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Creating the future of transport

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Valuing the Benefits of Road Maintenance

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Contents

List of figures

List of tables

Executive Summary

Introduction

This report describes the output and results from a study for the Department for Transport (DfT) carried out by TRL Ltd and CH2M Hill to improve the evidence base for valuing the benefits of highways maintenance spending on local roads in England (excluding London). The purpose of the study was to demonstrate how the condition of the local road network evolves over time under different spending trajectories and how this impacts both maintenance and costs to road users and society.

The study included the principal quantifiable impacts of road maintenance on road users in a new model, the Highways Maintenance Appraisal Tool (HMAT). The model predicts the quantifiable impacts of levels of road maintenance. It is recognised that there are constraints, due to existing knowledge, with regard to how far some impacts may be quantified. Within the current study, the aim has been to identify all quantifiable impacts, whilst acknowledging that some impacts can only be described qualitatively, resulting in the following relationships and impacts being covered:

- Carriageway condition, traffic growth and vehicle speed, to derive user time and vehicle operating cost impacts.
- Maintenance treatments and traffic growth, to derive the embodied carbon, user time and accident impacts.
- Maintenance treatments, to derive the job impacts.
- Allocated budgets, to derive the accident impacts.

The model allows assessment of the quantifiable costs and benefits of different levels of road maintenance funding. It is established within a framework which allows consideration of the impacts of road maintenance, and is designed to be applied both at the national level and with smaller (e.g. a single Local Authority) networks.

Principles of model development

There were four key requirements for the model development:

- The model was required to work with data 'that is available now'.
- The study was commissioned on the basis that literature reviews conducted in earlier studies had identified all other relevant studies
- It was recognised that not all effects can be quantified but within the project, the aim was to enable users of the model to consider all potential impacts, both qualitative and quantitative. Those impacts which could be quantified have been modelled and it has been considered reasonable to assume that the dominant quantifiable effects will be due to changes in carriageway conditions.
- The model must be flexible and easy to use by a range of users, particularly Local Authorities. To meet this requirement a spreadsheet approach was adopted.

Key assumptions made in order to deliver a working model have been collated and presented in the report.

Model approach

The model has been designed in accordance with the latest Department for Transport Transport Appraisal Guidance (WebTAG) and allows for ease of update to incorporate changes to such data.

To be consistent with the latest developments for local roads in England, the carriageway analysis in the Highways Maintenance Efficiency Programme (HMEP) Lifecycle Planning

Toolkit was selected for the prediction of conditions and maintenance need and has been adopted unchanged in HMAT.

Model framework and analysis modules
HMAT is a Microsoft Excel workbook and adopts a modular design to aid future updating of specific aspects in the model when they become available. The function of each of the modules within the tool is described in the report. The Aggregated Outputs Module is a separate Microsoft Excel workbook which collates results from analyses to aid the comparison of outcomes from analyses.

As part of the model development, analyses of data provided from Local Authority road networks was used to quality check the results from example analyses. Separate stand alone developments of each impact model were created to check the results for each impact in the HMAT model using data from Local Authority road networks.

Outputs from the analysis for the national network
Various analyses, including sensitivity tests, have been carried out to demonstrate and provide assurance in the model behaviour. The analyses carried out included:

- Constant budget
- Increased and decreased maintenance budgets
- Steady state network condition
- Changes in the input data to test the sensitivity of the model

The results from the analyses have shown that HMAT is a tool that is capable of examining the direct and indirect costs associated with road maintenance and the behaviour of the model is consistent with expectations although the effort required to build a robust set of input data should not be underestimated. Nevertheless, the results of the analyses have already shown there are potential savings from reduced indirect costs by increasing the direct maintenance spend above the current budget limits.

An earlier study of road maintenance funding in Scotland concluded from a range of analyses of maintenance funding that "for every £1 reduction in road maintenance, there is a cost of £1.50 to the wider economy", based on the ratio of reduction in benefits to reductions in expenditure.

The aim of this study was not to establish the levels of benefits provided by road maintenance but to provide a tool to enable that analysis to be undertaken and to show, with the best data available, what the size of those benefits may be. In this study, the resulting BCRs from base case analyses of example increases and decreases in maintenance funding and an analysis to achieve a specified target condition for the network showed a saving of between £2.70 and £4.30 for every £1.00 increase in direct maintenance costs (using discounted costs). The sensitivity analyses undertaken, produced a range of the BCRs between £2.20 and £7.00. These findings reinforced the conclusions from the earlier studies (e.g. for Transport Scotland) by demonstrating some higher value for money outcomes when using the national dataset for local roads in England (excluding London).

1 Introduction

The Department for Transport (DfT) has commissioned TRL Ltd and CH2M Hill to undertake a project to improve the evidence base for valuing the benefits of highways maintenance spending on local roads in England (excluding London).

The aim of the project was to demonstrate how the condition of the local road network evolves over time under different spending trajectories and how this affects both maintenance and the costs to road users and society. Outputs from the research enable the overall value for money (such as a Net Present Value or Benefit Cost Ratio) of different levels of funding to be estimated.

The project has produced the Highways Maintenance Appraisal Tool (HMAT) which predicts the quantifiable impacts of levels of road maintenance. It is recognised that there are constraints, due to existing knowledge, with regard to how far some impacts may be quantified. Within the project, the aim has been to identify the quantifiable impacts.

Some impacts can only be described qualitatively. An aim of the study has been to ensure that users of the model remain aware that qualitative impacts are important, need to be described and must be considered when assessing the overall impacts of road maintenance.

The project considered the national local road network (excluding London) but the model is suitable for use with smaller (e.g. a single Local Authority) networks. Data has been collected for use with the model for the application of the model at the national level and analyses of the national network have been undertaken.

Prediction tools for carriageway condition are available to address a range of contexts, from detailed project level assessments (using detailed data) through to strategic level analyses (using coarser network level data). Following a review of the available models, the Highways Maintenance Efficiency Programme (HMEP) Lifecycle Planning Toolkit (HMEP, 2012) was adopted for the prediction of conditions and maintenance need in this project. The HMEP Toolkit is a Microsoft Excel workbook and was adopted unchanged but used with data collected from Local Authorities use of the toolkit. Modules to represent the enhanced functionality required for the economic analysis and assessment of impacts on road users and society were 'wrapped around' this core analysis element.

A separate Microsoft Excel workbook, the Aggregated Outputs Module, was developed to collate the relevant data from separate HMAT workbooks to compare the results from different analyses. This report should be read in conjunction with the HMAT user guide (Buckland, 2014).

Data was collected to represent the national local road network in England (excluding London) and analyses undertaken with that data to better understand the behaviour of the model and the sensitivity of the model results to changes in key model data.

This report describes the steps taken to parameterise the model for use with the national local road network (excluding London). The report describes the approach adopted and the results obtained from some initial analyses while the Appendices provide more technical detail of the model components and the data that that was used in the analysis of the national network.

2 Overview of Model Development

2.1 Principles of model development

There were three requirements for the model development:

- **The model must work with data that is available now.** DfT was aware that the quality of data varies across different networks and asset types and the availability of data also tends to vary depending on the road type or hierarchy. The intention was to ensure that the model works with existing data and allows for future refinement and enhancement as more or improved data becomes available in the future.
- **It was understood that not all effects can be quantified.** This should be made clear to users of the model. It was also considered reasonable to assume, given that the focus of the study was on marginal changes to funding, that the dominant effects were due to changes in carriageway conditions. Winter service activity was excluded from the study, but other activities were considered and the limits of this assumption have also been considered during the model development and testing.
- **The model needs to be flexible and easy for use by a range of users.** The intention was that the model will be used by both DfT for national analyses, and across the range of Local Authorities. It should allow for this range of users and so be relatively simple to use and adopt a software approach (e.g. a spreadsheet) that can be used by the different types of users.

The model has been designed in accordance with the latest DfT Transport Appraisal Guidance (WebTAG), (DfT 2014). For example, it uses WebTAG values of time and vehicle operating costs and applies the current government discount rate for economic cost comparisons. Updates are released to WebTAG, for example in terms of unit cost and prices, when required and the model allows for ease of update to incorporate these changes to the data.

Whilst WebTAG sets the overall framework for analysis, it does not define the precise application of various methods used to determine specific impacts. For example, the guidance for vehicle operating costs derivation is in terms of speed and distance travelled, and road condition is not included. For this study, the model was to test the impact of maintenance and road conditions on the costs to road users and society (e.g. the impacts of conditions on vehicle operating costs, users' travel time, carbon emissions and accidents). An approach for deriving the impact of conditions on vehicle operating costs was therefore needed. Where assumptions or considerations have been needed, they have been documented in the report.

The prediction of road conditions under different budget constraints and maintenance policies is complex. Given that the focus of the development was on carriageway condition and its impact on the user, rather than develop a bespoke approach solely for this study, it was agreed to adopt an approach already in use. To be consistent with the latest developments for local roads in England, existing models were reviewed and the Highways Maintenance Efficiency Programme (HMEP) Lifecycle Planning Toolkit (HMEP, 2012) was selected for the prediction of carriageway condition and maintenance need. The HMEP Toolkit was adopted unchanged, and the enhanced functionality required for the economic analysis and assessment of the impacts on road users and society 'wrapped around' this core analysis element. With such an approach, it will be relatively straightforward in future to incorporate any minor changes to the HMEP Toolkit as they become available.

Finally, the study was commissioned on the basis that no significant further work would be undertaken reviewing recent literature, recognising the fact that two recent studies in the UK had covered the subject area in detail (Parkman et al, 2012 and Gould et al, 2013). Those earlier studies have been used as a foundation for this project and the approaches adopted in them have been developed and updated to meet the requirements of the development of HMAT.

2.2 Model framework

The initial focus for the project was to review the relevant material, as noted in Section 2.1, and develop an overall framework for the model. The overall framework, shown in Figure 1, provides the logical design for the various analyses procedures that are within the model with module(s) addressing specific parts of the analysis.

Table 1 lists the modules and their respective function within HMAT. Section 3 provides a brief description of each of the modules with further background to the modules described in Appendix A, specifically providing justification for various elements of the modules and key assumptions or decisions taken for the model design.

The HMEP Toolkit is a Microsoft Microsft Excel workbook that allows for only one funding scenario to be tested at a time. Given this study was to understand the impacts of levels of road maintenance possible under different patterns of investment, a means of comparing different analyses was needed. To achieve this, the design of the HMAT model was based on:

- All but one of the analysis modules were 'wrapped' around the HMEP Toolkit to become the Highway Maintenance Appraisal Tool (HMAT).
- The Aggregated Outputs Module is a separate MS Excel workbook which collates and compares the relevant results from separate HMAT analyses.

For the user, this means that each analysis is undertaken as a separate setup of the HMAT workbook. Multiple workbooks are then considered by the Aggregated Outputs Module to generate the comparisons between different analyses.

Table 1: Function of modules within HMAT

Module	Function
Standard inputs	Defines standard information for use in the model such as average scheme lengths, road condition data etc.
Activity allocation	Allows user to establish how the total budget allocation is distributed across the different: • Road types • Maintenance treatment types (e.g. surface dressing) It also allows the user to show how each activity contributes to various strategic drivers to support any qualitative analysis.
Traffic projection	Determines the volume of traffic by different vehicle types and the projected traffic growth over the analysis period.
Treatment analysis and condition projection	Predicts the treatment requirements and resulting conditions. This module is the current HMEP adopted unchanged. It was recognised that the HMEP Toolkit is for strategic analyses of road network maintenance requirements under different budget scenarios. It adopts a tried and tested probabilistic modelling approach (WSP, 2010).
Condition impact	Predicts the vehicle operating costs (fuel consumption etc.), travel speeds and CO_2 emissions due to carriageway conditions. The predictions use look-up tables based on the outputs of a suite of analyses using the Highway Development and Management (HDM-4) tool (Kerali et al, 2006).
Treatment impact	Predicts the embodied carbon consumed by carriageway maintenance activity and also the costs due to travel time delays, accidents and vehicle CO_2 emissions at roadworks. The predictions use look-up tables based on the outputs of a suite of analyses using the asphalt Pavement Embodied Carbon Tool (asPECT) (Wayman et al, 2011) and the Queues and Delays at Roadworks (QUADRO) tool (DfT, 2002).
Accident analysis	Determines the safety impacts of maintenance based on: • Changes in skid resistance on the network • Changes in lighting availability on the network
Job impacts analysis	Determines the estimated direct job and gross value added (GVA) impacts on the road maintenance sector caused by the level of budget.

