9	0.0	0.0	0.0	6.0	812.5	258.8	10.0	1000	
140,007,014.0 100,001 101,001 101,000 100,00000000	801	Claims for additional payment - not accepted to	IRC .	487,783.93	420,222.47	820					1.1	100	6.1	.0.0	8.0	0.0	2.0	8.0	431.2	298.0	19.6	1000	
	ATIONAL TO	21 ML		186,987,054,96	103,350,031,327	943,394						12	45,537	6,717	12,831	91,908	1,798		17,849	100,000		21,000	

Figure B.1 Allocation of works to budget heads (1)

DAC Malcrow												TRL	Analys	sis							
Procession of the American Ame				_	_													20% red	uction scenario	40% reducti	on scenario
	1			_														5% from	nal budget	2% from from m	nal budget
Personal Transc	-			-	04	<u>1e</u>	contr	ributio	n (%)				Uutcom	e contribu	ution (£k)			Ű B O	rigi	by, 1 17% fro	rigi
terter	Second	-	2010/11 2010/11 300)			talmuty .	ndition	stainability	ue for Money	stomer Care	etv	ssa	iability	ndition	stainability	ue for Money	stomer Care	6 from Condit stomer Care a stainability (Sb	ivity as % of c	from Reliabili stomer Care, ndition and 7% stainability (£	ivity as % of c
Work Calls - Description of Works - Ballynt -	A DESCRIPTION OF A DESC	CONTRACTOR -		2	4	P	Col	Sus	Val	C	Saf	Ace	Rel	C.	Sus	Val	C	Cus Sus	Act	Sus Cours	Act
Summarised to RAMP headings inventory, impaction, Techng, Routine & Cyclic		-9	_	41%	-11	3%	15%	14%	0%	18% 2	20,634	2,723	3,816	7,364	6,925	0	8,902	40,928	_	32,048	
Weinstein weins Thurburg machineteries - Laniagener		-		12	H	1%	5 89%	4%	0%	4%	U 1.804	0	0	U 43.025	1.802	0	1.802	26,563	-	11.105	
Druchural memorance - rolet structures	28	20		41%	128	3%	8%	2%	0%	4%	9,602	3,994	3,793	1,519	473	0	767	18,970		16,778	
What improvements	- 34	24		144	- 29	0%	0%	0%	0%	26% 1	13,097	0	4,922	0	0	0	6,378	22,404	-	17,973	
Additional leventing, Inspection, Texting, Positive & Cyclic Additional Inventing, Inspection, Texting, Positive & Cyclic	21 Balance	10	10		-	20	0 0	) 0		0 1	5,200.0	0.0	3,800.0	0.0	0.0	0.	0 0.0	19,000.	0 100%	17,733.3	93%
Additional Miscellaneoux			0	- 54		20	) 10	) 10		10	2,000.0	0.0	800.0	400.0	400.0	0.	0 400.0	3,502.	7 88%	2,855.0	71%
	Deater				-																
Additional Diructural maintenance - carriageway				- 6		10	20	) 20		50	0.0	0.0	400.0	800.0	800.0	0.	0 2,000.0	2,630.	4 66%	1,210.0	30%
	Bearies	·																			
Additional Diructural maintenance - Isail Muctures	2	8	1.0	81		20	0 0			0	4,000.0	0.0	1,000.0	0.0	0.0	0.	0 0.0	5,000.	0 100%	4,666.7	93%
	Balance	6																			
Applicated Minor Interconnection				1 10	+	20				25	0.0	0.0	0.0	0.0	0.0	0.	0 0.0	0.	0 92%	0.0	75%
	Bearer					T															
FUARY Signature																					
Inventory, Haperbox, Taxbog, Houdrie & Cycle	<u>n</u>	40				1												59,928	87%	49,781	72%
Miscelaneous Dructural maintenance - carriageneix																		3,507	56%	2,858	24%
Bruchesi mantenense-roat structures	22	8																23,970	96%	21,444	86%
Minor Improvements (1911): 5 - NetColo Cal, 8 - NetColo Capital, 11 - Etrat Road Jake	42	24																22,404	93%	17,973	75%
	200	128								6	66,337	6,717	18,531	53,108	10,408	0	20,249	139,00	3	104,372	
					_	-					38%	4%	11%	30%	6%	09	% <u>12%</u>	799	8	60%	

Figure B.2 Allocation of works to budget heads (2)

# Appendix C Pavement Network Model outputs

This Appendix contains the outputs from the Transport Scotland Pavement Network Model prepared by WDM Ltd:

- Scenario 1 (Base case): Constant annual level of spend (2010/11 funding level continues) for 20 years
- Scenario 2: Reduction in the annual spend in Scenario 1 by 20% (starting 2010/11) for the first 10 years. Return the annual spend to current 2010/11 levels using annual uniform increases, between 2020 and 2025. From 2026, increase annual funding by 2.5% per year
- Scenario 3: Reduction in the annual spend in Scenario 1 by 40% (starting 2010/11) for the first 10 years. Return the maintenance budget to current 2010/11 levels using annual uniform increases, between 2020 and 2025. From 2026, increase annual funding by 2.5% per year

#### Scenario 1: Maintain with current expenditure £46.4m

#### Work Area Table Total

Maintenance	Area of Work (m <sup>2</sup> )													
Activity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019				
Reconstruction	555874	519650	535330	547636	627584	596462	634640	646685	641298	656200				
Strengthening	958647	1123071	1051473	1012786	637850	815521	637551	581845	605011	509911				
Surface dressing	467405	468328	474663	474817	474756	475954	475857	476585	476736	477112				

Maintenance					Area of W	/ork (m²)				
Activity	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Reconstruction	644009	646271	649337	640786	656765	650620	656487	638622	617143	612949
Strengthening	627372	567471	549909	604233	508356	536991	505534	595801	713385	731714
Surface dressing	438661	500137	501636	502136	502123	502436	502727	502926	502738	502761

#### Financial Plan Table Total

Maintenance					(£	m)				
Activity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Reconstruction	20	17	18	19	25	22	25	25	25	26
Strengthening	23	25	24	23	18	20	18	17	17	16
Surface dressing	4	4	4	4	4	4	4	4	4	4
Total	46	46	46	46	46	46	46	46	46	46

Maintenance					(£	m)				
Activity	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Reconstruction	25	26	26	25	26	26	27	25	23	23
Strengthening	18	17	16	17	16	16	16	17	19	19
Surface dressing	4	4	4	4	4	4	4	4	4	4
Total	46	46	46	46	46	46	46	46	46	46

#### **Condition Summary Table – Deflectograph & SCANNER**

				Defle	ectograph	& SCANNE	R PI			
Road Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Motorway	21%	26%	25%	25%	25%	24%	22%	21%	18%	16%
Dual APTR	18%	21%	21%	23%	24%	24%	24%	24%	23%	23%
Single APTR	9%	11%	11%	12%	13%	14%	15%	16%	16%	18%
Overall	11%	14%	14%	15%	16%	17%	17%	17%	17%	19%

					Deflectog	raph & SC	ANNER PI				
Road Type	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Motorway	14%	13%	12%	12%	11%	10%	9%	9%	8%	7%	6%
Dual APTR	22%	20%	19%	18%	16%	15%	14%	12%	11%	9%	8%
Single APTR	18%	18%	18%	19%	19%	19%	19%	20%	20%	20%	21%
Overall	18%	18%	18%	18%	18%	18%	17%	17%	17%	17%	17%

					SCRI	ΜΡΙ				
Road Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Motorway	5%	4%	4%	4%	4%	4%	4%	4%	5%	5%
Dual APTR	13%	12%	12%	12%	12%	12%	11%	11%	11%	11%
Single APTR	29%	29%	29%	29%	30%	30%	30%	30%	29%	29%
Overall	24%	24%	24%	24%	24%	25%	24%	24%	24%	24%