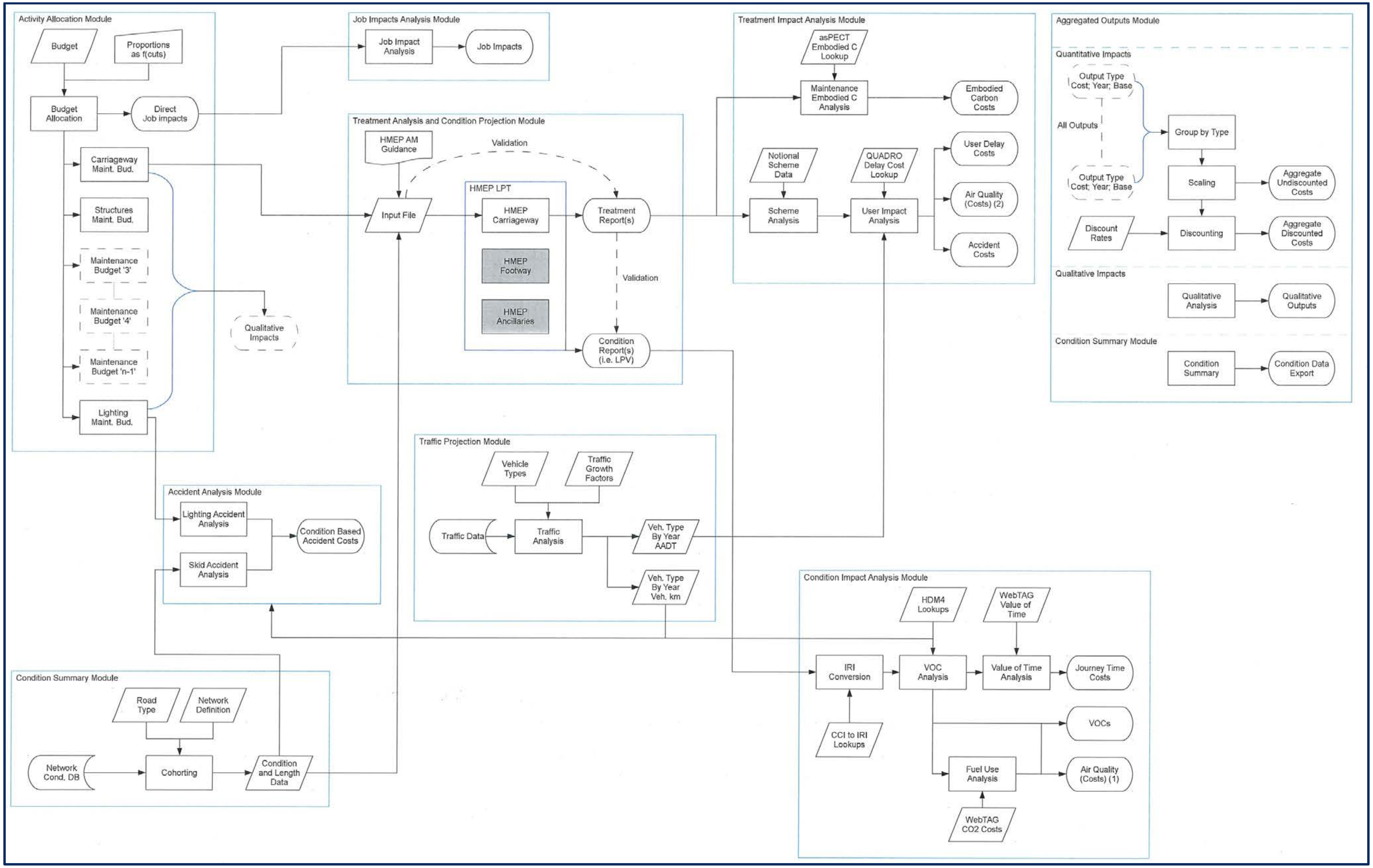

Figure 1: Overall model framework

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3 Analysis modules

This Section describes the individual analysis modules that together form the HMAT model. Each module developed for this study is described, apart from the treatment analysis and condition projection module which used the existing HMEP Toolkit. The HMEP User Guide (HMEP, 2012) describes this in detail. Appendix A provides more detail on each of the HMAT modules.

3.1 Standard inputs module

The standard inputs module captures some of the key information that is used in a number of modules in the model. It ensures that data is entered once only and helps provide a framework for data to be input in other modules. The data entered allows for a specific network to be represented and modelled, as well as setting up some of the high-level analysis assumptions. The data entered comprises:

- Road types – the model can accommodate up to 100 road types
- Average maintenance length (km) for a road type – used to estimate the average number of maintenance lane closures and the closure related (roadworks) impacts.
- Treatment information – treatments to be used in the analysis (e.g. surface dressing) and the carbon embodied in each treatment for use in the Treatment Impact Analysis module
- Road condition information – the condition bands used to describe the network condition
- Analysis parameters – analysis period and start year for the analysis

3.2 Activity allocation module

Maintenance and operational budgets cover numerous activities undertaken by a Highway Authority, each of which has a different focus in terms of its relative contribution to the overall corporate objectives.

The application of asset management, or maintenance, drivers is used to allocate overall budgets across the different maintenance activities. This module adopts a maintenance driver approach to derive carriageway budgets (and other required budget lines) from the total maintenance budget.

Through additional road type and treatment type information this allows the user to gain an understanding of how the changes in overall budgets affect the budgets for surface treatments and different road hierarchies, and the impacts that subsequently result from that, such as a change in the number of accidents.

It was recognised that the breakdown of the overall budget may be affected by the size of the budget. The activity allocations can therefore be specified for three different ranges of overall budget.

3.3 Treatment analysis and condition projection module

The HMEP Lifecycle Planning Toolkit (HMEP, 2012) has been used to predict the treatment impacts on road conditions and was incorporated unchanged within HMAT.

3.4 Traffic projection module

Based on the HDM-4 study undertaken for the local English road network (WSP, 2010), the study on the Scottish local road network (Parkman et al, 2012) and the RAC Foundation study (Gould et al, 2011), it was recognised that there are significant differences in the vehicle operating costs due to carriageway condition, for different vehicle types.

The five typical vehicle types used in the model fit the WebTAG differentiation of vehicle types. They are:

- Cars (including motorbikes)
- Light Good Vehicles (LGV)
- Ordinary Good Vehicles type 1 (OGV1) (i.e. Rigid 3-axle + Articulated 3-axle)
- Ordinary Good Vehicles type 2 (OGV2) (i.e. Rigid 4-axle + Articulated 4, 5 and 6-axle)
- Buses and coaches (PSV)

The vehicle classification is specifically relevant for goods vehicles where it was found that there are significant cost differences between vehicles with 3-axles, and vehicles with more than 3-axles, so by having type 1 and type 2 split in the model this differentiation could be considered.

The traffic projection module uses the five vehicle types to support the condition impact analysis and treatment impact analysis modules.

Traffic growth is entered by the user for each vehicle type either separately for each road type or for the entire network. Default traffic growth rates have been provided from the National Traffic Model (NTM) for traffic growth until 2040. Differentiation of growth by engine type (i.e. electric, petrol or diesel) was derived based on data provided in WebTAG (DfT, 2014).

Clearly, the prediction of future traffic so far into the future has a high degree of uncertainty. However, by allowing flexibility to define the traffic growth rate for each year of the analysis period, the effect of other assumptions (e.g. the impact of a local traffic model) can be tested.

3.5 Condition summary

Carriageway condition at the start of the analysis period is summarised using the condition bands defined as part of the Standard Inputs, for each road type. The changes in condition, due to deterioration and improvement following maintenance, are provided by the HMEP Toolkit (HMEP, 2012).

3.6 Condition impacts module

As road carriageway surfaces deteriorate, there are various impacts that can be quantified:

- Greater unevenness results in higher vehicle operating costs due to:
    - Increased fuel consumption
    - Increased consumption of lubricants
    - Increased wear and tyre on tyres and other parts

    - Increased depreciation of vehicle value

- Travel speeds reduce and so there are increased travel time costs
- Increased fuel consumption leads to increased generation of CO_2 and other emissions

The Condition Impact Analysis module is used to quantify these effects. WebTAG does not cover the relationship between roughness and user costs but provides standard user cost estimates.

The World Bank HDM model (Watanada et al, 1987) and other models such as the TRL RTIM (Robinson et al, 1975) were originally developed for roads in developing countries and had a key focus on road roughness impacts on the road user and the associated vehicle operating costs. They have since been upgraded and extended (e.g. the HDM-4 model (Kerali et al, 2006) is used in Eastern Europe and analyses have been carried out for local roads in England (WSP, 2010)) but the basic conceptual frameworks remain. The logic of these models is a link between road condition (predominantly summarised by road roughness) and road user costs in terms of vehicle operating costs and travel time.

The HDM study remains the most widely applicable and reported model for assessing vehicle operating cost changes based on road condition. It was necessary to identify a transformation of existing and typical English local road condition data to the International Roughness Index (IRI) used in HDM-4.

A series of runs with HDM-4 were completed using vehicle fleet information that aligned with the DfT and WebTAG standard vehicle types. The outputs from the HDM-4 runs were captured in a series of look-up tables relating carriageway condition to vehicle type for use in HMAT.

Road safety might also be compromised as pavement condition deteriorates. Higher safety risks due to reductions in the skid resistance of surfaces result in increased accident costs and these have been described in Section 3.8. Other potential safety related risks (e.g. when users try to avoid potholes) cannot easily be quantified and are not captured within HMAT.

3.7 Treatment impacts module

As a result of the maintenance treatments undertaken on the network, various impacts can be quantified:

- Embodied carbon from the maintenance activity
- Delays at roadworks experienced by road users
- Changes in accidents due to roadworks
- Changes in carbon costs due to roadworks

The Treatment Impact Analysis Module quantifies these effects. The maintenance treatments predicted by the model lead to the lengths of carriageway maintained for each road type. These maintenance lengths can be translated into numbers of schemes based on the average scheme length for each road type (see Standard Inputs). More maintenance creates more disruption on the network, therefore impacts road users and there is a trade-off to be made between the costs and effects of maintenance (i.e. improving condition) and the additional impacts of the maintenance (e.g. delays to users).

Delays to traffic were estimated using the Highways England software package Queues and Delays at Roadworks (QUADRO) (DfT, 2002) which was used to create a look-up table for use within HMAT.

The asphalt Pavement Embodied Carbon Tool (asPECT) (Wayman et al, 2011) was used to determine the embodied carbon for maintenance treatments. For each treatment type and associated treatment data (e.g. depth planed out, recycled content), the asPECT tool provided estimates for the embodied carbon that was converted into cost using WebTAG prices of carbon.

3.8 Accident analysis module

The purpose of this module was to establish the predicted safety impacts in terms of accidents from two specific sources:

- Changes in skid resistance on the network due to changes in road surfacing budgets.
- Changes in lighting availability due to changes in lighting budgets.

The module is based on broad, conceptual principles which are applied at an aggregated network level (i.e. network level funding changes translated directly into predicted summary changes at the network level) rather than using a more detailed condition projection model (e.g. impact of funding on different types of street-lighting maintenance resulting in different conditions of the lighting asset or the level of lighting provided).

The skidding accident analysis was based around general conclusions from supporting literature (Rogers and Garget, 1991, and Viner et al, 2005) that show lower skid resistance tends to correlate with an increased accident rate. However, there was no established relationship for use at the network level, so a new relationship was derived. It was necessary first to demonstrate that resurfacing investment on the network to date has been shown to have a positive effect in reducing skid resistance. Based on this assumption, the change in funding and the related change in the proportion of the network with poor skid resistance are specified by the user for the network to be analysed.

The lighting accident model is based on results of studies described in the available literature (Crabb et al, 2005; Crabb, Beaumont et al, 2009; Crabb, Crinson et al, 2009; Institution of Lighting Engineers, 2006; Institution of Lighting Engineers, 2010; British Standards Institution, 2003). It assumes a simple approach that should a 100% reduction in street lighting ever be implemented (i.e. turning off electricity to all lights), then the accident rate on routes currently lit would increase by 10% (consistent with assumptions used in the past by the Highways Agency in cost benefit analyses). The model then also assumes the approach is also applicable on a pro rata basis for any partial reduction in lighting. Whilst it is simplistic and does not account for targeted lighting reduction approaches that might be implemented by Local Authorities, it does provide a starting point from which more detailed scrutiny can be undertaken exogenously to the model and enables the potential impacts to be shown alongside other impacts derived by HMAT. In HMAT there is no reduction in accidents derived from increases in the lighting budget.

3.9 Job impacts module

At a high level, construction-stage employment created by expenditure on a given maintenance scheme can be calculated by dividing total turnover (or expenditure) in the

UK construction industry by the total employment in that industry, which gives an estimate of the jobs supported per pound spent. That figure was then applied to the estimated maintenance expenditure to calculate the number of jobs that will be supported or created. This showed the direct employment impacts of road maintenance expenditure.

There may be wider job impacts that are realised due to the impact of maintenance on the network. Changes in journey time savings, vehicle operating costs and accidents, for example, may result in changes in local economic activity and employment. However, information was not available to the project to show which differences in road schemes and local economies result in differential impacts on employment and Gross Value Added (GVA).

The approach used for this study was to extract data from the Construction component of the Annual Business Survey (Office of National Statistics, 2012). The data showed estimates for turnover, GVA and employment in the industry for the purpose of benchmarking GVA and employment created by expenditure on a road maintenance project. This then enabled the impacts of jobs to be included in the other impacts of road maintenance, meaning that any changes in budgets reflected a change in the job impacts in the road maintenance sector.

4 HMAT data for the national network

This Section sets out the sources of data used for the HMAT analyses undertaken for the national network. The full detail of final values used is provided in Appendix B while the results of the analyses are reported in Section 5 and Appendix C.

In summary, data has been assembled from four sources:

- Nationally available datasets
- Data available in the HMEP Toolkit
- Data derived from other studies
- Data obtained from Local Authorities

4.1 Data available at the national level

Data for the national network was provided by DfT to describe the size, use and funding of maintenance for the network. In particular, the data provided for use in the analyses of the national network was:

- Length of the network broken down by road type (DfT)
- Traffic carried by the network broken down by road type and vehicle type (DfT)
- Condition of the national network as measured by SCANNER surveys, primarily on the classified network (DfT relies on data provided by each Local Authority to generate the overall national condition reports. TRL had access to all SCANNER survey data that has been supplied to DfT by Local Authorities for reporting the condition of the classified network and held, by TRL, in the National Road Condition database)
- Total maintenance budget for the national network (Department for Communities and Local Government)

All of this data can be amended by users for analysis of other networks and can be updated for the national network as more current data becomes available.