#### **Condition Summary Table – SCRIM**

	SCRIM PI										
Road Type	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Motorway	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Dual APTR	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	13%
Single APTR	29%	29%	29%	29%	28%	28%	28%	28%	29%	29%	29%
Overall	24%	24%	24%	24%	23%	23%	23%	23%	24%	24%	24%

#### Scenario 2: 20% reduction in current expenditure to £37.12m

#### Work Area Table Total

Maintenance					Area of W	/ork (m²)				
Activity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Reconstruction	436885	438968	442139	447997	499794	485553	507764	516657	511529	522821
Strengthening	710532	704613	687260	674355	430105	508138	404421	366023	390112	327470
Surface dressing	494168	495134	501648	501387	500998	501829	501626	501775	501848	502138

Maintenance					Area of W	/ork (m²)				
Activity	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Reconstruction	546973	583967	618043	642410	686649	700490	724786	733472	741486	762487
Strengthening	459392	403805	390741	433534	368454	393798	376942	438032	504992	511507
Surface dressing	369239	404103	405546	406288	406445	407073	407533	407927	408060	408390

#### Financial Plan Table Total

Maintenance					(£	m)				
Activity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Reconstruction	16	16	16	16	20	19	20	21	21	21
Strengthening	17	17	17	17	13	14	13	12	12	11
Surface dressing	4	4	4	4	4	4	4	4	4	4
Total	37	37	37	37	37	37	37	37	37	37

Maintenance					(£	m)				
Activity	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Reconstruction	22	24	26	27	29	30	31	31	31	32
Strengthening	14	13	14	15	14	15	14	16	17	17
Surface dressing	3	3	3	3	3	3	3	3	3	3
Total	39	41	43	45	46	48	49	50	51	52

#### **Condition Summary Table – Deflectograph & SCANNER**

				Defle	ectograph	& SCANNE	R PI			
Road Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Motorway	21%	26%	26%	27%	28%	28%	27%	26%	24%	23%
Dual APTR	18%	21%	21%	23%	26%	26%	27%	28%	27%	29%
Single APTR	9%	11%	11%	12%	14%	16%	16%	18%	18%	21%
Overall	11%	14%	14%	15%	17%	18%	19%	20%	20%	23%

Road Type	Deflectograph & SCANNER PI										
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Motorway	21%	20%	18%	17%	15%	14%	12%	11%	9%	8%	6%
Dual APTR	28%	28%	27%	27%	27%	27%	26%	26%	25%	25%	24%
Single APTR	22%	22%	23%	23%	24%	24%	24%	25%	25%	25%	26%
Overall	23%	23%	23%	23%	24%	24%	24%	24%	24%	24%	24%

Road Type	SCRIM PI											
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019		
Motorway	5%	4%	4%	4%	4%	4%	4%	4%	4%	4%		
Dual APTR	13%	12%	12%	12%	12%	12%	12%	12%	12%	13%		
Single APTR	29%	29%	29%	29%	29%	29%	29%	29%	29%	29%		
Overall	24%	24%	24%	24%	24%	24%	24%	24%	24%	24%		

#### **Condition Summary Table – SCRIM**

Road Type	SCRIM PI										
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Motorway	5%	5%	5%	5%	4%	4%	4%	5%	5%	5%	5%
Dual APTR	13%	13%	13%	13%	13%	13%	13%	13%	12%	13%	13%
Single APTR	29%	29%	29%	29%	29%	29%	28%	28%	28%	28%	29%
Overall	24%	24%	24%	24%	24%	24%	23%	23%	23%	24%	24%
# Scenario 3: 40% reduction in current expenditure to £27.84m

#### Work Area Table Total

Maintenance	Area of Work (m <sup>2</sup> )									
Activity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Reconstruction	273896	274806	277014	282331	334874	320566	343175	352315	346797	358455
Strengthening	681597	681012	668298	658677	411039	489834	384453	344956	371159	307286
Surface dressing	507730	508762	515065	514426	513635	514194	513587	513889	513668	513625

Maintenance	Area of Work (m <sup>2</sup> )									
Activity	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Reconstruction	419860	493935	562282	618259	698304	712208	738233	746641	754809	776666
Strengthening	448145	389555	376519	425401	355428	380299	358981	415156	477915	480151
Surface dressing	375014	401214	401532	402501	403142	403969	404794	405521	406036	406562

### Financial Plan Table Total

Maintenance		(£m)									
Activity	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
Reconstruction	9	9	9	9	13	12	13	14	13	14	
Strengthening	15	15	15	15	11	12	10	10	10	9	
Surface dressing	4	4	4	4	4	4	4	4	4	4	
Total	28	28	28	28	28	28	28	28	28	28	

Maintenance	(£m)									
Activity	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Reconstruction	16	20	23	25	29	30	31	31	31	32
Strengthening	12	12	13	14	14	14	14	16	17	17
Surface dressing	3	3	3	3	3	3	3	3	3	3
Total	32	35	39	43	46	48	49	50	51	52

#### **Condition Summary Table – Deflectograph & SCANNER**

	Deflectograph & SCANNER PI									
Road Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Motorway	21%	27%	27%	29%	31%	31%	31%	31%	30%	29%
Dual APTR	18%	22%	22%	24%	27%	28%	29%	31%	30%	32%
Single APTR	9%	11%	11%	12%	15%	16%	17%	19%	19%	23%
Overall	11%	14%	14%	16%	18%	20%	20%	22%	22%	25%

	Deflectograph & SCANNER PI										
Road Type	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Motorway	28%	27%	26%	24%	22%	19%	17%	14%	11%	9%	6%
Dual APTR	31%	32%	32%	32%	32%	31%	31%	31%	30%	30%	29%
Single APTR	23%	24%	25%	26%	27%	28%	29%	30%	30%	31%	32%
Overall	25%	26%	26%	27%	27%	28%	28%	29%	29%	29%	29%

# **Condition Summary Table – SCRIM**

	SCRIM PI									
Road Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Motorway	5%	5%	5%	5%	4%	5%	5%	5%	5%	5%
Dual APTR	13%	13%	13%	13%	13%	13%	13%	13%	13%	13%
Single APTR	29%	29%	29%	29%	29%	30%	29%	29%	29%	29%
Overall	24%	24%	24%	25%	25%	25%	25%	24%	24%	24%

	SCRIM PI										
Road Type	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Motorway	5%	5%	5%	5%	4%	4%	4%	4%	5%	5%	5%
Dual APTR	13%	13%	13%	13%	13%	13%	13%	13%	12%	13%	13%
Single APTR	29%	29%	30%	30%	30%	30%	30%	29%	29%	29%	29%
Overall	24%	24%	25%	25%	25%	25%	25%	24%	24%	24%	24%

# **Appendix D Summary of key data and assumptions**

# D.1 Traffic data

For this analysis, the traffic carried by the trunk road network was derived from the data extracted from the Transport Scotland asset database for 2008 and is summarised in Table D.1.

# Table D.1 Annual total vehicle km travelled by road type and vehicle type(2008)

Vehicle Type		Traffic (Vehicle kilometres)								
venicie rype	Motorway	Dual	Single	All						
Car	4,769,787,191	5,416,703,223	5,804,398,697	15,990,889,112						
LGV	657,082,076	434,925,796	382,040,517	1,474,048,391						
PSV	133,969,557	88,766,829	78,087,386	300,823,773						
OGV1	161,215,253	106,710,352	93,868,098	361,793,704						
OGV2	561,990,914	371,913,699	326,848,004	1,260,752,618						
Total Heavy Vehicles	857,175,724	567,390,880	498,803,488	1,923,370,095						

Traffic growth rates used in the analysis were consistent with the National Road Transport Forecast (NRTF) given by STAG (Transport Scotland, 2011b) (Transport Scotland, 2011b) and (Department for Transport, 2011) and are reproduced for the modelled years in Table D.2.