Different levels of maintenance budget were considered in the analyses. The effects of different traffic levels on the network were considered as part of the sensitivity tests.

HMAT uses values for various parameters that are published as part of the WebTAG documentation. Some of the data used acts as default data that may be amended by users as part of an analysis if better data exists for the specific network to be analysed. However, much of this data is initially hidden from users (i.e. is not shown in the HMAT user interface) and the worksheets need to be unhidden (see the HMAT User Guide (Buckland, 2014)).

Data items that can be modified by users, but were not modified for the base analyses of the national network are:

- High/central/low costs of carbon taken from WebTAG Table A3.4 (DfT, 2014). For the analyses of the national network the central value was used.
- Carbon emissions from vehicles (i.e. CO_2 per litre of fuel)
- Annual traffic growth rates for each vehicle type

Of these data items, only different values of the annual traffic growth rates were included in the sensitivity tests.

4.2 WebTAG data

Values for a number of the parameters used in the analysis of the national network were taken from WebTAG (DfT, 2014), specifically the following tables of values:

- Value of Time - Table A1.3.6, using the 'All week' average value of time market prices for each vehicle type (£ per hour).
- CO_2 costs - The non-traded price of CO_2e (2010 price) was taken from Table A3.4
- Vehicle fuel efficiency – The cumulative changes in vehicle efficiency factors were taken from Table A1.3.10a.
- Vehicle fuel costs - The resource cost of fuel was taken from Table A1.3.7. There are different values for fuel costs for cars during work and non-work time. Currently there are no electric fuel costs for LGV but WebTAG requires the use of the same values as for cars for work and non-work time. The current proportions were taken from Table A1.3.4.

4.3 HMEP data

The HMEP Toolkit provides example datasets for use in analyses. Where possible this data has been updated by the data collected from Local Authorities or data provided by DfT. Those values are described in Section 4.5.

The HMEP Toolkit includes transition matrices for the projection of carriageway condition together with guidance on the difficulties with changing or developing new matrices. Those matrices were a significant part of the development of that toolkit and were tested for their suitability for use on the local road network by a group of Authorities during the HMEP development.

The matrices in the HMEP Toolkit are for use with the same road types and condition bands used in the analyses of the national network. The data provided by the Local Authorities for use in the analyses of the national network showed few Authorities have made changes to the matrices. The transition matrices provided in the HMEP Toolkit were therefore used for the national analyses.

4.4 Data from other studies

Data from a variety of other sources (e.g. vehicle operating cost data) has been used in the development of the HMAT model but that data is expected to be changed rarely by the users so the worksheets are initially hidden in the user interface. Data items that are available to change in HMAT but were not changed for the analyses of the national network are:

- CO_2 quantity of each maintenance treatment type.
- Proportions of maintenance work undertaken, on each road type, using 24 hour closures, off-peak day-time closures and night closures.
- Output rates for undertaking maintenance for each treatment type on each road type

- Number of slight, serious and fatal accidents on the road network and the breakdown of that number into time of day of the accidents (i.e. daylight and darkness).
- Budgets available for operation of street lighting and the treatment of carriageway skid resistance.
- Job impact data associated with road maintenance
- Base vehicle speeds (i.e. with no maintenance work present) for each vehicle type on each road type.
- Transition of condition index values to road roughness (IRI) values

These data items were not varied in the sensitivity tests for the analyses of the national network.

Vehicle operating costs for use in HMAT were derived from HDM-4 analyses and are factored up in HMAT for the level of traffic and carriageway condition. To examine the sensitivity of the base analyses of the national network to changes in vehicle operating costs the unit costs (stored in look-up tables) were changed as part of the sensitivity analyses.

4.5 Local Authority data

During development of HMAT, the default setup provided by the HMEP Toolkit was used. In order to increase the confidence in the model predictions, five Local Authorities provided data from their use of HMEP. The information allowed enhanced datasets to be developed for the inputs on

- Road width
- Carriageway condition
- Maintenance works costs
- Effect of treatments on carriageway condition.

To further improve the data used for analyses at the national level, a pro-forma was prepared and sent to Local Authorities to request data to use in the HMEP Toolkit, to update the data used during development of HMAT. The data could also be supplied in existing data analysis files (e.g. using the HMEP Toolkit), where those analyses had already been carried out by Local Authorities.

The key reason for collecting data from a wider range of Authorities was to improve the representation of the national network and to enable the level of variability seen in the new data to be represented in sensitivity testing of the data used in the HMAT model. The aim of the analyses was to demonstrate the use of the model with the best data available and to provide an initial assessment of the effects of variability in that data.

Data was provided by the Authorities shown in Table 2 by the Region of the country and type of Authority[1]. Only two County Councils provided the completed pro-forma. All other

[1] In some cases, the Authorities have been allocated to a type of Authority deemed to be close to the actual Authority type, to provide a reasonable coverage of the types of Authorities considered in the data collection and to show any variation of the data between Authority types.

Authorities sent one or more HMEP files. One Authority sent HMEP files used for analysis of the footway network only so that data was not used for the national road network.

Table 2: Local Authorities that provided data

Region	County	City	MBC
North	*North Yorkshire* *East Riding of Yorkshire*	Durham Salford	Knowsley Kirklees
Midlands	*Cambridgeshire* *Herefordshire* Norfolk Northamptonshire	Derby	Sandwell
South East	*Hertfordshire* Surrey		Slough
South West	Dorset	Poole Torbay	

Italics: Five initial Authorities providing data for the HMAT development

Source: Analysis of returned Local Authority data

5 Analyses using HMAT

Three iterations of analysis informed the use of HMAT with the final set of data for the analysis of the national network:

- Initial demonstration runs
- Use of enhanced data
- Analysis of the national network

All these analyses played a key role in providing assurance on the reliability of the results from the HMAT model. A key part of HMAT is the condition projection, maintenance treatment implementation and treatment effects provided by the HMEP Toolkit. During the development of that toolkit, Local Authority users undertook extensive testing of the analyses that enabled the HMEP Steering Group to confirm, prior to the release of that Toolkit, that the toolkit was fit for purpose. Although the HMEP Toolkit was included in HMAT without change, checks were made that analyses in the stand alone HMEP Toolkit provided the same results as the predictions from the condition projection and maintenance treatment implementation module in HMAT, and the effects on carriageway conditions reflected the changes in levels of maintenance funding.

As part of the development of the impacts modules in HMAT (e.g. Treatments and Condition Impacts) separate stand alone developments of each impact model were created to check the results for each impact in the HMAT model. These checks were made on completion of the development of HMAT (i.e. all the modules had been included in HMAT) using data from the demonstration analyses and from the data for the national network.

An important outcome from the use of the stand alone impact models was to confirm that there were no 'tipping points' in the analyses (i.e. where small changes in data values cause sudden and large changes in the modelled impacts) for the ranges of data considered in the Base Analyses and Sensitivity Tests in this development.

In addition to direct comparisons with the HMEP Toolkit and the stand alone models of the indirect costs, where possible, sense checks were carried out on the results of all the analyses. For some changes in the data there is little experience of the potential impacts but it was possible to confirm the correct directions of changes in the results (e.g. more funding leads to more maintenance). The checks made with the analyses therefore provided assurance in the behaviour of the model and, hence, the reliability of the analysis results.

5.1 Initial demonstration analyses

During development of the HMAT model, analyses were used to demonstrate the analysis capabilities of the model and to highlight aspects of the analysis that play a key role in determining the outcomes. It was recognised that these analyses would not provide results that showed reliable predictions of the impacts of maintenance funding but they would provide sense checks on the performance of the model (e.g. more funding leads to more maintenance, better carriageway condition and reduced indirect [user] costs).

Four analyses were used to show the capabilities of the HMAT model and to show the summary results in the Aggregated Outputs Module. The aim of the analyses was to show HMAT:

- Functions correctly and gives intuitively correct results based on the input data

- Can be calibrated and adjusted so that users can generate results from analyses that are appropriate and robust

The analyses were used to investigate the impacts of different funding levels or maintaining specified levels of carriageway condition. The analyses are described in Table 3 and used typical and realistic data for the English local road network with the default condition projection and treatment strategy setups provided within the HMEP Toolkit. An analysis period of 60 years was used.

The analyses chosen allowed different questions to be investigated and hence show the types of 'what if' questions the model can help answer. For example:

- What is the impact on network condition when maintaining current budget levels?
- What budget would be required to maintain the network in a steady state based on the current condition?
- How do condition profiles change when the budget/time profile changes?
- What impact does an initial, but temporary, increase in investment have?
- Within each analysis, what is the impact on road users and society?
- How do direct costs compare with indirect costs?
- What is the best overall strategy (e.g. in terms of Benefit-Cost Ratio (BCR) or Net Present Value (NPV)) from those analysed?

Table 3: Demonstration analyses

Title	Description
Current Budget	Use the current funding level for all years of the analysis.
Steady State	Maintain the network so that the total percentage of the network in Poor (P) and Very Poor (VP) condition remains constant (this was achieved by keeping constant the percentage of each road type in Poor and Very Poor condition).
Budget Increase 10%	Increase the budget by 10% in the first 10 years, with steps down to a reduced constant budget in years 14 onwards so that the total budget is the same as the current budget across the analysis period (60 years).
Budget Increase 20%	Increase the budget by 20% in the first 10 years, with steps down to a reduced constant budget in years 14 onwards so that the total budget is the same as the current budget across the analysis period.

The results of the analyses showed consistency in the behaviour of the model but highlighted some key aspects that needed further consideration when using the model to investigate the real impacts of maintenance funding:

- Budget allocation rules can restrict the availability of funds and lead to only small proportions of the available budgets being spent in a year
- The adopted Treatment Strategies can result in a polarisation of carriageway condition into Very Good and Very Poor conditions
- Performance targets must be clearly defined to achieve the required analysis (e.g. specifying targets for only some of the condition bands can lead to unexpected levels of condition in other bands that do not have a target condition).

Review of the results from the analyses showed the predictions of impacts based on changing carriageway conditions were plausible and explainable (e.g. increased funding leads to more maintenance, better carriageway conditions and appropriate changes in indirect costs). The detailed quality assurance checks on the model using the HMEP Toolkit and the stand alone models of the indirect costs, described at the start of Section 5, had shown the reliability of the predictions in HMAT and provided confidence that the model was fit for purpose. However, refinements to the data in the model (e.g. Treatment Strategies) were required to focus on the prediction of carriageway condition and the maintenance undertaken to ensure the effects of changes to levels of maintenance funding could be better understood.

Refining the prediction of change in carriageway condition under different funding levels required consideration of a number of aspects including:

- How the available budget is allocated between road types and treatment types
- How the treatments address the levels of condition (i.e. the Treatment Strategies)
- Unit costs of different treatments
- Effects of treatments on condition
- Predicted rate of deterioration of the carriageway

For the initial demonstration analyses, the default setup provided by the HMEP Toolkit was used. Further analyses then varied the HMEP setup. In particular, the issue of there being 'unspent' budget for the carriageway analysis was investigated by changing the HMEP default Treatment Strategy for each road type.

In addition, changes in the budget allocations were considered while maintaining the original Treatment Strategy in order to isolate the impact of revised budget allocations.

Finally a revised analysis of retaining the network condition (i.e. steady state) was undertaken adopting a new Treatment Strategy. The four analyses used for these investigations are shown in Table 4.

The new analyses further demonstrated the use of the model and examined the overall behaviour of the costs following changes to some key parameters. The analyses enabled some general conclusions to be drawn for the local road network in England (excluding London):

- The analyses showed again that increasing investment in maintenance may result in other benefits (reduction in indirect costs) to society and the converse (reduced maintenance investment may result in loss of benefits).
- The analysis of steady state shows that spending more money (e.g. to retain steady state) may also increase indirect costs if the Treatment Strategy is not optimised.

- The model requires calibration and improved data to provide more confidence in the model predictions that more closely align with the behaviour experienced on the road network. The results from these initial analyses showed that refinement would be possible with further investigation.

Table 4: Analyses used for further testing

Title	Description
Refined Treatment Strategy	The previous analysis for a 20% budget increase was repeated with a revision to the Treatment Strategy. The aim was to increase the direct outturn costs so that there was less unallocated budget. This was the only difference to the demonstration analyses and all budget constraints remained as shown in Table 3.
Doubled Budget	The constant budget analysis was re-analysed with the current budget doubled for each of the first five years and a return to the current budget for year 6 onwards. Note that there were no corresponding reductions in budget after year 5 so the total budget over the analysis period was higher than with the constant current budget.
90% Budget Reduction	The constant budget analysis was re-analysed with the current budget reduced by 90% for each of the first five years and a return to the current budget for year 6 onwards. Note that there were no corresponding increases in budget after year 5 so the total budget over the analysis period was lower than with the constant current budget.
Revised Steady State	A different approach to determining the steady state budget was adopted with the percentage of the network in each of the condition bands notionally constant over the analysis period for each road type.

The initial eight analyses (i.e. Table 3 and Table 4) showed the model behaviour to be as expected with increases in budget leading to improved carriageway condition, lower vehicle operating costs but increased impacts of roadworks while lower budgets had the opposite effects. The analyses also showed the importance of the Treatment Strategies and Budget Allocations but confirmed that further investigations, using more reliable data from Local Authorities engaged in highway maintenance planning, would be worthwhile. At that stage, sensitivity testing with the improved data would also help to confirm the parts of the model that have the biggest impacts on the results and thus help in maintenance budget planning.