Year	Car	LGV	PSV	HGV
2009	1	1	1	1
2010	1.014600	1.021700	1.006900	1.024400
2013	1.057812	1.092228	1.029521	1.102951
2017	1.113016	1.194830	1.062652	1.216857
2020	1.147082	1.275811	1.090629	1.306208
2025	1.190979	1.414822	1.143427	1.463062
2030	1.231660	1.556266	1.204254	1.627888

# Table D.2 Traffic growth rate factors from NRTF

Summarising the data by Light and Heavy Goods Vehicles (including PSVs) allowed the percentage of HGVs to be calculated for each road type, shown in Table D.3.

Road Type	HGV
Motorway	24%
Dual APTR	15%
Single APTR	13%

#### Table D.3 Percentage of HGV by road type

#### **D.2 GDP deflator**

Where cost data was not available in 2002 prices the costs were deflated to 2002 using the GDP deflator indices in Table D.4 taken from STAG (Transport Scotland, 2011b) (Transport Scotland, 2011b) and webtag guidance (Department for Transport, 2011).

	GDP deflato	r at market prices	
Year	2010 = 100	Per cent change on previous year	GDP (£m)
2002	81.274	3.10	1,075,564
2003	83.771	3.07	1,139,744
2004	85.883	2.52	1,202,956
2005	87.627	2.03	1,254,058
2006	90.301	3.05	1,328,363
2007	93.004	2.99	1,404,845
2008	95.763	2.97	1,445,580
2009	97.147	1.45	1,394,989
2010	100.000	2.94	1,455,397
2011	103.000	3.0	1,526,000
2012	105.472	2.4	1,603,000
2013	108.320	2.7	1,694,000
2014	111.244	2.7	1,789,000
2015	114.248	2.7	1,889,000

#### Table D.4 GDP deflator indices

### **D.3 Fuel Efficiency Improvements**

The engine fuel efficiency factors used in this study, shown in Table D.5, were taken from STAG (Transport Scotland, 2011b) (Transport Scotland, 2011b) and webtag guidance (Department for Transport, 2011).

Year	Average Car	Average LGV	PSV	3 axle Truck	Artic
2010-2015	-1.87	-1.72	0	0	0
2015-2020	-2.71	-1.7	0	0	0
2020-2025	-3.13	-0.96	0	0	0
2025-2030	-2.33	-0.26	0	0	0

### Table D.5 Engine fuel efficiency factors

# **D.4 Increase in cost of fuel**

Factors for the increase in fuel costs used in this study, shown in Table D.6, were taken from STAG (Transport Scotland, 2011b) (Transport Scotland, 2011b) and webtag guidance (Department for Transport, 2011).

#### Table D.6 Increase in fuel costs

Year	Average Car	Average LGV
2020-2025	0.99	1.02
2025-2030	0.95	0.96

# **D.5** Economic cost of accidents and casualties

The costs of accidents from the STAG and (Transport Scotland, 2011b) (Transport Scotland, 2011b) webTAG guidance (Department for Transport, 2011) relate to 2007 and have been increased by the growth in GDP per capita (estimated as 2.5% per year), as recommended by the specification, to bring to 2010 figures. The costs are shown in Table D.7.

Type of Accident	Casualty Cost (£)	Accident Cost (£)
Fatal	1,764,367	2,021,141
Serious injury	199,462	231,715
Slight injury	15,378	23,939
Average all accidents	56,914	81,424

#### Table D.7 Costs of road accidents

# **D.6 Discount rate**

The annual discount rate assumed in all analyses is the Treasury Test Discount Rate taken from the Scottish Transport Statistics website and is 3.5%.

# **D.7 Longitudinal Profile Variance (3m)**

A conversion of IRI to 3m LPV has been adopted based on a preliminary analysis of the FILTER experiment correlating various profile measurements (Alonso, 2001). This is shown in Equation D1.

LPV =	0.2117	7 IRI1.8507	(D1)
Where	LPV	is the 3m Longitudinal Profile Variance (mm <sup>2</sup> )	
	IRI	is the International Roughness Index (m/km)	

# Appendix E Detailed annual and cumulative costs

Table E.1 to Table E.14 show the detailed annual and cumulative costs for each aspect of the analysis and for each Scenario.

# Table E.1 Undiscounted annual costs: 2010/11 to 2020/21

Itom						Year					
Item	2010/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21
Total Agency Costs (£m)											
Scenario 1: Base case	141	141	141	141	141	141	141	141	141	141	141
Scenario 2: 20% cut	114	114	114	114	114	114	114	114	114	114	114
Scenario 3: 40% cut	85	85	85	85	85	85	85	85	85	85	85
Vehicle operating costs due to su	le operating costs due to surface condition deterioration (£m)										
Scenario 1: Vehicle operating costs	4,294	4,345	4,395	4,446	4,515	4,585	4,654	4,723	4,784	4,844	4,905
Scenario 2: Vehicle operating costs	4,294	4,348	4,403	4,457	4,530	4,603	4,676	4,749	4,813	4,878	4,942
Scenario 3: Vehicle operating costs	4,294	4,351	4,407	4,464	4,539	4,615	4,690	4,766	4,833	4,900	4,967
Increase in travel time costs due	e to surface	condition	s (£m)								
Scenario 1: Travel time costs	21	21	21	22	22	22	23	23	23	24	24
Scenario 2: Travel time costs	21	22	22	23	24	25	26	27	27	28	29
Scenario 3: Travel time costs	21	22	23	24	25	26	28	29	30	31	33
Skid resistance analysis (£m)											
Scenario 1: Accident costs	23	23	23	23	23	23	23	23	23	23	23
Scenario 2: Accidents costs	23	23	23	23	23	23	23	23	23	23	23
Scenario 3: Accident costs	23	23	23	24	24	24	25	25	26	26	27
Delay costs at (carriageway) roa	dworks (£r	n)									
Scenario 1: Delay costs	9	9	9	9	9	8	8	7	7	7	7
Scenario 2: Delay costs	9	6	6	6	6	5	6	5	5	5	5
Scenario 3: Delay costs	9	5	5	5	5	4	4	4	4	4	4
Lighting analysis (£m)											
Scenario 1: Lighting accident costs	8	8	8	8	8	8	8	8	8	8	8
Scenario 2: Lighting accident costs	8	9	9	9	9	9	9	9	9	9	9
Scenario 3: Lighting accident costs	8	9	9	9	9	9	9	9	9	9	9
CO <sub>2</sub> Emissions (£m)											
Scenario 1: CO <sub>2</sub> costs	320	327	334	341	348	354	361	368	374	380	386
Scenario 2: CO <sub>2</sub> costs	320	326	333	340	346	353	359	365	371	377	383
Scenario 3: CO <sub>2</sub> costs	319	326	333	339	345	351	358	364	369	375	381

# Table E.2 Undiscounted annual costs: 2021/22 to 2030/31

Item					Yea	r				
	2021/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31
Total Agency Costs (£m)										
Scenario 1: Base case	141	141	141	141	141	141	141	141	141	141
Scenario 2: 20% cut	119	125	130	136	141	145	149	152	156	160
Scenario 3: 40% cut	97	108	119	130	141	145	149	152	156	160
Vehicle operating costs due to surface condition deterioration (£m)										
Scenario 1: Vehicle operating costs	4,960	5,015	5,070	5,125	5,180	5,241	5,302	5,363	5,425	5,486
Scenario 2: Vehicle operating costs	4,998	5,053	5,109	5,164	5,220	5,279	5,338	5,398	5,457	5,516
Scenario 3: Vehicle operating costs	5,023	5,079	5,135	5,191	5,247	5,304	5,362	5,420	5,478	5,535
Increase in travel time costs due to sur	face condition	ons (£m)								
Scenario 1: Travel time costs	24	25	25	26	26	26	27	27	28	28
Scenario 2: Travel time costs	30	30	31	32	32	33	33	33	34	34
Scenario 3: Travel time costs	33	34	35	36	37	37	37	37	38	38
Skid resistance analysis (£m)										
Scenario 1: Accident costs	23	23	23	23	23	23	23	23	23	23
Scenario 2: Accidents costs	23	23	23	23	23	23	23	23	23	23
Scenario 3: Accident costs	26	25	24	24	23	23	23	23	23	23
Delay costs at (carriageway) roadworks	s (£m)									
Scenario 1: Delay costs	7	7	7	7	7	7	7	7	7	7
Scenario 2: Delay costs	5	6	6	6	6	7	7	7	7	7
Scenario 3: Delay costs	4	5	5	6	6	7	7	7	7	7
Lighting analysis (£m)										
Scenario 1: Lighting accident costs	8	8	8	8	8	8	8	8	8	8
Scenario 2: Lighting accident costs	8	8	8	8	8	8	8	8	8	8
Scenario 3: Lighting accident costs	9	9	9	9	9	8	8	8	8	8
CO <sub>2</sub> Emissions (£m)										
Scenario 1: CO <sub>2</sub> costs	392	399	405	411	418	426	435	444	452	459
Scenario 2: CO <sub>2</sub> costs	389	395	402	408	414	423	432	440	449	456
Scenario 3: CO <sub>2</sub> costs	387	393	400	406	412	421	430	439	447	454