5.2 Use of enhanced data

To address the summary conclusions from the initial analyses that the model should be used with improved data to increase the confidence in the model predictions and assess the sensitivity of key parameters, five Local Authorities provided data for their road networks.

The data was analysed to produce an interim enhanced dataset (in advance of a wider consultation with Local Authorities). The aim of the new data was to better represent the national network. The Authorities that provided data were:

- Cambridgeshire County Council.
- East Riding County Council.
- Herefordshire County Council.
- Hertfordshire County Council.
- North Yorkshire County Council.

The data returned from those Authorities allowed enhanced datasets to be developed and used in the model with improved data for the following model inputs:

- Road width – revised widths based on the averages of the values from the Authorities for each road type resulted in small changes (increases to rural A and B-roads and urban U-roads, and decreases to urban A and B-roads, all C-roads and rural U-roads) to the widths used in the initial demonstration analyses.
- Carriageway condition – based on the average percentage in each condition band from the Authorities for ech road type, resulted in a slightly improved initial condition for B-roads, a slightly worsening in the condition of A and C-roads but a much bigger worsening in the condition for U-roads.
- Maintenance works costs – based on the average costs for the treatments from the Authorities resulting in lower costs for the surface treatments (i.e. Surface Dressing and Micro-Asphalt) but higher costs for the deeper treatments (i.e. Moderate Overlay, Moderate Inlay, Deep Inlay and Reconstruction).
- Effects of treatments on carriageway condition – the proposed treatment effects from North Yorkshire County Council were used in the enhanced dataset because they were one of two Authorities whose data were in close agreement, and they had proposed using five condition bands therefore mapping directly to the condition bands used in the initial analyses.

Although the initial demonstration analyses suggested a high importance of Treatment Strategies in the model, the data provided by the Authorities showed little change from the Treatment Strategies provided with the HMEP Toolkit. This prevented a comparison of the Strategies used in the demonstration analyses with different Strategies that are used by Local Authorities. Similarly the new Local Authority data, being based on the HMEP Toolkit, did not show the Activity Allocation stage of the HMAT process. The budget allocations used in the demonstration analyses were therefore not changed for use with the enhanced data.

Analyses using example data from five Local Authorities assessed the impacts of carriageway maintenance under three levels of funding which were developed from the earlier analyses used to demonstrate the model during its development. The analyses are shown in Table 5.

All the analyses used a 60 years analysis period and examined the indirect costs resulting from[2]:

- Road condition affecting time, operating and carbon costs of vehicle use
- Roadworks affecting time, operating and carbon costs of vehicle use
- Accidents

Table 5: Analyses with enhanced data

Title	Description
Current Budget	Use the current funding level for all years of the analysis period. This was the option which other analyses were compared against.
Budget Increase 10%	Budget increased by 10% for 10 years, then reduce the budget level to achieve the same total spend over the analysis period.
Steady State	Maintain the network condition in steady state (in all 5 condition bands) over the analysis period.

The additional analyses using the interim Local Authority data allowed the demonstration analyses to be improved. The changes in the direct and indirect costs caused by the new data could all be explained by the basic logic of the model and the changes to the data used (see earlier in this Section). The consistency in behaviour increased the confidence in the suitability of the model for the analysis of alternative budgets but the small samples of values of parameters in the new data were not sufficient to provide a reliable and representative picture of the budget needed for maintenance of the entire local road network in England (e.g. all the new data provided by Local Authorities was from County Councils) so there was a need to assess data parameters from other Authority types and regions.

The analyses using the enhanced data coupled with the analyses undertaken during the development of HMAT and the initial demonstration analyses, provided increased assurance in the behaviour of the HMAT model. The results confirmed the expected effects of increases in budget leading to improved carriageway condition, lower vehicle operating costs but increased impacts of roadworks while lower budgets had the opposite effects and worse starting conditions needed more maintenance to achieve the condition targets. However, it was recognised that further testing, with data provided by a bigger number of Local Authorities, would further increase that confidence and show the potential impacts of different maintenance budgets for the local road network.

[2] In HMAT analysis results, the total indirect costs are shown also for the impacts of Embodied Carbon and Jobs/Employment. To avoid the possibility of double counting, the indirect costs used from the analyses of the national network excluded Embodied Carbon and Jobs/Employment.

5.3 Approach for analyses of the national network

The initial demonstration analyses, using reasonable estimates for the values of model data parameters derived from standard data sets (e.g. WebTAG), national data (e.g. DfT traffic figures and carriageway condition), best estimates from the project team experience of work done on local roads and enhanced data from five local Authorities provided confidence that the HMAT model is suitable for use with both local and national road networks.

As part of the provision of better data for the model from five Local Authorities, confirmation was sought on what data could be easily provided by a wider survey of Local Authorities.

National analyses with the HMAT model would need to cover all Authority and road types in the network and all traffic levels. The demonstration analyses had shown that the HMAT model needed improvement in a number of aspects to show the effects on carriageway condition and the impacts on road users under different funding levels:

- Confirmation of the network start condition for unclassified roads
- How the available budget is allocated between road types and treatment types
- How the treatment types are established to address the various condition bands (i.e. Treatment Strategies)
- Unit costs of different treatments
- Effects of treatments on condition
- Predicted rate of deterioration of the carriageway

To further improve the data to be used in analyses of the national network, a wider data collection exercise was undertaken using a standard pro-forma. The wider data collection was aimed at addressing the first five of the six areas noted above. It was not expected that the HMEP transition matrices would be modified to change the rates of carriageway deterioration. The Authorities that provided data are shown in Table 2 and the data used in HMAT for the national network analyses is described in Appendix B.

The variability in the data provided showed no single set of data from one of the Authorities was sufficiently representative of all the Authorities providing data for use in analyses of the national network and data for the whole network would need to be taken from a selection of Authorities (e.g. by taking data for particular road types from different Authorities). It also showed that the data for the national network would not provide a good representation of any single Local Authority. Nevertheless, the variability in the new data did show the likely variation in the data across the national local road network and the model data and parameter values with the highest degree of variability. Appendix B describes how the data provided from the Local Authorities was used to create the data for use with the national network.

The aim of the analyses with the best data available for the national network was to show the effects of different levels of maintenance funding on the national network in England (i.e. local roads excluding London). To better understand the effects of changes caused by the use of the new data, the data was introduced into the analyses gradually (i.e. aspects of the data in different analyses) until the full set of data was used. Further analyses with the data were then used to assess the sensitivity of the results to key model parameters.

Traffic levels

The indirect costs associated with maintenance arise mainly from the traffic carried by the network on the different road types. The current level of traffic on the network was provided by DfT and the traffic growth values were taken from the National Transport Model. The traffic carried by each road type (in vehicle km) is shown in Figure 2.

Continuation of the growth rates leads to high traffic flow values that are unlikely to be achieved in practice. The high flows then lead to high vehicle operating costs and journey times that dominate the indirect costs. To avoid the effects of high traffic flows unrealistically dominating the long-term effects of the funding strategies, it was assumed there would be no further growth beyond 2039.

For A, B and C-roads, those in rural areas carry more than urban roads but for U-roads, it is the urban roads with most traffic. Cars made up most of the traffic on all road types but the overall growth in traffic (to year 2039) was fairly even for all road types.

The highest traffic flows are on Motorways but the length of this road type in the network is so short, that road type makes only a small contribution to the overall effect for all the network.

Discounting indirect costs

The indirect costs seen in the results from the demonstration analysis of continued use of the current budget with example data from five Local Authorities are shown in Figure 3 for undiscounted and discounted costs. The principal components of the indirect costs were from the effects of carriageway condition shown as vehicle operating costs (Condition - VOC), change in journey time costs arising from carriageway condition (Condition – Time) and, to a lesser extent, the costs of carbon from the fuel used by vehicles (Condition – Carbon (from fuel)). The dominant component of the undiscounted total costs at the start of the analysis period was the vehicle operating costs but these became generally constant as the condition of much of the network was restored to Very Good condition. Increases in the value of time were as given by WebTAG but traffic growth was capped. The overall effect was for the vehicle operating costs to become generally constant. After discounting, the component of travel time became constant and the main cause of the lower costs was discounting the uniform vehicle operating costs.

Analysis period

The demonstration analyses used an analysis period of 60 years but for the analyses of the national network the aim was to reduce the period to 30 years for the base analyses. As most maintenance interventions would have a shorter life span than 30 years, it was considered that a shorter appraisal period would capture most impacts and sensitivity tests were included to confirm this assumption. The shorter analysis period also reduced model run times.

To enable the effects of using the new Local Authority data with a 30 years analysis period to be shown in comparison with the results from the demonstration analyses, the demonstration analyses were repeated using a 30 years analysis period.

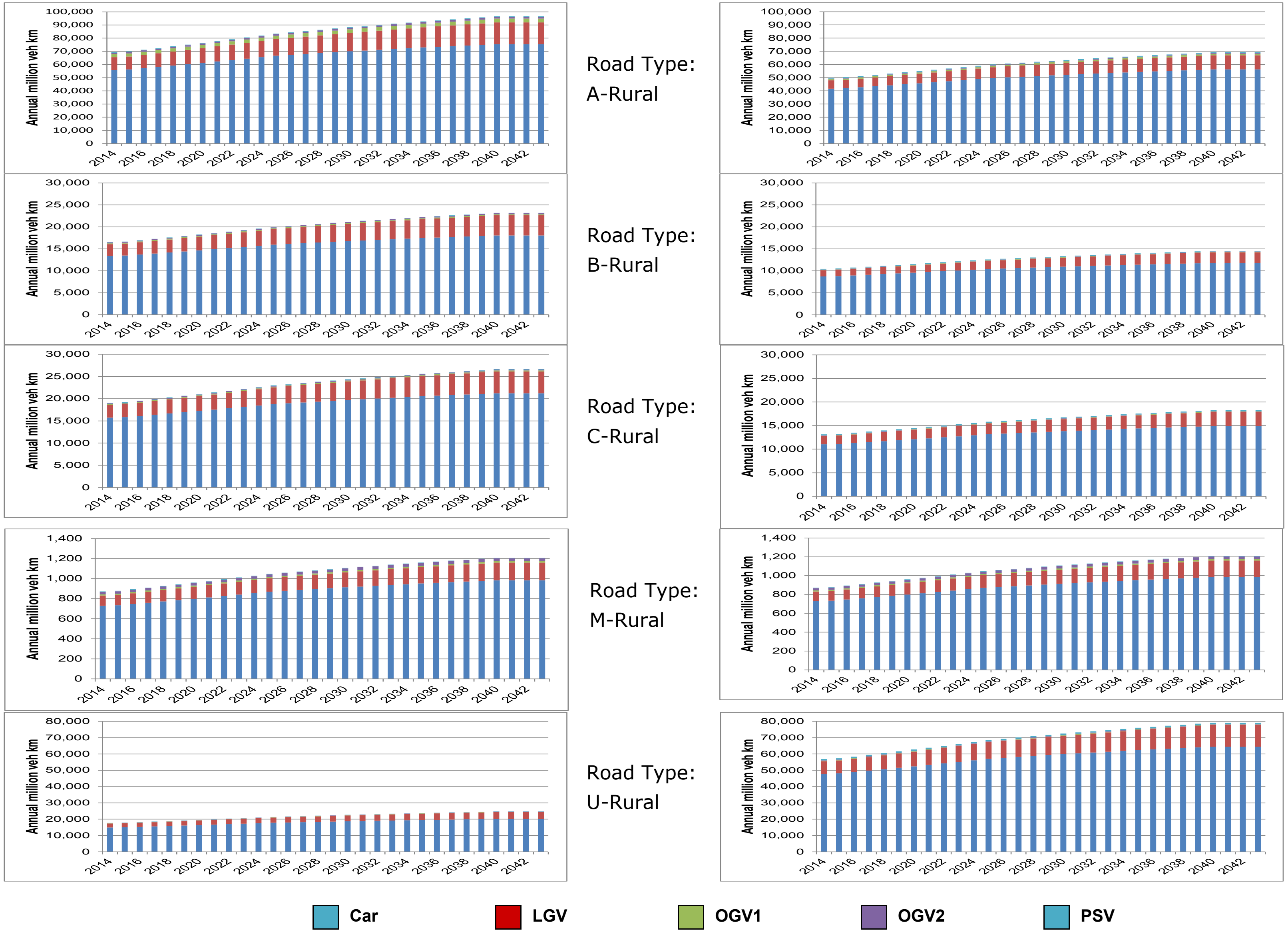
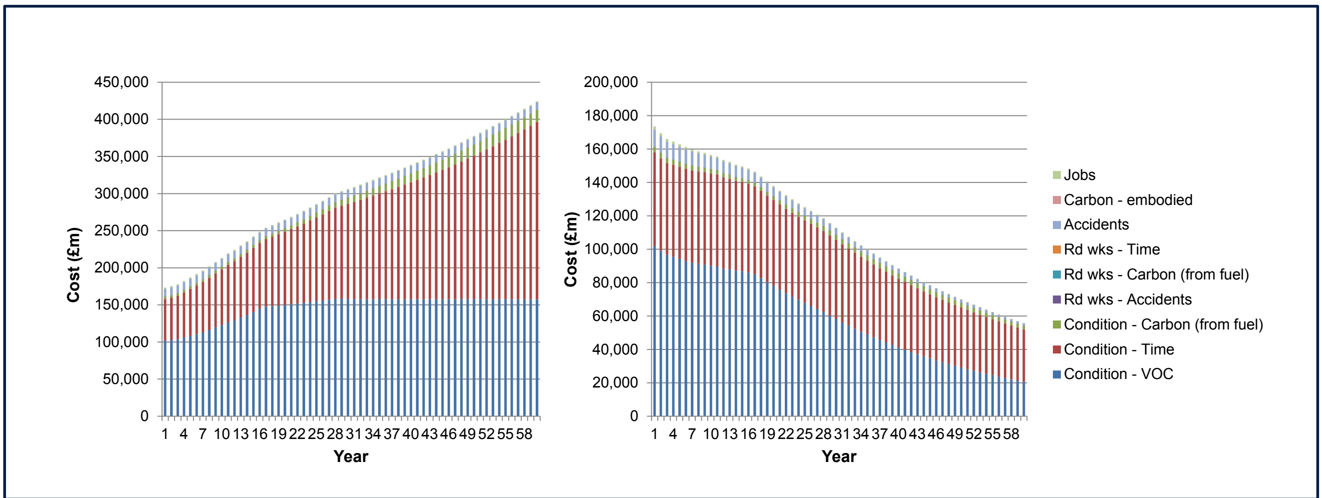


Figure 2: Traffic (veh. km) carried on each road type

Much of the benefits from the different funding options are derived from lower costs associated with traffic on the network. Shorter analysis periods removed the years with higher traffic flows that contribute higher benefits so the benefits are reduced with shorter analysis periods.