#### Table E.3 Undiscounted annual costs compared to Base Case: 2010/11 to 2020/21

Thom						Year					
Item	2010/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21
Total Agency Costs (£m)											
Scenario 1: Base case	0	0	0	0	0	0	0	0	0	0	0
Scenario 2: 20% cut	-28	-28	-28	-28	-28	-28	-28	-28	-28	-28	-28
Scenario 3: 40% cut	-56	-56	-56	-56	-56	-56	-56	-56	-56	-56	-56
Vehicle operating costs due to surface of	ondition de	terioratio	n (£m)								
Scenario 1: Vehicle operating costs	0	51	101	152	221	291	360	429	490	550	611
Scenario 2: Vehicle operating costs	0	54	109	163	236	309	382	455	519	584	648
Scenario 3: Vehicle operating costs	0	57	113	170	245	321	396	472	539	606	673
Increase in travel time costs due to sur	face condition	ons (£m)									
Scenario 1: Travel time costs	0	0	0	0	1	1	2	2	2	3	3
Scenario 2: Travel time costs	0	1	1	2	3	4	5	6	6	7	8
Scenario 3: Travel time costs	0	1	2	3	4	5	7	8	9	10	12
Skid resistance analysis (£m)											
Scenario 1: Accident costs	0	0	0	0	0	0	0	0	0	0	0
Scenario 2: Accidents costs	0	0	0	0	0	0	0	0	0	0	0
Scenario 3: Accident costs	0	0	1	1	1	2	2	3	3	4	4
Delay costs at (carriageway) roadworks	s (£m)										
Scenario 1: Delay costs	0	0	1	0	0	-1	-0	-1	-1	-1	-2
Scenario 2: Delay costs	0	-2	-2	-2	-2	-3	-3	-3	-4	-4	-4
Scenario 3: Delay costs	0	-4	-4	-4	-4	-5	-4	-5	-5	-5	-5
Lighting analysis (£m)											
Scenario 1: Lighting accident costs	0	0	0	0	0	0	0	0	0	0	0
Scenario 2: Lighting accident costs	0	0	0	0	0	0	0	0	0	0	0
Scenario 3: Lighting accident costs	0	0	0	0	0	0	0	0	0	0	0
CO <sub>2</sub> Emissions (£m)											
Scenario 1: CO <sub>2</sub> costs	0	7	14	21	28	34	41	48	54	60	66
Scenario 2: CO <sub>2</sub> costs	-0	6	13	20	26	32	39	45	51	57	63
Scenario 3: CO <sub>2</sub> costs	-1	6	12	19	25	31	37	44	49	55	61

#### Table E.4 Undiscounted annual costs compared to Base Case: 2021/22 to 2030/31

Thom					Yea	r				
Item	2021/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31
Total Agency Costs (£m)										
Scenario 1: Base case	0	0	0	0	0	0	0	0	0	0
Scenario 2: 20% cut	-22	-17	-11	-6	0	4	7	11	15	19
Scenario 3: 40% cut	-45	-34	-22	-11	0	4	7	11	15	19
Vehicle operating costs due to surface of	ondition det	erioratio	n (£m)							
Scenario 1: Vehicle operating costs	666	721	776	831	886	947	1,008	1,069	1,131	1,192
Scenario 2: Vehicle operating costs	704	759	815	870	926	985	1,044	1,104	1,163	1,222
Scenario 3: Vehicle operating costs	729	785	841	897	953	1,010	1,068	1,126	1,184	1,241
Increase in travel time costs due to sur	Irface conditions (£m)									
Scenario 1: Travel time costs	3	4	4	4	5	5	6	6	7	7
Scenario 2: Travel time costs	9	9	10	11	11	12	12	12	13	13
Scenario 3: Travel time costs	12	13	14	15	15	16	16	16	17	17
Skid resistance analysis (£m)										
Scenario 1: Accident costs	0	0	0	0	0	0	0	0	0	0
Scenario 2: Accidents costs	0	0	0	0	0	0	0	0	0	0
Scenario 3: Accident costs	3	3	2	1	0	0	0	0	0	0
Delay costs at (carriageway) roadworks	s (£m)									
Scenario 1: Delay costs	-1	-1	-1	-1	-2	-2	-2	-1	-1	-1
Scenario 2: Delay costs	-3	-3	-3	-2	-2	-2	-2	-2	-1	-1
Scenario 3: Delay costs	-4	-4	-3	-2	-2	-2	-2	-2	-1	-1
Lighting analysis (£m)										
Scenario 1: Lighting accident costs	0	0	0	0	0	0	0	0	0	0
Scenario 2: Lighting accident costs	0	0	0	0	0	0	0	0	0	0
Scenario 3: Lighting accident costs	0	0	0	0	0	0	0	0	0	0
CO <sub>2</sub> Emissions (£m)										
Scenario 1: CO <sub>2</sub> costs	72	79	85	91	98	106	115	123	132	139
Scenario 2: CO <sub>2</sub> costs	69	75	82	88	94	103	112	120	129	136
Scenario 3: CO <sub>2</sub> costs	67	73	80	86	92	101	110	118	127	134

# Table E.5 Cumulative undiscounted costs: 2010/11 to 2020/21

Itom						Year					
	2010/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21
Total Agency Costs (£m)											
Scenario 1: Base case	141	283	424	566	707	849	990	1,132	1,273	1,414	1,556
Scenario 2: 20% cut	114	228	341	455	569	683	797	910	1,024	1,138	1,252
Scenario 3: 40% cut	85	171	256	341	427	512	597	683	768	854	939
Vehicle operating costs due to surface of	ondition det	erioratio	n (£m)								
Scenario 1: Vehicle operating costs	4,294	8,639	13,034	17,480	21,996	26,580	31,234	35,958	40,742	45,586	50,491
Scenario 2: Vehicle operating costs	4,294	8,642	13,045	17,502	22,032	26,635	31,311	36,060	40,873	45,751	50,693
Scenario 3: Vehicle operating costs	4,294	8,645	13,052	17,516	22,056	26,671	31,361	36,127	40,960	45,860	50,827
Increase in travel time costs due to sur	face condition	ons (£m)									
Scenario 1: Travel time costs	21	42	64	85	107	129	152	175	199	222	246
Scenario 2: Travel time costs	21	43	65	88	112	137	162	189	216	245	274
Scenario 3: Travel time costs	21	43	66	90	115	141	169	198	228	259	292
Skid resistance analysis (£m)											
Scenario 1: Accident costs	23	45	68	91	113	136	159	181	204	227	249
Scenario 2: Accidents costs	23	45	68	91	113	136	159	181	204	227	249
Scenario 3: Accident costs	23	46	69	92	116	141	165	191	216	243	270
Delay costs at (carriageway) roadworks	s (£m)										
Scenario 1: Delay costs	9	17	26	35	44	52	60	68	75	82	89
Scenario 2: Delay costs	9	15	21	27	34	39	45	50	55	60	65
Scenario 3: Delay costs	9	13	18	23	28	32	37	41	44	48	52
Lighting analysis (£m)											
Scenario 1: Lighting accident costs	8	17	25	34	42	50	59	67	76	84	93
Scenario 2: Lighting accident costs	8	17	25	34	42	51	59	68	76	85	93
Scenario 3: Lighting accident costs	8	17	26	34	43	51	60	69	77	86	94
CO <sub>2</sub> Emissions (£m)											
Scenario 1: CO <sub>2</sub> costs	320	647	981	1,322	1,670	2,025	2,386	2,753	3,127	3,507	3,893
Scenario 2: CO <sub>2</sub> costs	320	646	979	1,319	1,665	2,018	2,377	2,742	3,113	3,490	3,873
Scenario 3: CO <sub>2</sub> costs	319	646	978	1,317	1,662	2,014	2,371	2,735	3,104	3,479	3,860