(Undiscounted) **(Discounted)**

Figure 3: Indirect costs of the current budget analysis

Reducing the analysis period to 30 years therefore generally showed a lower benefit than the 60 years analysis period and a lower Benefit-Cost Ratio (BCR) for the analysis. For the budget analyses the 30 year BCRs were within 10% of their 60 year counterpart. Long term benefits are more important in analyses using a performance target (e.g. steady state) where the 30 year BCR was reduced by 27%. This is because for the performance target analyses in this study, in later years of the analysis period the network condition was better than with the constant budget so benefits from the performance target analyses were removed with a shortened analysis period. If an analysis using a 30 years analysis period showed benefits, then those benefits would be increased for an analysis period of up to 60 years.

5.4 Analyses of the national network

Using experience gained from the demonstration analyses and with the analyses with example data from the sample of five Local Authorities, to better understand the effects of different maintenance budgets, the analyses used to demonstrate the effects of levels of maintenance funding were modified for use with the new set of Local Authority data. The Base Analyses are shown in Table 6.

The maintenance funding for Analysis 1 was the same as in the demonstration analyses but the new data collected from the survey of Local Authorities was used to describe how the maintenance work was undertaken. Analysis 1 was used as the base case in each of the national network analyses to compare the results from the other analyses.

5.4.1 Budget analyses

This Section sets out how the high level budget changes in Analysis 2 and Analysis 3 were applied to spending on carriageway maintenance by road and treatment types.

In Analysis 2 and Analysis 3 the changes to the current budget were applied in the first 5 years of the analysis period. As total maintenance budgets change, so the priorities of different maintenance actions change (see Section 3.2) and the Activity Allocations aim to take account of these changes. For these analyses, the Activity Allocations described in Appendix B have been used. Table 7 shows the breakdown of the total budget into the budgets for carriageway maintenance, lighting, carriageway skidding resistance maintenance and other activities for the budget levels in the three budget analyses (i.e. Analyses 1, 2 and 3). Based on the Activity Allocations adopted, in which carriageway treatments more closely associated with safety are protected (i.e. if possible, take a smaller reduction) when budgets are reduced and increased budgets enable more carriageway maintenance to be undertaken, the 10% increase in the total maintenance budget (Analysis 2) results in a 15% increase in the carriageway maintenance budget and a 10% decrease in the total maintenance budget (Analysis 3) results in a 20% decrease in the carriageway maintenance budget.

Table 6: Base Analyses of the national network

Analysis		Description
1	**Budget analysis: Current Budget**	Use the current funding level for all years of the analysis period.
2	**Budget analysis: Budget Increase 10%**	Budget increased by 10% for 5 years, then the budget level reduced to the current budget level for all later years in the analysis period.
3	**Budget analysis: Budget Decrease 10%**	Budget decreased by 10% for 5 years, then the budget level increased to the current budget level for all later years in the analysis period.
4	**Performance analysis: Specified performance target**	A performance target (i.e. condition of the network) to be reached by year 10 was set for each road type and the condition in year 10 retained for all later years.

The carriageway maintenance budget was further constrained by the percentage of the budget available for each maintenance treatment on each road type (and this limits the total budget for each road type). Although the overall percentage changes (to the total maintenance budget and the allocation to carriageway maintenance) in the total budget were specified and calculated for the budget analyses, the changes in the road and treatment allocations varied. The effect of the Activity Allocations used to create the budget constraints are shown in Table 8 and Table 9. For the increase in budget, for all but urban A-roads, the percentage increase for each road type was bigger than the overall maintenance budget increase. The percentage increase was generally similar across all road types but the budget for rural C-roads had the biggest increase. With the overall budget reduction, for all road types, the budgets were decreased more than the reduction in the overall budget, with Motorways, B, C and U-roads taking the biggest reductions.

Table 7: Carriageway annual budget allocations

Work type	Analysis 1	Analysis 2		Analysis 3	
	Budget (£k)	Budget (£k)	% Change from Analysis 1	Budget (£k)	% Change from Analysis 1
Carriageway (including skidding)	1,990,585	2,290,090	15%	1,592,854	-20%
Skidding resistance	46,293	50,922	10%	49,941	8%
Lighting	555,512	580,929	5%	566,185	2%
Other	2,083,170	2,221,175	7%	2,007,301	-4%
Total budget	**4,629,267**	**5,092,194**	**10%**	**4,166,340**	**-10%**

Note: Budgets for Analysis 2 and Analysis 3 are for years 1 to 5 only. The current budget is used for other years

Table 8: Budget allocations for road types

Road Type	Analysis 1	Analysis 2		Analysis 3	
	Budget (£k)	Budget (£k)	% Change from Analysis 1	Budget (£k)	% Change from Analysis 1
A-roads (R)	437,929	494,785	13%	388,406	-11%
A-roads (U)	218,964	238,358	9%	191,038	-13%
B-roads (R)	79,623	91,604	15%	70,044	-12%
B-roads (U)	19,906	22,901	15%	15,929	-20%
C-roads (R)	278,682	334,165	20%	216,670	-22%
C-roads (U)	39,812	45,802	15%	31,857	-20%
Motorways (R)	19,906	22,901	15%	15,929	-20%
Motorways (U)	19,906	22,901	15%	15,929	-20%
U-roads (R)	437,929	508,337	16%	321,944	-26%
U-roads (U)	437,929	508,337	16%	325,109	-26%
Totals	**1,990,585**	**2,290,090**	**15%**	**1,592,854**	**-20%**

(R) – Rural (U) – Urban
Note: Budgets for Analysis 2 and Analysis 3 are for years 1 to 5 only. The current budget is used for other years

For individual maintenance treatments on each road type, with the Activity Allocations adopted for carriageway maintenance and the increased budget, surfacing treatments were allocated the biggest increases on all road types. When the overall maintenance budget was reduced, the budgets for the cheaper surfacing treatment (i.e. surface dressing) still increased so that more holding treatments could be applied but the percentage used for the higher cost surfacing treatment (i.e. Micro Asphalt) was reduced. With the reduced budget, the higher cost strengthening treatments took the biggest reductions. These effects are the results of the Activity Allocations derived from the review of Local Authority reports but the effects are not always obvious and show the importance of making sure the allocations adopted reflect the real importance given to different aspects of maintenance.

The allocations for skidding resistance and lighting are based on the total carriageway budget and are not broken down by road type and treatment type. The overall budget reductions do not result in the same reductions for these work types as they impact on accidents and the allocations aim to avoid increases in accident rates.

The percentage breakdown of the total budget varies with the size of the budget. HMAT considers 3 bands described by the levels of carriageway budget, each with different allocations to road types and treatment types. In each band, the percentage allocation to a road type or a treatment type when a budget changes may not be the same as the overall change in budget level and the allocations can change between the bands (e.g. in the national dataset described in Appendix B, Table 32 and Table 33 show A-roads and surfacing treatments get bigger shares of the budget with lower budgets).

In allocating the overall budget available, the user can specify a range of different settings to reflect preferences and objectives for the maintenance funding. To interpret the results of the model correctly it is important to fully understand how the high level budget inputs have been applied at the detailed level. Simply varying the high level budget by an overall percentage does not translate into the same change across all activities, road and treatment types.

5.4.2 Performance based analyses

DfT proposed the performance targets to be achieved by year 10 in the performance based analysis (Analysis 4), based on the network conditions in 2013/14. The targets were initially given as the sum of the percentages of the network in Very Poor and Poor condition bands and half of the percentage in the Fair condition band. However, that definition could not be adopted in the HMEP Toolkit so the target percentages[3] used for each of the road types were based on the sum of the percentages of the network in Very Poor and Poor condition bands:

- A-roads – 2.6%
- B-roads – 2.8%
- C-roads – 3.0%
- U-roads – 6.0%

The condition for Motorways was set the same as for A-roads. Within each road type, urban and rural roads were assumed to be in the same condition.

These target conditions represent improvements in the current condition and significant improvements in the conditions at the end of the analysis period.

[3] In the HMAT model the performance targets are shown as integers so in the model data all targets for A-roads, B-roads C-roads and Motorways appear as 3%.

Table 9: Budget allocations for maintenance treatments

Road Type	Treatment	Analysis 1 Budget (£k)	Analysis 2 Budget (£k)	Analysis 2 % Change from Analysis 1	Analysis 3 Budget (£k)	Analysis 3 % Change from Analysis 1
A-roads (R)	Surface Dressing	43,793	54,358	24%	54,275	24%
	Micro Asphalt	43,793	49,479	13%	46,558	6%
	Moderate Overlay	87,586	103,837	19%	77,681	-11%
	Moderate Inlay	87,586	98,957	13%	73,823	-16%
	Deep Inlay	87,586	94,077	7%	69,964	-20%
	Reconstruction	87,586	94,077	7%	66,105	-25%
A-roads (U)	Surface Dressing	21,896	26,187	20%	26,695	22%
	Micro Asphalt	21,896	23,836	9%	22,899	5%
	Moderate Overlay	43,793	50,022	14%	38,208	-13%
	Moderate Inlay	43,793	47,672	9%	36,310	-17%
	Deep Inlay	43,793	45,321	3%	34,412	-21%
	Reconstruction	43,793	45,321	3%	32,514	-26%
B-roads (R)	Surface Dressing	7,962	10,064	26%	9,788	23%
	Micro Asphalt	7,962	9,160	15%	8,396	5%
	Moderate Overlay	15,925	19,224	21%	14,009	-12%
	Moderate Inlay	15,925	18,321	15%	13,313	-16%
	Deep Inlay	15,925	17,417	9%	12,617	-21%
	Reconstruction	15,925	17,417	9%	11,921	-25%
B-roads (U)	Surface Dressing	1,991	2,516	26%	2,226	12%
	Micro Asphalt	1,991	2,290	15%	1,909	-4%
	Moderate Overlay	3,981	4,806	21%	3,186	-20%
	Moderate Inlay	3,981	4,580	15%	3,027	-24%
	Deep Inlay	3,981	4,354	9%	2,869	-28%
	Reconstruction	3,981	4,354	9%	2,711	-32%
C-roads (R)	Surface Dressing	27,868	36,712	32%	30,277	9%
	Micro Asphalt	27,868	33,416	20%	25,972	-7%
	Moderate Overlay	55,736	70,129	26%	43,334	-22%
	Moderate Inlay	55,736	66,833	20%	41,181	-26%
	Deep Inlay	55,736	63,537	14%	39,029	-30%
	Reconstruction	55,736	63,537	14%	36,877	-34%
C-roads (U)	Surface Dressing	3,981	5,032	26%	4,452	12%
	Micro Asphalt	3,981	4,580	15%	3,819	-4%
	Moderate Overlay	7,962	9,612	21%	6,371	-20%
	Moderate Inlay	7,962	9,160	15%	6,055	-24%
	Deep Inlay	7,962	8,709	9%	5,738	-28%
	Reconstruction	7,962	8,709	9%	5,422	-32%
Motorways (R) and (U)	Surface Dressing	1,991	2,516	26%	2,226	12%
	Micro Asphalt	1,991	2,290	15%	1,909	-4%
	Moderate Overlay	3,981	4,806	21%	3,186	-20%
	Moderate Inlay	3,981	4,580	15%	3,027	-24%
	Deep Inlay	3,981	4,354	9%	2,869	-28%
	Reconstruction	3,981	4,354	9%	2,711	-32%
U-roads (R)	Surface Dressing	43,793	55,847	28%	44,988	3%
	Micro Asphalt	43,793	50,834	16%	38,591	-12%
	Moderate Overlay	87,586	106,681	22%	64,389	-26%
	Moderate Inlay	87,586	101,667	16%	61,191	-30%
	Deep Inlay	87,586	96,654	10%	57,992	-34%
	Reconstruction	87,586	96,654	10%	54,794	-37%
U-roads (U)	Surface Dressing	43,793	55,847	28%	45,430	4%
	Micro Asphalt	43,793	50,834	16%	38,970	-11%
	Moderate Overlay	87,586	106,681	22%	65,022	-26%
	Moderate Inlay	87,586	101,667	16%	61,792	-29%
	Deep Inlay	87,586	96,654	10%	58,562	-33%
	Reconstruction	87,586	96,654	10%	55,333	-37%
Totals		**1,990,585**	**2,290,090**	**15%**	**1,592,854**	**-20%**

(R) – Rural (U) – Urban The same budgets are used for urban and rural Motorways
Notes: Budgets for Analysis 2 and Analysis 3 are for years 1 to 5. Analysis 1 budgets are used for other years

5.4.3 Use of the Local Authority data

As part of the investigation into the use and behaviour of the HMAT model, the effect of introducing the new data from the survey of Local Authorities into Analyses 1, 2, 3 and 4 for the national analyses was investigated by comparing the results from Analyses 2, 3 and 4 with those from Analysis 1. Note that the results for Analysis 1 changed when the new data was used. Descriptions of the data used in the analyses are given in Appendix B.

To better understand the effects of the new data, the data was changed in HMAT in six stages and the results from each stage reviewed to make sure the effects on the results of analyses were in line with the direction of change seen in the earlier demonstration analyses. The six stages were

- Network data - The carriageway widths were updated.
- Maintenance data - Maintenance works costs were updated based on the new Local Authority data and average scheme lengths updated for each road type.
- Condition data - The road conditions were updated for 2013/14 from the data that had been supplied to DfT by Local Authorities for reporting the condition of the classified network and held, by TRL, in the National Road Condition database
- Treatment Strategies – Amended to remove the polarisation of network condition into Very Good and Very Poor conditions that occurred in the analyses used for the example data from the five Local Authorities.
- Budget allocation - Constraints on budget allocation by maintenance treatment and road type were amended to allow (nearly) all the available carriageway budget to be spent in each year of the analysis period.
- Analysis period - The demonstration analyses used a 60 years analysis period but this was changed show a shorter analysis period (30 years) could be used for the analyses for the national network without making significant changes to the analysis results.

The analyses with the new Local Authority data continued to show the same forms of variation seen in the earlier analyses (e.g. increases in budget leading to improved carriageway condition, lower vehicle operating costs but increased impacts of roadworks while lower budgets had the opposite effects).

The HMAT model incorporating the new Local Authority data was used for the analyses of the national network. Analyses 1, 2, 3 and 4 represent the use of the best data obtained from the survey of Local Authorities and have been used to describe the results of the analyses for the national network.

Analyses 1, 2 and 3 with the best dataset showed the different direct and indirect costs and predicted condition of the carriageway network. The performance analysis (i.e. Analysis 4) used the same data (with a 30 years analysis period). The results from Analysis 4 have been included with the other budget analyses to aid the comparisons.

To understand the relative benefits and costs of different options, the results from Analyses 2, 3 and 4 were compared with those from Analysis 1. To derive the Benefit-Cost Ratio (BCR), the change in indirect costs (those experienced by the user) is treated as (potentially negative) benefit while the change in direct cost is the (potentially negative) cost.

For example, if a budget reduction analysis results in higher indirect costs (negative benefit) and a reduction in direct costs (a negative cost), the BCR is positive. The same is true where higher direct costs (positive cost) result in a reduction in indirect costs (a positive benefit). If the change in indirect costs is greater than the change in direct costs, the BCR will be greater than 1.

Table 10 shows the overall Benefit-Cost Ratios for the analyses obtained by comparing Analyses 2, 3 and 4 against Analysis 1. These results are discussed in Section 5.4.4.

Table 10: Benefit-Cost Ratio (BCR) for the Base Analyses

Analyses	Analysis period (years)	BCR[1]
1 and 2	30	2.7
1 and 3		2.9
1 and 4		4.3

[1] BCR = Change in discounted indirect costs per £1 change in direct maintenance works costs excluding the impacts of carbon and employment.

5.4.4 Summary results of the Base Analyses

In the Aggregated Outputs Module, the results from Analyses 2, 3 and 4 are shown compared to Analysis 1. Figure 14 in Appendix D shows the summary results for these analyses using the data from the Local Authority survey.

Compared with continued use of the current budget (Analysis 1), the increased budget analysis (Analysis 2) provides a £2.70 (discounted) reduction in the indirect costs for each extra £1 spent on direct works costs. Where the budget was reduced (Analysis 3), each £1 reduction in direct works costs produced an increase in indirect costs of £2.90 (discounted). Compared with using the current budget (Analysis 1), achieving the required performance target (Analysis 4) showed the biggest reduction of £4.30 (discounted) in indirect costs for every £1 increase in direct works costs. Analysis 4 again shows the benefits of the improved condition achieved with the specified performance targets and Sensitivity Test A (see Appendix C) shows those benefits are increased with longer analysis periods.

However, while detailed examination of the outputs from HMAT reveals some of the problems seen in the earlier demonstration analyses (around condition polarisation and unspent budgets) have been reduced, the HMEP settings used to represent the national network could be further optimised. Section 5.4.1 highlights the complex interactions within the model that are seen when changing the overall budget. Changing other elements of the inputs similarly requires appropriate knowledge especially of the HMEP lifecycle carriage way condition tool in order to obtain the best insights from the HMAT tool.

Section 5.5 discusses the results in more detail and highlights areas for further improvement. For example, the improved budget allocations in Analysis 1 resulted in nearly all the budget being spent (see Figure 5) for all road types except A-roads and Motorways. For B, C and U-roads, nearly 100% of the budget was spent in all years but the conditions of these roads deteriorated over the analysis period (see Figure 6).

For rural A-roads, a high percentage of the budget was spent initially but the condition of these roads improved slightly over the analysis period and there was money available for other road types if the budget allocations could be modified. However, in the model, money not used on one road type is not made available for other road types, or in later years on the same road type, it remains unspent in the analysis. For urban A-roads more than 90% of the available budget was spent in the first three years but this dropped to nearly 50% by year 7 (i.e. 2020). The percentage then remained at that level for the remainder of the analysis period.

The analysis suggests several aspects for improving further the HMEP settings (beyond the scope of this project). All changes will affect all funding options and the precise effects on the BCRs are uncertain. Nevertheless, the analyses (i.e. Base Analyses and Sensitivity Tests) have shown the HMAT model is flexible and can easily be adapted for use by Local Highway Authorities that have a closer understanding of the local network. With that local knowledge HMAT can help gain a better understanding of how different maintenance strategies affect the indirect costs incurred by road users and society.

5.5 Review of the Base Analyses of the national network

During the development of HMAT, two sets of data were used with the model to better understand the implications of different levels of maintenance funding (see Sections 5.1 and 5.2) prior to undertaking the analyses of the national network (see Section 5.3). The Base Analyses of the national network used the best data available for this stage of the model development and this Section describes what the analyses show from using that data. The key areas of interest in the current study, based on experience gained during the development of the model and the earlier analyses, and described in this Section are:

- Unspent available funding
- Condition of the network resulting from the allocated funding
- Impacts of network condition on costs to road users and society

In addition, Section 5.5.4 describes the main outcomes from Analyses 2, 3 and 4. Examples of the results from the analyses are included with the descriptions but further results are shown in Appendix E.

5.5.1 Unspent budgets

The Base Analyses included changes to the data used by improving the budget allocations between road types and treatment types to enable a greater percentage of the available budget to be spent in each year of the analysis period. Following the data collection from the survey of Local Authorities, these analyses represented the use of HMAT with the best data available in this project. The data provided a good basis for examining how the different components of the overall indirect costs were affected by the three different funding options (i.e. Analyses 1, 2 and 3).

Using the new data, the increased percentage of the budget spent resulted in more maintenance and an overall higher direct maintenance works cost but provided a better network condition and lower indirect costs resulting from the carriageway condition. The conditions for each road type are shown in Figure 5 and Figure 6 for Analysis 1 and Analysis 2 respectively. The causes of these conditions are discussed below.

The improved budget allocations that achieved a greater level of spend of the total available carriageway budget for Analyses 1, 2 and 3 are shown in Appendix B (Table 32 and Table 33) for road types and treatment types respectively. Performance target analyses are not constrained by the budget level so the improved budget allocations did not affect Analysis 4.

The changes in condition through the analysis period are closely linked to the funding available which is determined by the budget allocations (see Figure 4).

Analysis 1 showed the use of the current budget throughout the 30 years analysis period. The improved budget allocations resulted in nearly all the budget being spent (see Figure 4) for all road types except A-roads and Motorways. For B, C and U-roads, nearly 100% of the budget was spent in all years but the conditions of these roads deteriorated over the analysis period (see Figure 5). For rural A-roads, a high percentage of the budget was spent and the condition of these roads improved slightly over the analysis period but there was still money not spent from the available budget. If in another analysis, the allocations are modified such that unspent money could be used for other road types then the overall network conditions would improve. That analysis was not included in the scope of this project. In the model, money not used on one road type is not made available for other road types, or in later years on the same road type as it remains unspent in the analysis. The budget allocations must therefore be modified to enable all the funding to be used. In the analyses in this project, more than 90% of the available budget for urban A-roads was spent in the first three years but this dropped to nearly 50% by year 7 (i.e. 2020). The percentage then remained at that level for the remainder of the analysis period.

Figure 7 shows the percentage of the available budget used for Surface Dressing, Deep Inlay and Reconstruction on A-roads in Analysis 1. With the Treatment Strategies in these analyses, Surface Dressing is used to treat carriageway in the Fair condition band but the Deep Inlay and Reconstruction both treat the Very Poor condition. For rural A-roads it is the incomplete spend of the Reconstruction budget that provides the variation in the percentage of spend of the total budget (see Figure 5). For urban A-roads, there was a low percentage of the budget spent on all three treatments for much of the analysis period. Figure 7 shows the percentage of the budget spent in the early years of the analysis period is high but in later years there was a bigger reduction in the percentage for the more expensive treatments. All of the Surface Dressing budget was used only in year 1 and for Deep Inlay only up to year 5. The percentage spend for Reconstruction was very low after year 5 (very little of the Reconstruction budget was used after year 8) as all the Very Poor condition had been treated at the start of the analysis period. This is another example of the interactions between Treatment Strategies, budget allocations, the deterioration matrices and the effects of the maintenance treatments. Providing funding for expensive treatments may improve the network condition and avoid the need for that treatment in future years (if the deterioration does not lead to other parts of the network needing those treatments.

Figure 8 shows the increased budget in years 1 to 5 could not be spent for rural or urban A-roads. The increased funding did, however, increase the spending on reconstruction and reduced the funding needed for that treatment in later years.

5.5.2 Resulting condition of the network

The network conditions resulting from the new data in Analysis 1 (i.e. constant current budget) are shown in Figure 5 for all road types except Motorways (where the condition was Very Good after a few years at the start of the analysis period).

In Analysis 1, the lower percentages of the budgets used for urban A-roads were sufficient to improve the condition over the analysis period (see Figure 5) so the budget allocations could be improved by using some of this budget on the road types where condition deteriorated over the analysis period (e.g. B, C or U-roads). Over the analysis period, only 60% of the urban A-roads budget was spent (see Figure 4) but the Poor and Very Poor condition had been removed (see Figure 5).

In this analysis, the minimum budget[4] was allocated to Motorways but that was more than sufficient for the Very Poor and Poor condition to be treated early in the analysis period and little money was then needed for strengthening treatments in later years.

For A-roads, the percentage in Very Good condition was retained through the analysis period and the improvement in the percentage in Good condition achieved during the first five years was retained for the rest of the analysis period. For rural A-roads there was a small increase in the percentage in Very Poor condition but overall, the total percentage in Fair, Poor and Very Poor condition was constant over the last 25 years of the analysis period. For urban A-roads, the percentage in Very Poor and Poor condition reduced in the first five years of the analysis period. The percentage in Good condition increased while the percentage in Very Good condition remained constant.

The use of nearly all the budgets for B-roads and C-roads was not sufficient to prevent increases in the percentage of these road types in Very Poor condition but over the analysis period there was a decrease in the percentage of the roads in Poor condition. There was also a decrease in the percentage in Good condition during the first 10 years. Sufficient maintenance was undertaken to enable the Very Good conditions to be retained over the analysis period and the percentages in Good condition were constant over the last 15 to 20 years of the analysis period. The percentage in Fair condition was steady for the last half of the analysis period.

The reductions in the percentages of the roads in Good, Fair and Poor condition match the increase in the percentage in Very Poor condition. It is likely that further adjustments to the Treatment Strategies could improve the selection of maintenance treatments (i.e. result in a smaller increase in the percentage in Very Poor condition) but this would need to be paid for by an increase in the percentage of the roads in Poor and Fair condition by redistributing the budgets between road types, if the overall maintenance budget is not increased (e.g. by reducing the share of the budgets for U-roads).

In the data for this analysis, except for the lower budget envelope (which was not used for the current budget level), U-roads receive the biggest percentage of the budget and it is spent in all the years, resulting in the network condition improving for rural U-roads (i.e. the total percentage of Very Good, Good and Fair conditions increases after a small decrease in the early years and the percentage in Poor condition decreases). The funding was not sufficient to prevent an increase in the percentage of these road types in Very

[4] The model cannot allocate less than 1 per cent of the total budget to any road type or maintenance treatment.

Poor condition in the first half of the analysis period for rural U-roads and throughout the period for urban U-roads. With the current budget, the percentage of rural U-roads in Very Poor condition reduced in the second half of the analysis period but is still higher at the end of the analysis period than at the start. For urban U-roads, the percentage in Very Poor condition increased throughout the analysis period.

5.5.3 Indirect (user) costs resulting from carriageway condition

Figure 3 showed the external cost impacts of maintenance funding using the data from the sample of five Local Authorities in Analysis 1 (current level of maintenance funding). This showed the principal impacts arise from carriageway condition and comprise vehicle operating costs and travel time costs with a smaller contribution from the costs of carbon in vehicle fuel.