#### Table E.6 Cumulative undiscounted costs: 2021/22 to 2030/31

Item					Yea	r				
	2021/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31
Total Agency Costs (£m)										
Scenario 1: Base case	1,697	1,839	1,980	2,122	2,263	2,405	2,546	2,687	2,829	2,970
Scenario 2: 20% cut	1,371	1,496	1,626	1,762	1,904	2,049	2,197	2,350	2,506	2,666
Scenario 3: 40% cut	1,035	1,143	1,262	1,392	1,534	1,679	1,828	1,980	2,136	2,296
Vehicle operating costs due to surface of	ondition det	terioratio	n (£m)							
Scenario 1: Vehicle operating costs	55,451	60,466	65,536	70,661	75,842	81,083	86,385	91,749	97,173	102,659
Scenario 2: Vehicle operating costs	55,691	60,744	65,853	71,017	76,237	81,517	86,855	92,253	97,710	103,226
Scenario 3: Vehicle operating costs	55,851	60,930	66,065	71,255	76,502	81,806	87,169	92,588	98,066	103,602
Increase in travel time costs due to sur	face condition	ons (£m)								
Scenario 1: Travel time costs	271	296	321	346	372	399	425	453	481	509
Scenario 2: Travel time costs	304	334	366	397	430	462	495	528	562	596
Scenario 3: Travel time costs	326	360	395	430	467	504	541	578	616	654
Skid resistance analysis (£m)										
Scenario 1: Accident costs	272	295	317	340	363	385	408	431	453	476
Scenario 2: Accidents costs	272	295	317	340	363	385	408	431	453	476
Scenario 3: Accident costs	296	321	345	369	391	414	437	460	482	505
Delay costs at (carriageway) roadworks	5 (£m)									
Scenario 1: Delay costs	97	104	111	119	126	133	140	147	154	162
Scenario 2: Delay costs	71	76	82	89	95	102	108	115	122	130
Scenario 3: Delay costs	56	61	66	73	79	86	92	99	106	114
Lighting analysis (£m)										
Scenario 1: Lighting accident costs	101	109	118	126	135	143	151	160	168	177
Scenario 2: Lighting accident costs	102	110	119	127	136	144	153	161	170	178
Scenario 3: Lighting accident costs	103	112	120	129	137	146	154	163	171	179
CO <sub>2</sub> Emissions (£m)										
Scenario 1: CO <sub>2</sub> costs	4,286	4,685	5,090	5,501	5,919	6,345	6,780	7,224	7,676	8,135
Scenario 2: CO <sub>2</sub> costs	4,262	4,657	5,059	5,467	5,881	6,304	6,736	7,176	7,625	8,081
Scenario 3: CO <sub>2</sub> costs	4,247	4,640	5,040	5,446	5,858	6,279	6,709	7,148	7,595	8,050

# Table E.7 Discounted annual costs: 2010/11 to 2020/21

Item						Year					
Atem	2010/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21
Total Agency Costs (£m)											
Scenario 1: Base case	141	137	132	128	123	119	115	111	107	104	100
Scenario 2: 20% cut	114	110	106	103	99	96	93	89	86	84	81
Scenario 3: 40% cut	85	82	80	77	74	72	69	67	65	63	61
Vehicle operating costs due to su	urface cond	ition det	erioratio	n (£m)							
Scenario 1: Vehicle operating costs	4,294	4,198	4,103	4,010	3,935	3,860	3,786	3,712	3,633	3,555	3,477
Scenario 2: Vehicle operating costs	4,294	4,201	4,110	4,020	3,948	3,876	3,804	3,733	3,655	3,579	3,504
Scenario 3: Vehicle operating costs	4,294	4,204	4,114	4,026	3,956	3,886	3,816	3,746	3,670	3,595	3,521
Increase in travel time costs due	e to surface	conditio	ns (£m)								
Scenario 1: Travel time costs	21	21	20	19	19	19	18	18	18	17	17
Scenario 2: Travel time costs	21	21	21	21	21	21	21	21	21	21	21
Scenario 3: Travel time costs	21	21	21	22	22	22	22	23	23	23	23
Skid resistance analysis (£m)											
Scenario 1: Accident costs	23	22	21	20	20	19	18	18	17	17	16
Scenario 2: Accidents costs	23	22	21	20	20	19	18	18	17	17	16
Scenario 3: Accident costs	23	22	22	21	21	20	20	20	20	19	19
Delay costs at (carriageway) roa	dworks (£ı	n)									
Scenario 1: Delay costs	9	8	9	8	8	6	7	6	5	5	5
Scenario 2: Delay costs	9	6	6	6	5	5	5	4	4	4	3
Scenario 3: Delay costs	9	5	5	4	4	3	4	3	3	3	3
Lighting analysis (£m)											
Scenario 1: Lighting accident costs	8	8	8	8	7	7	7	7	6	6	6
Scenario 2: Lighting accident costs	8	8	8	8	7	7	7	7	6	6	6
Scenario 3: Lighting accident costs	8	8	8	8	8	7	7	7	7	6	6
CO <sub>2</sub> Emissions (£m)											
Scenario 1: CO <sub>2</sub> costs	320	316	312	308	303	298	294	289	284	279	274
Scenario 2: CO <sub>2</sub> costs	320	315	311	307	302	297	292	287	282	276	271
Scenario 3: CO <sub>2</sub> costs	319	315	310	306	301	296	291	286	280	275	270

#### Table E.8 Discounted annual costs: 2021/22 to 2030/31

Item					Yea	r				
	2021/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31
Total Agency Costs (£m)										
Scenario 1: Base case	97	94	90	87	84	82	79	76	74	71
Scenario 2: 20% cut	82	83	83	84	84	84	83	82	81	80
Scenario 3: 40% cut	66	71	76	80	84	84	83	82	81	80
Vehicle operating costs due to surface of	ce condition deterioration (£m)									
Scenario 1: Vehicle operating costs	3,397	3,319	3,242	3,166	3,092	3,023	2,955	2,887	2,822	2,757
Scenario 2: Vehicle operating costs	3,423	3,344	3,267	3,190	3,116	3,045	2,975	2,906	2,839	2,772
Scenario 3: Vehicle operating costs	3,441	3,361	3,283	3,207	3,132	3,059	2,988	2,918	2,849	2,782
Increase in travel time costs due to sur	face condition	ons (£m)								
Scenario 1: Travel time costs	17	16	16	16	15	15	15	15	14	14
Scenario 2: Travel time costs	20	20	20	20	19	19	18	18	18	17
Scenario 3: Travel time costs	23	23	22	22	22	21	21	20	20	19
Skid resistance analysis (£m)										
Scenario 1: Accident costs	16	15	14	14	14	13	13	12	12	11
Scenario 2: Accidents costs	16	15	14	14	14	13	13	12	12	11
Scenario 3: Accident costs	18	17	16	15	14	13	13	12	12	11
Delay costs at (carriageway) roadworks	s (£m)									
Scenario 1: Delay costs	5	5	5	5	4	4	4	4	4	4
Scenario 2: Delay costs	4	4	4	4	4	4	4	4	4	4
Scenario 3: Delay costs	3	3	3	4	4	4	4	4	4	4
Lighting analysis (£m)										
Scenario 1: Lighting accident costs	6	6	5	5	5	5	5	5	4	4
Scenario 2: Lighting accident costs	6	6	5	5	5	5	5	5	4	4
Scenario 3: Lighting accident costs	6	6	5	5	5	5	5	5	4	4
CO <sub>2</sub> Emissions (£m)										
Scenario 1: CO <sub>2</sub> costs	269	264	259	254	249	246	242	239	235	231
Scenario 2: CO <sub>2</sub> costs	266	262	257	252	247	244	241	237	234	229
Scenario 3: CO <sub>2</sub> costs	265	260	256	251	246	243	240	236	233	228