Figure 31 shows the breakdown of the undiscounted costs of these three primary contributors for Analysis 1, for each of the road types, excluding Motorways. Although Motorways carried higher traffic flows, the annual undiscounted costs of these carriageway condition impacts grew uniformly from only £0.5 to £1.0 billion/year over the analysis period. This is only approximately 6% of the next lowest level of costs (£7 to £15 billion/year for urban B-roads) and approximately 1% of the highest level of costs (£40 to £80 billion/year each for rural A-roads and urban U-roads).

The changes in the condition impacts through the analysis period were generally consistent for all road types (annual costs approximately doubling over the analysis period) with vehicle operating costs contributing the major share. The growth in traffic over the analysis period was less than 50% on all road types (excluding Motorways) (see Figure 2) so it was the increases in Poor and Very Poor condition over the analysis period, seen for B, C and U-roads (see Figure 5) that were the main contributor to the increased vehicle operating costs and travel time costs.

5.5.4 Review of the impacts in the Base Analyses

For Analyses 1, 2 and 3, overall for each analysis, 92% of the available budget was spent using the new allocations but there were differences in the years when most of the budget was spent. For Analysis 1 (current budget), between 91% and 96% was spent in each year year (the spend in the later years is in the lower part of this range). For Analysis 2 (increased budget), 95% of the budget was spent in each of the first 3 years and between 91% and 95% in all years. For Analysis 3 (reduced budget) between 95% and 97% was spent in each of the first 5 years and between 91% and 92% in all later years. The higher percentage in the early years reflects the similar level of spend (compared with Analysis 1) in a lower total budget. The budget in the later years is the same for Analyses 1, 2 and 3 and the small differences result from the variation in the condition in year 6 (for Analyses 2 and 3) for the period using the current budget. These small differences can lead to significant differences in the indirect costs and reinforce the case for making sure the budgets and treatment data repsresent the performance and operation of the network as well as possible. The results for Analysis 4 (performance target) were not affected by the revised budget constraints.

5.5.4.1 Analysis 2

Analysis 2 provided increased funding in the first five years of the analysis period and the same funding level as Analysis 1 from the sixth year. In the first five years, the percentage of the budget spent was a little less in Analysis 2 than in Analysis 1 (see Figure 32), suggesting that for some road types and treatments, all the extra funding was not needed (the funding constraints are based on percentages of the total budget so the constrained level of funding increased as the total budget increased).

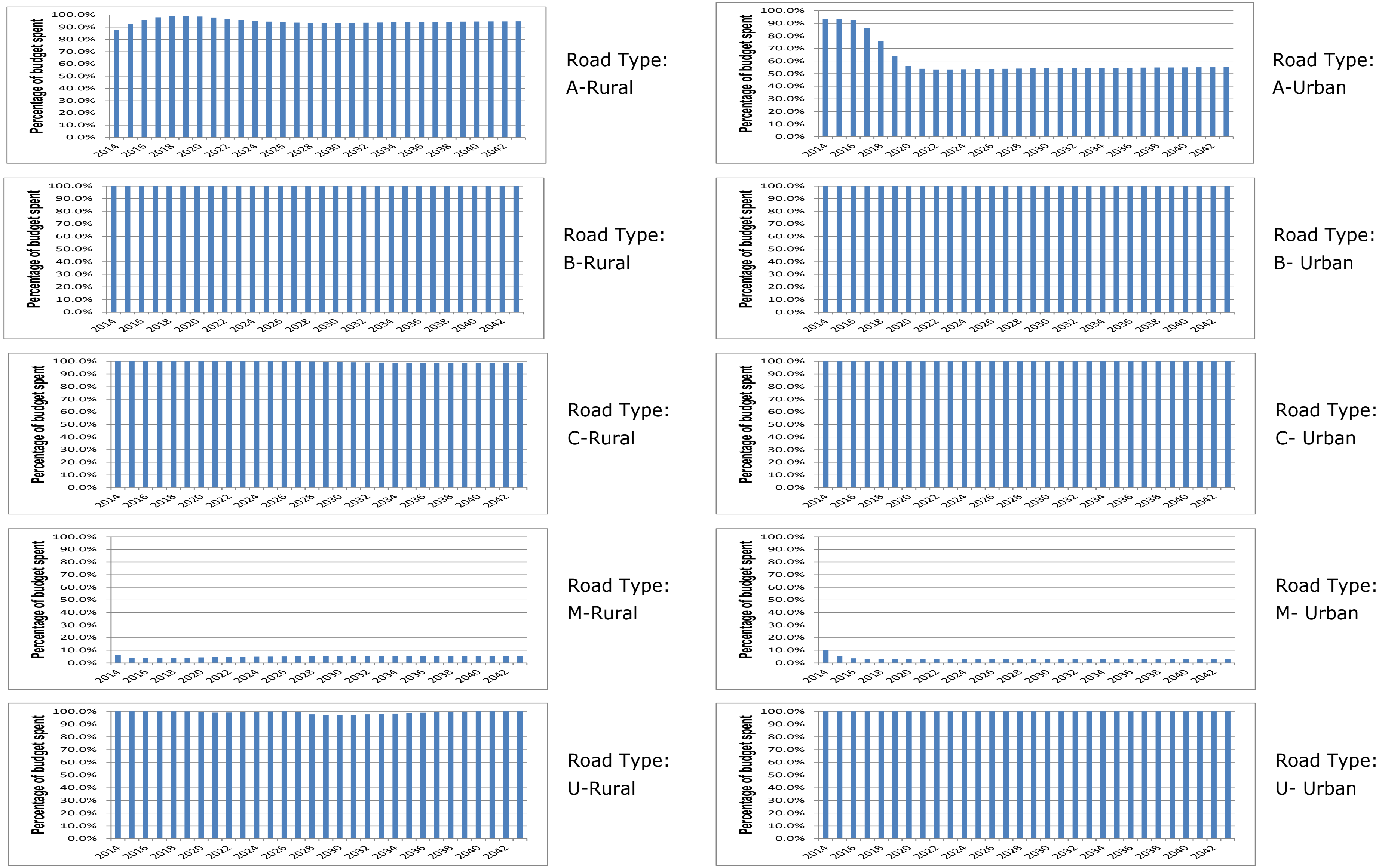
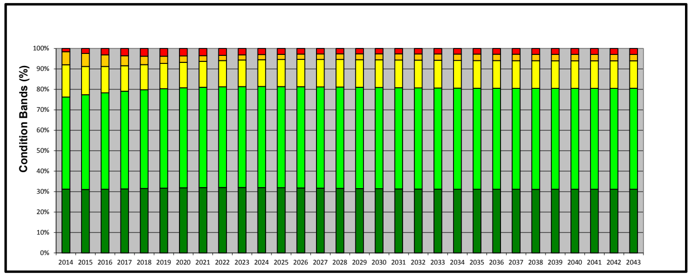
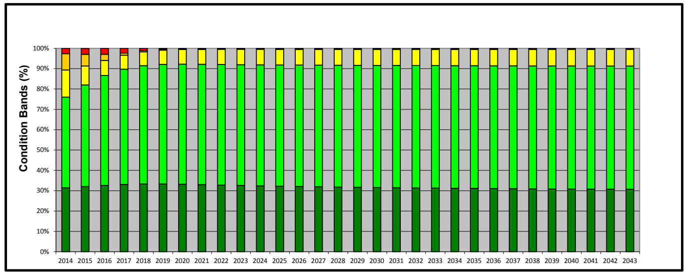


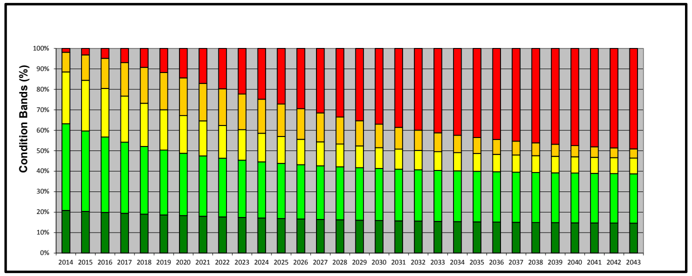
Figure 4: Share of available (undiscounted) budget that is spent: Analysis 1



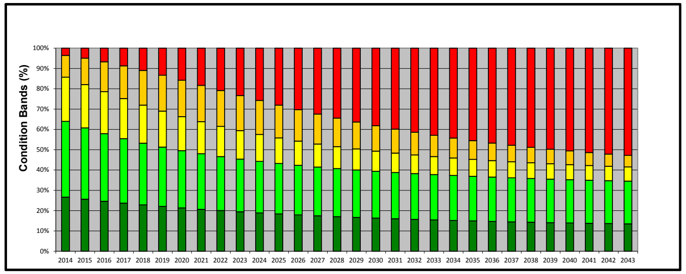
Road Type:
A-Rural



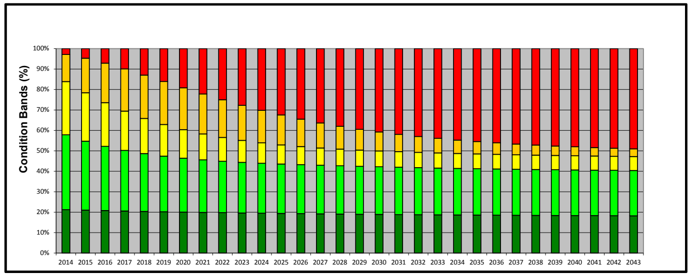
Road Type:
A-Urban



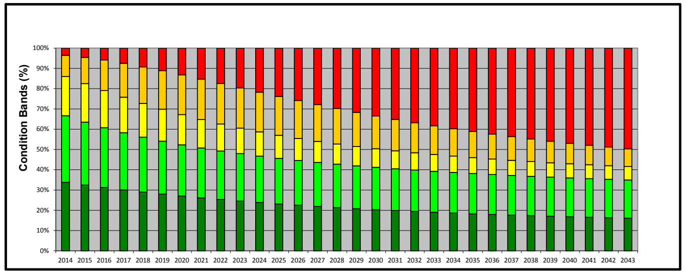
Road Type:
B-Rural



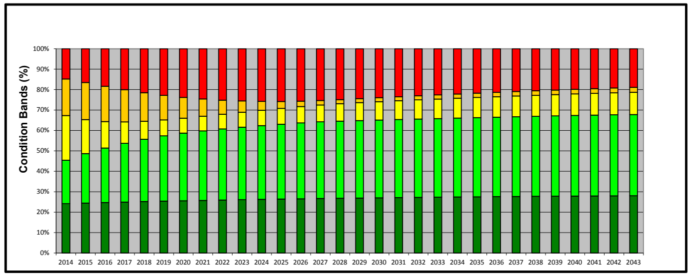
Road Type:
B- Urban



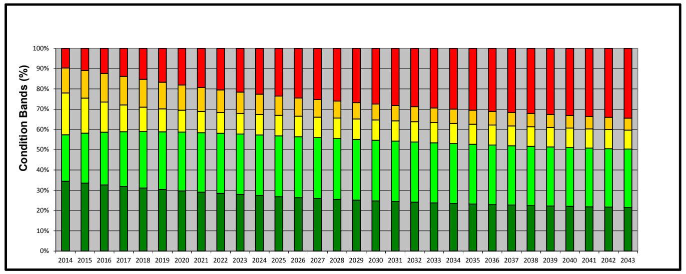
Road Type:
C-Rural



Road Type:
C- Urban



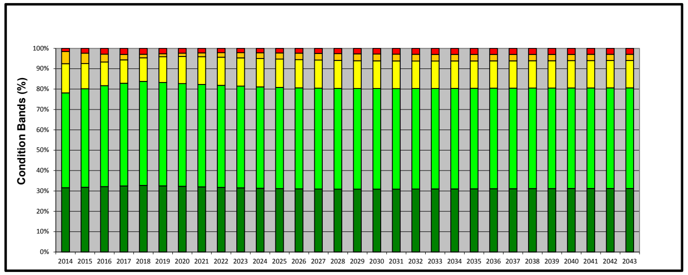
Road Type:
U-Rural



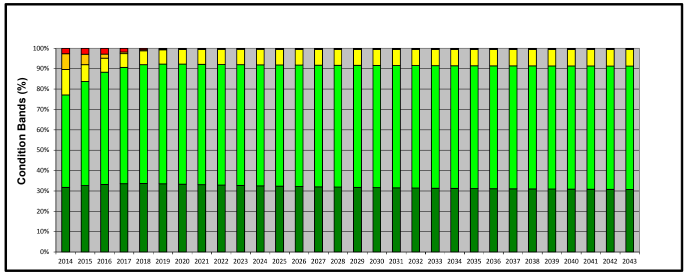
Road Type:
U- Urban

Very Poor Poor Fair Good Very Good

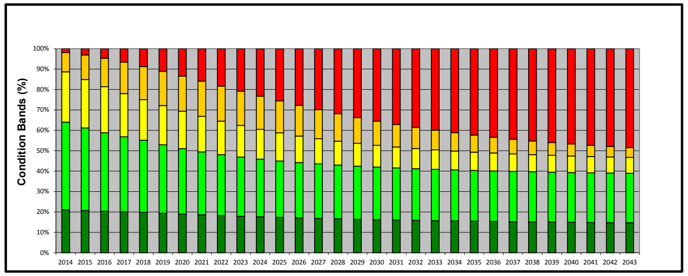
Figure 5: Carriageway condition for each road type: Analysis 1