#### Table E.9 Discounted annual costs compared to Base Case: 2010/11 to 2020/21

Item						Year					
Atem	2010/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21
Total Agency Costs (£m)											
Scenario 1: Base case	0	-5	-9	-14	-18	-22	-26	-30	-34	-38	-41
Scenario 2: 20% cut	-28	-31	-35	-39	-42	-46	-49	-52	-55	-58	-61
Scenario 3: 40% cut	-56	-59	-62	-64	-67	-70	-72	-74	-77	-79	-81
Vehicle operating costs due to su	urface cond	ition det	erioratio	n (£m)							
Scenario 1: Vehicle operating costs	0	-96	-191	-284	-359	-434	-508	-582	-661	-740	-817
Scenario 2: Vehicle operating costs	0	-93	-184	-274	-346	-419	-490	-561	-639	-715	-790
Scenario 3: Vehicle operating costs	0	-90	-180	-268	-338	-408	-478	-548	-624	-699	-773
Increase in travel time costs due	e to surface	conditio	ns (£m)								
Scenario 1: Travel time costs	0	-1	-1	-2	-2	-2	-3	-3	-3	-4	-4
Scenario 2: Travel time costs	0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
Scenario 3: Travel time costs	0	0	0	0	1	1	1	2	2	2	2
Skid resistance analysis (£m)											
Scenario 1: Accident costs	0	-1	-2	-2	-3	-4	-4	-5	-5	-6	-7
Scenario 2: Accidents costs	0	-1	-2	-2	-3	-4	-4	-5	-5	-6	-7
Scenario 3: Accident costs	0	-1	-1	-1	-2	-2	-3	-3	-3	-3	-4
Delay costs at (carriageway) roa	dworks (£ı	n)									
Scenario 1: Delay costs	0	-0	-0	-0	-1	-2	-2	-3	-3	-3	-4
Scenario 2: Delay costs	0	-3	-3	-3	-3	-4	-4	-5	-5	-5	-5
Scenario 3: Delay costs	0	-4	-4	-4	-4	-5	-5	-6	-6	-6	-6
Lighting analysis (£m)											
Scenario 1: Lighting accident costs	0	-0	-1	-1	-1	-1	-2	-2	-2	-2	-2
Scenario 2: Lighting accident costs	0	-0	-0	-1	-1	-1	-1	-2	-2	-2	-2
Scenario 3: Lighting accident costs	0	-0	-0	-1	-1	-1	-1	-2	-2	-2	-2
CO <sub>2</sub> Emissions (£m)											
Scenario 1: CO <sub>2</sub> costs	0	-4	-8	-13	-17	-22	-26	-31	-36	-41	-46
Scenario 2: CO <sub>2</sub> costs	-0	-5	-9	-14	-18	-23	-28	-33	-38	-44	-49
Scenario 3: CO <sub>2</sub> costs	-1	-5	-10	-14	-19	-24	-29	-34	-40	-45	-50

#### Table E.10 Discounted annual costs compared to Base Case: 2021/22 to 2030/31

Item					Yea	r				
	2021/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31
Total Agency Costs (£m)										
Scenario 1: Base case	-45	-48	-51	-54	-57	-60	-63	-65	-68	-70
Scenario 2: 20% cut	-60	-59	-58	-57	-57	-58	-59	-59	-60	-61
Scenario 3: 40% cut	-75	-70	-65	-61	-57	-58	-59	-59	-60	-61
Vehicle operating costs due to surface of	ondition det	terioratio	n (£m)							
Scenario 1: Vehicle operating costs	-897	-975	-1,052	-1,128	-1,202	-1,271	-1,340	-1,407	-1,472	-1,537
Scenario 2: Vehicle operating costs	-871	-950	-1,027	-1,104	-1,178	-1,250	-1,319	-1,388	-1,456	-1,522
Scenario 3: Vehicle operating costs	-853	-933	-1,011	-1,087	-1,162	-1,235	-1,306	-1,376	-1,445	-1,512
Increase in travel time costs due to sur	face condition	ons (£m)								
Scenario 1: Travel time costs	-4	-5	-5	-5	-6	-6	-6	-6	-7	-7
Scenario 2: Travel time costs	-1	-1	-1	-1	-2	-2	-3	-3	-4	-4
Scenario 3: Travel time costs	2	2	1	1	1	0	-0	-1	-1	-2
Skid resistance analysis (£m)										
Scenario 1: Accident costs	-7	-8	-8	-9	-9	-10	-10	-10	-11	-11
Scenario 2: Accidents costs	-7	-8	-8	-9	-9	-10	-10	-10	-11	-11
Scenario 3: Accident costs	-5	-6	-7	-8	-9	-10	-10	-10	-11	-11
Delay costs at (carriageway) roadworks	s (£m)									
Scenario 1: Delay costs	-4	-4	-4	-4	-4	-5	-5	-5	-5	-5
Scenario 2: Delay costs	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Scenario 3: Delay costs	-6	-5	-5	-5	-5	-5	-5	-5	-5	-5
Lighting analysis (£m)										
Scenario 1: Lighting accident costs	-3	-3	-3	-3	-3	-4	-4	-4	-4	-4
Scenario 2: Lighting accident costs	-3	-3	-3	-3	-3	-4	-4	-4	-4	-4
Scenario 3: Lighting accident costs	-3	-3	-3	-3	-3	-4	-4	-4	-4	-4
CO <sub>2</sub> Emissions (£m)										
Scenario 1: CO <sub>2</sub> costs	-51	-56	-61	-66	-71	-74	-78	-81	-85	-89
Scenario 2: CO <sub>2</sub> costs	-54	-59	-63	-68	-73	-76	-80	-83	-87	-91
Scenario 3: CO <sub>2</sub> costs	-55	-60	-65	-69	-74	-77	-81	-84	-87	-92

# Table E.11 Cumulative discounted costs: 2010/11 to 2020/21

Item						Year					
	2010/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21
Total Agency Costs (£m)											
Scenario 1: Base case	141	278	410	538	661	780	895	1,006	1,114	1,217	1,318
Scenario 2: 20% cut	114	224	330	433	532	628	720	810	896	980	1,060
Scenario 3: 40% cut	85	168	247	324	399	471	540	607	672	735	795
Vehicle operating costs due to surface of	condition de	eterioratio	on (£m)								
Scenario 1: Vehicle operating costs	4,294	8,492	12,595	16,605	20,540	24,400	28,186	31,899	35,532	39,086	42,563
Scenario 2: Vehicle operating costs	4,294	8,495	12,605	16,625	20,573	24,448	28,252	31,985	35,640	39,219	42,723
Scenario 3: Vehicle operating costs	4,294	8,498	12,612	16,638	20,594	24,480	28,296	32,041	35,712	39,307	42,829
Increase in travel time costs due to sur	face conditi	ions (£m)									
Scenario 1: Travel time costs	21	42	62	81	100	119	137	155	173	191	208
Scenario 2: Travel time costs	21	42	63	84	104	125	146	167	188	209	229
Scenario 3: Travel time costs	21	42	64	85	107	129	152	174	197	220	244
Skid resistance analysis (£m)											
Scenario 1: Accident costs	23	45	66	86	106	125	143	161	179	195	211
Scenario 2: Accidents costs	23	45	66	86	106	125	143	161	179	195	211
Scenario 3: Accident costs	23	45	67	88	109	129	149	169	189	208	227
Delay costs at (carriageway) roadworks	s (£m)										
Scenario 1: Delay costs	9	17	26	34	42	48	55	61	66	71	76
Scenario 2: Delay costs	9	15	21	26	32	36	41	45	49	53	56
Scenario 3: Delay costs	9	13	18	22	27	30	34	37	39	42	45
Lighting analysis (£m)											
Scenario 1: Lighting accident costs	8	17	24	32	39	46	53	60	66	72	78
Scenario 2: Lighting accident costs	8	17	25	32	40	47	54	60	67	73	79
Scenario 3: Lighting accident costs	8	17	25	33	40	47	54	61	68	74	80
CO <sub>2</sub> Emissions (£m)											
Scenario 1: CO <sub>2</sub> costs	320	636	948	1,256	1,559	1,857	2,151	2,440	2,724	3,003	3,276
Scenario 2: CO <sub>2</sub> costs	320	635	946	1,253	1,554	1,851	2,143	2,430	2,712	2,989	3,260
Scenario 3: CO <sub>2</sub> costs	319	634	945	1,251	1,552	1,847	2,138	2,424	2,705	2,980	3,250

# Table E.12 Cumulative discounted costs: 2021/22 to 2030/31

Item					Yea	r				
	2021/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31
Total Agency Costs (£m)										
Scenario 1: Base case	1,415	1,508	1,599	1,686	1,770	1,852	1,931	2,007	2,081	2,152
Scenario 2: 20% cut	1,142	1,225	1,308	1,392	1,476	1,560	1,643	1,725	1,806	1,886
Scenario 3: 40% cut	861	933	1,009	1,089	1,174	1,257	1,340	1,422	1,503	1,584
Vehicle operating costs due to surface of	ondition det	terioratio	n (£m)							
Scenario 1: Vehicle operating costs	45,961	49,280	52,522	55,688	58,780	61,803	64,757	67,645	70,466	73,223
Scenario 2: Vehicle operating costs	46,146	49,490	52,757	55,947	59,063	62,107	65,082	67,988	70,827	73,599
Scenario 3: Vehicle operating costs	46,269	49,630	52,914	56,120	59,252	62,311	65,299	68,217	71,066	73,848
Increase in travel time costs due to sur	face condition	ons (£m)								
Scenario 1: Travel time costs	224	241	257	273	288	303	318	333	347	362
Scenario 2: Travel time costs	250	270	290	310	329	348	366	384	401	419
Scenario 3: Travel time costs	267	289	312	334	355	377	397	417	437	456
Skid resistance analysis (£m)										
Scenario 1: Accident costs	227	242	256	270	284	297	310	322	334	345
Scenario 2: Accidents costs	227	242	256	270	284	297	310	322	334	345
Scenario 3: Accident costs	245	262	277	292	305	318	331	343	355	366
Delay costs at (carriageway) roadworks	5 (£m)									
Scenario 1: Delay costs	81	86	91	95	100	104	107	111	115	119
Scenario 2: Delay costs	60	64	67	71	75	79	83	86	90	94
Scenario 3: Delay costs	48	51	55	58	62	66	70	73	77	81
Lighting analysis (£m)										
Scenario 1: Lighting accident costs	84	90	95	100	105	110	115	119	124	128
Scenario 2: Lighting accident costs	85	91	96	101	106	111	116	120	125	129
Scenario 3: Lighting accident costs	86	92	97	102	107	112	117	122	126	130
CO <sub>2</sub> Emissions (£m)										
Scenario 1: CO <sub>2</sub> costs	3,545	3,809	4,068	4,322	4,572	4,817	5,060	5,299	5,534	5,765
Scenario 2: CO <sub>2</sub> costs	3,526	3,788	4,045	4,297	4,544	4,788	5,029	5,266	5,499	5,729
Scenario 3: CO <sub>2</sub> costs	3,515	3,775	4,031	4,281	4,528	4,770	5,010	5,246	5,479	5,707

Impacts of Maintenance on the Trunk Road Network in Scotland

Vear	Total Road User and	l Impact Costs (anal (£m)	ysed in this study)	Total Transport Co analysed ro	ost (Cumulative) - Su ad user and impact o	um of agency and costs (£m)
rear	Scenario 1: Base case	Scenario 2: 20% cut	Scenario 3: 40% cut	Scenario 1: Base case	Scenario 2: 20% cut	Scenario 3: 40% cut
2010/11	4,675	4,675	4,674	4,816	4,788	4,760
2011/12	9,408	9,409	9,409	9,691	9,636	9,580
2012/13	14,199	14,204	14,209	14,623	14,546	14,465
2013/14	19,048	19,061	19,073	19,614	19,517	19,415
2014/15	23,973	23,999	24,020	24,680	24,568	24,447
2015/16	28,973	29,016	29,050	29,822	29,699	29,562
2016/17	34,050	34,113	34,163	35,040	34,910	34,761
2017/18	39,203	39,290	39,360	40,334	40,201	40,042
2018/19	44,422	44,538	44,630	45,695	45,563	45,398
2019/20	49,709	49,858	49,975	51,123	50,996	50,829
2020/21	55,062	55,248	55,395	56,618	56,500	56,334
2021/22	60,477	60,701	60,878	62,175	62,072	61,913
2022/23	65,954	66,217	66,423	67,793	67,713	67,566
2023/24	71,493	71,796	72,031	73,473	73,422	73,293
2024/25	77,094	77,438	77,702	79,215	79,200	79,094
2025/26	82,756	83,142	83,435	85,019	85,045	84,969
2026/27	88,488	88,914	89,235	90,892	90,963	90,914
2027/28	94,290	94,755	95,102	96,836	96,952	96,929
2028/29	100,163	100,665	101,036	102,850	103,014	103,016
2029/30	106,106	106,643	107,037	108,935	109,148	109,173
2030/31	112,117	112,687	113,103	115,088	115,353	115,399

#### Table E.13 Cumulative undiscounted total costs

Voor	Total Road User and	l Impact Costs (anal (£m)	ysed in this study)	Total Transport Co analysed ro	est (Cumulative) - Su ad user and impact o	im of agency and costs (£m)
ICal	Scenario 1: Base case	Scenario 2: 20% cut	Scenario 3: 40% cut	Scenario 1: Base case	Scenario 2: 20% cut	Scenario 3: 40% cut
2010/11	4,675	4,675	4,674	4,816	4,788	4,760
2011/12	9,248	9,248	9,249	9,526	9,472	9,417
2012/13	13,720	13,725	13,730	14,131	14,055	13,977
2013/14	18,094	18,106	18,117	18,631	18,539	18,441
2014/15	22,386	22,409	22,428	23,047	22,941	22,827
2015/16	26,596	26,633	26,663	27,376	27,261	27,134
2016/17	30,726	30,780	30,823	31,621	31,500	31,363
2017/18	34,776	34,849	34,907	35,782	35,659	35,514
2018/19	38,740	38,834	38,909	39,853	39,730	39,581
2019/20	42,619	42,737	42,831	43,836	43,717	43,566
2020/21	46,414	46,559	46,673	47,731	47,619	47,469
2021/22	50,123	50,294	50,429	51,537	51,436	51,290
2022/23	53,747	53,944	54,099	55,256	55,169	55,031
2023/24	57,289	57,511	57,684	58,887	58,819	58,693
2024/25	60,749	60,996	61,188	62,435	62,388	62,277
2025/26	64,128	64,401	64,610	65,899	65,878	65,783
2026/27	67,434	67,730	67,955	69,286	69,290	69,212
2027/28	70,667	70,985	71,224	72,598	72,628	72,564
2028/29	73,829	74,166	74,418	75,836	75,891	75,840
2029/30	76,920	77,276	77,540	79,001	79,082	79,043
2030/31	79,941	80,314	80,588	82,093	82,200	82,172

#### Table E.14 Cumulative discounted total costs

# **Appendix F** Increase in travel time costs

Table F.1, Table F.2 and Table F.3 show the increases in travel time and the associated costs for Scenario 1, 2 and 3 respectively.

Year	Road		Incre	ease in tra	avel time (		Increase in travel time cost (£m)							
rear	Туре	Car	LGV	PSV	OGV1	OGV2	Total	Car	LGV	PSV	OGV1	OGV2	Total	
2010	Motorway	514532	82263	14342	23957	109123	744218	4.46	0.79	0.85	0.20	0.92	7.22	
2010	Dual	502486	63903	11149	22648	103273	703459	4.36	0.61	0.66	0.19	0.87	6.69	
2010	Single	545127	65329	12080	23191	105709	751435	4.73	0.63	0.71	0.20	0.89	7.15	
2013	Motorway	461997	75735	12629	22214	101175	673751	4.12	0.75	0.77	0.19	0.88	6.71	
2013	Dual	499146	65090	10862	23234	105953	704285	4.45	0.65	0.66	0.20	0.92	6.88	
2013	Single	586736	72119	12753	25787	117579	814974	5.23	0.72	0.77	0.22	1.02	7.96	
2017	Motorway	392261	66846	10519	19774	90036	579435	3.75	0.72	0.68	0.19	0.85	6.19	
2017	Dual	493071	66846	10525	24064	109728	704234	4.71	0.72	0.68	0.23	1.04	7.38	
2017	Single	644839	82426	13752	29727	135581	906326	6.16	0.89	0.89	0.28	1.28	9.51	
2020	Motorway	338082	59682	9028	17748	80781	505322	3.37	0.68	0.61	0.18	0.80	5.63	
2020	Dual	486117	68275	10333	24707	112651	702083	4.84	0.77	0.70	0.25	1.12	7.68	
2020	Single	687986	91123	14612	33038	150704	977464	6.85	1.03	0.99	0.33	1.50	10.70	
2025	Motorway	323679	61021	8728	18328	83394	495150	3.45	0.75	0.63	0.20	0.90	5.93	
2025	Dual	431783	64750	9266	23663	107839	637300	4.60	0.79	0.67	0.26	1.17	7.49	
2025	Single	733128	103712	15723	37980	173244	1063787	7.82	1.27	1.14	0.41	1.87	12.51	
2030	Motorway	310502	62251	8527	18912	86018	486211	3.55	0.83	0.66	0.22	1.01	6.27	
2030	Dual	371321	59192	8113	21876	99618	560120	4.24	0.79	0.63	0.26	1.17	7.08	
2030	Single	794210	119500	17347	44266	201910	1177233	9.07	1.59	1.34	0.52	2.37	14.89	

 Table F.1 Increase in travel time and associated costs for Scenario 1

Voor	Road		Incr	ease in tra	vel time (	Increase in travel time cost (£m)							
fedr	Туре	Car	LGV	PSV	OGV1	OGV2	Total	Car	LGV	PSV	OGV1	OGV2	Total
2010	Motorway	514532	82263	14342	23957	109123	744218	4.46	0.79	0.85	0.20	0.92	7.22
2010	Dual	502486	63903	11149	22648	103273	703459	4.36	0.61	0.66	0.19	0.87	6.69
2010	Single	545127	65329	12080	23191	105709	751435	4.73	0.63	0.71	0.20	0.89	7.15
2013	Motorway	507505	83199	13873	24403	111163	740144	4.52	0.83	0.84	0.21	0.97	7.37
2013	Dual	530923	69244	11554	24718	112744	749183	4.73	0.69	0.70	0.22	0.98	7.31
2013	Single	609286	74903	13245	26784	122147	846365	5.43	0.74	0.80	0.23	1.06	8.27
2017	Motorway	496368	84601	13311	25026	113996	733301	4.74	0.91	0.87	0.24	1.08	7.84
2017	Dual	564548	76562	12053	27566	125754	806482	5.39	0.82	0.78	0.26	1.19	8.45
2017	Single	699580	89455	14923	32266	147221	983444	6.68	0.96	0.97	0.31	1.39	10.32
2020	Motorway	486221	85858	12984	25533	116294	726890	4.84	0.97	0.88	0.25	1.16	8.10
2020	Dual	584616	82146	12430	29734	135652	844577	5.82	0.93	0.84	0.30	1.35	9.24
2020	Single	766012	101505	16275	36810	167995	1088596	7.63	1.15	1.10	0.37	1.67	11.91
2025	Motorway	409898	77296	11053	23216	105703	627167	4.37	0.95	0.80	0.25	1.14	7.51
2025	Dual	587528	88174	12613	32235	147060	867611	6.26	1.08	0.91	0.35	1.59	10.20
2025	Single	854952	121027	18344	44332	202372	1241027	9.12	1.48	1.33	0.48	2.19	14.60
2030	Motorway	287365	57613	7892	17503	79608	449980	3.28	0.77	0.61	0.21	0.93	5.80
2030	Dual	562857	89833	12305	33218	151511	849724	6.43	1.19	0.95	0.39	1.78	10.74
2030	Single	929556	139967	20312	51862	236752	1378448	10.62	1.86	1.57	0.61	2.78	17.44

 Table F.2 Increase in travel time and associated costs for Scenario 2

Voor	Road		Incre	ase in tra	vel time (	h)		Increase in travel time cost (£m)							
rear	Туре	Car	LGV	PSV	OGV1	OGV2	Total	Car	LGV	PSV	OGV1	OGV2	Total		
2010	Motorway	514532	82263	14342	23957	109123	744218	4.46	0.79	0.85	0.20	0.92	7.22		
2010	Dual	502486	63903	11149	22648	103273	703459	4.36	0.61	0.66	0.19	0.87	6.69		
2010	Single	545127	65329	12080	23191	105709	751435	4.73	0.63	0.71	0.20	0.89	7.15		
2013	Motorway	539275	88411	14742	25932	118136	786496	4.80	0.88	0.90	0.23	1.03	7.83		
2013	Dual	549861	71718	11966	25602	116782	775928	4.90	0.71	0.73	0.22	1.02	7.58		
2013	Single	621544	76415	13512	27325	124625	863421	5.54	0.76	0.82	0.24	1.08	8.44		
2017	Motorway	569085	97003	15261	28695	130731	840775	5.44	1.05	0.99	0.27	1.24	8.98		
2017	Dual	609630	82684	13016	29771	135834	870936	5.82	0.89	0.85	0.28	1.29	9.13		
2017	Single	729755	93325	15568	33663	153618	1025929	6.97	1.01	1.01	0.32	1.45	10.76		
2020	Motorway	590026	104200	15757	30988	141178	882148	5.87	1.18	1.07	0.31	1.40	9.83		
2020	Dual	649509	91277	13810	33041	150768	938405	6.47	1.03	0.93	0.33	1.50	10.26		
2020	Single	810321	107393	17218	38947	177781	1151660	8.07	1.21	1.17	0.39	1.77	12.60		
2025	Motorway	483167	91126	13029	27371	124660	739353	5.15	1.12	0.94	0.30	1.35	8.86		
2025	Dual	666079	99982	14301	36555	166808	983725	7.10	1.23	1.04	0.40	1.80	11.56		
2025	Single	943557	133604	20248	48944	223487	1369840	10.06	1.64	1.47	0.53	2.42	16.11		
2030	Motorway	270907	54313	7440	16501	75050	424210	3.09	0.72	0.58	0.19	0.88	5.47		
2030	Dual	640098	102185	13996	37790	172418	966486	7.31	1.36	1.08	0.44	2.02	12.22		
2030	Single	1078571	162465	23574	60207	274961	1599779	12.32	2.16	1.82	0.71	3.23	20.24		

Table F.3 Increase in travel time and associated costs for Scenario 3

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