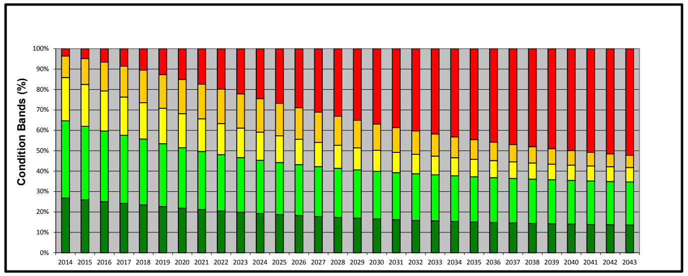
Road Type:
A-Rural



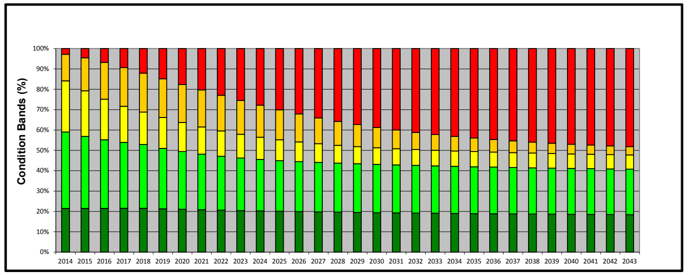
Road Type:
A-Urban



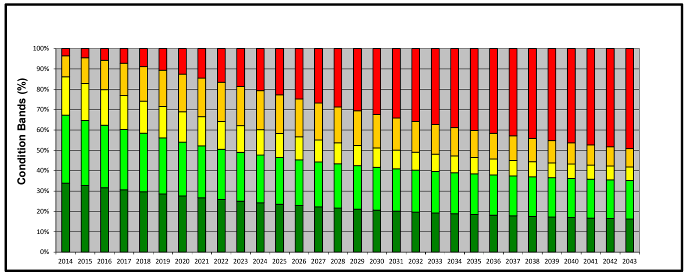
Road Type:
B-Rural



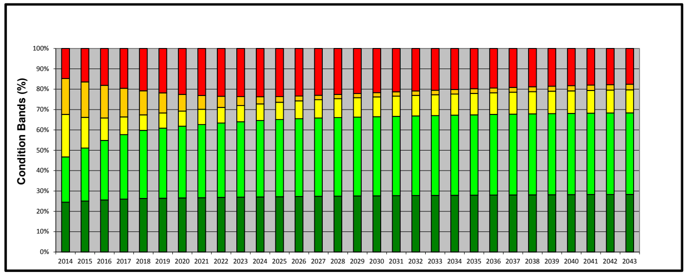
Road Type:
B- Urban



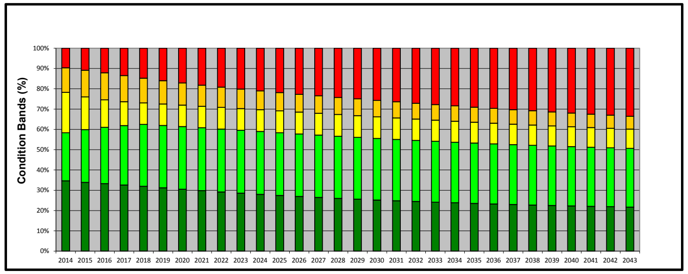
Road Type:
C-Rural



Road Type:
C- Urban



Road Type:
U-Rural



Road Type:
U- Urban

Very Poor **Poor** **Fair** **Good** **Very Good**

Figure 6: Carriageway condition for each road type: Analysis 2

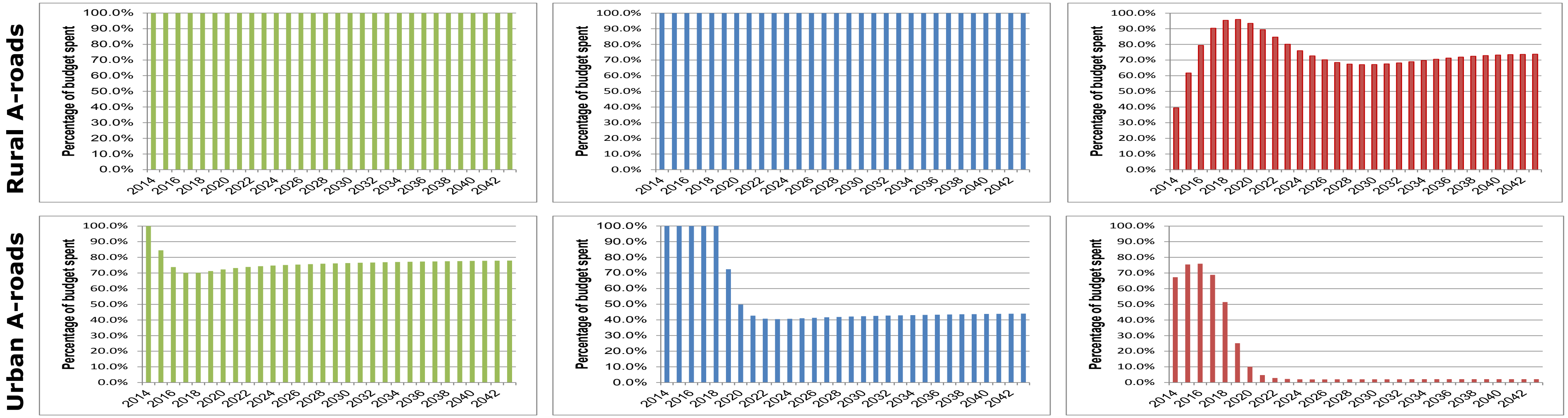


Figure 7: Percentage of budget spent: Analysis 1

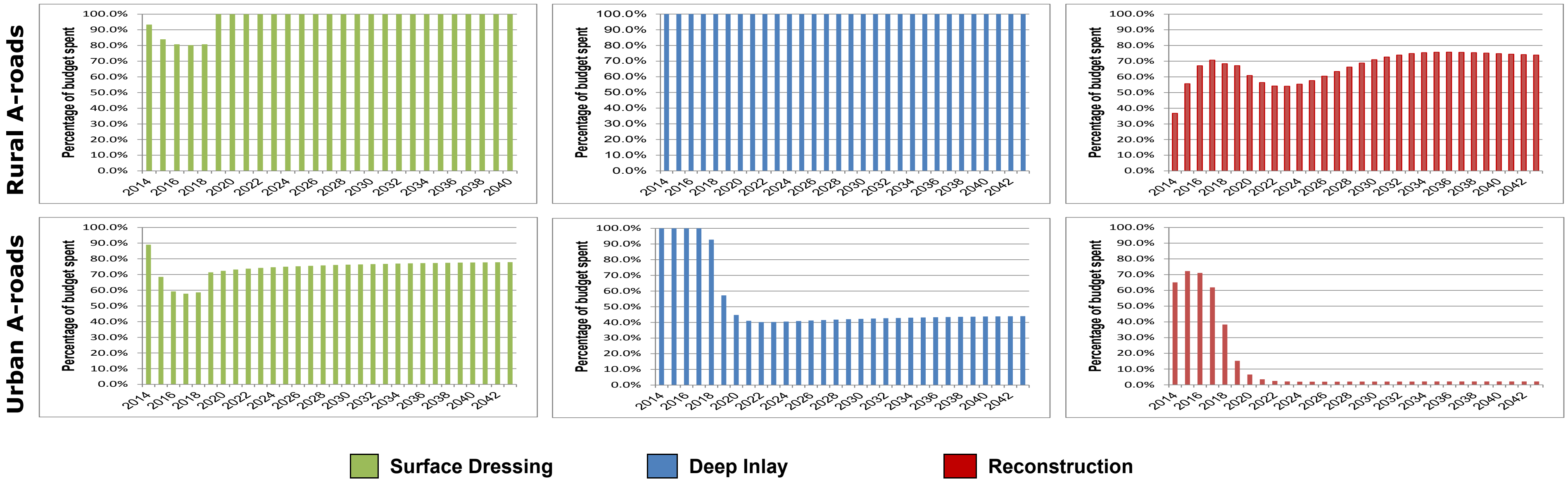


Figure 8: Percentage of budget spent: Analysis 2

Figure 32 shows the increased funding in the early years smoothed the percentage of the budget spent on rural A-roads and the percentages of the budget spent in years 3 to 7 were lower on urban A-roads compared with Analysis 1. With Analysis 2, there was little change in the longer term percentage spend per year on A-roads compared with Analysis 1. For U-roads, there was still a high percentage of the budget spent in each year, but the increased spend in the early years in Analysis 2 created lower percentage spends in years 4 and 5 for that analysis. This was not a significant change and arose primarily because of the particular budget allocation constraints used.

Figure 8 shows the percentage of the available budget spent for Surface Dressing, Deep Inlay and Reconstruction for A-roads and U-roads for Analysis 2. For A-roads, compared to Analysis 1 (see Figure 7) not all the Surface Dressing budget was spent in the first 5 years of the analysis period (i.e. the extra funding was not used). There was no change to the pattern of spend for Deep Inlay but less Reconstruction budget was spent in the first half of the analysis period. In the second half of the period, the percentage of the budget used was similar to the level of spend in Analysis 1.

For U-roads, the biggest change was seen in the percentage of the budget used for Surface Dressing. Lower percentages were used in Analysis 2 compared to Analysis 1 for each of the first five years but there was little difference in later years. In year 6 of Analysis 2, the first year of the use of the current budget level, the percentage of the budget used returned to the level seen in Analysis 1. There was little change for either Deep Inlay or Reconstruction but the percentages of the available budgets used up to year 8 were slightly lower in Analysis 2 compared to Analysis 1.

The small changes in condition caused by the increased funding in years 1 to 5 resulted in only small changes in the condition impacts that are not easily seen when considering the total costs in the analyses. Figure 33 and Figure 34 therefore show the changes in the impacts each year for Analysis 2 compared to Analysis 1. For each of the condition impacts on rural A-roads, the vehicle operating costs are higher with Analysis 1 in the early years of the analysis period as the condition improved with Analysis 2. Similarly, the vehicle speeds were higher at the start of the analysis period, in Analysis 2, so the time costs were reduced but the carbon (from fuel) increased. The same effects on vehicle operating costs and time costs were seen on urban A-roads but the differences were smaller than on rural roads. With the smaller effects, there was also a small reduction in the costs of carbon (from fuel).

The effects on B-roads and C-roads were the same as on A-roads but the changes were smaller. For rural U-roads, the bigger improvements in condition with Analysis 2 showed in lower vehicle operating costs and time costs, and higher carbon (from fuel) costs. The improved condition of urban U-roads also resulted in lower vehicle operating costs and time costs through the analysis period but the conditions and speeds meant the carbon costs were higher for Analysis 2, compared to Analysis 1.

Figure 6 shows the change in network condition for Analysis 2 for all road types except Motorways. The short term increased funding with Analysis 2 did not lead to significant improvements in the condition of any of the road types but did slow the increase in the percentage in Very Poor condition compared to Analysis 1. A-roads were in good condition at the start of the analysis period and the increased funding (compared to Analysis 1) made little further improvement over the analysis period. However, compared with Analysis 1, although the deterioration was slower in Analysis 2, there was little change in the conditions of B, C and U-roads at the end of the analysis period.

5.5.4.2 Analysis 3

Analysis 3 used a reduced budget at the start of the analysis period (for five years). However, the reduced funding resulted in little change to the condition of each road type. The reduced funding caused a small increase in the rate of deterioration of the network (see Figure 35) but the conditions at the end of the analysis period were little different to those seen in Analysis 1. At the start of the analysis period, compared to Analysis 1, more of the reduced budget was used (see the percentage of the budget used on A-roads in the first five years of the analysis period in Figure 36) and was sufficient in both Analyses 3 and 1 to achieve similar percentages of the road types in Very Good and Good condition to those seen in Analysis 2. There was a small increase in the percentage in Very Poor condition with a reduction in the percentage in Fair and Poor condition (see Figure 35) at the end of the analysis period. With analyses of this type, the differences may be small but with long network lengths and high levels of traffic, the small differences can aggregate to large sums of money.

The small increases in the percentage of the budget used are illustrated for A-roads in Figure 36. There was no significant change (compared to Analysis 1) in the percentage of the budget used on any of the road types. Figure 37 shows the percentages of the available budgets used for Surface Dressing, Deep Inlay and Reconstruction on A-roads in Analysis 3. Not all the budgets were spent in Analysis 1 so there was less effect with the reduced budget (Analysis 3) as there was still sufficient funding available and, therefore, still sufficient budgets available for the different treatments compared with Analysis 1 or 2.

Figure 38 and Figure 39 show the changes in the condition impacts with Analysis 3 compared to Analysis 1. The change in the poorer condition at the start of the analysis period resulted in higher vehicle operating costs and slower journeys (and therefore increased time costs) with Analysis 3 but the poorer condition resulted only in slower speeds and lower carbon (from fuel) costs rather than an increased use of fuel (that would result from a bigger worsening of condition). These changes are a reflection of the changes caused by the increased funding in Analysis 2 and are also shown in Figure 33 and Figure 34. For example, for rural A-roads, the worsening condition at the start of the analysis period that resulted from the reduced budget in Analysis 3 is opposite to the effect of the increased budget in Analysis 2.

5.5.4.3 Analysis 4

The target conditions used in Analysis 4 were improved conditions for all road types, compared to the condition at the start of the analysis period and the conditions achieved by the increased funding in Analysis 2. The target conditions were achieved in year 10 (see Figure 40) for all of the road types by increased spends (compared to the current budget level) in the early years of the analysis period on all road types. Having reached the target conditions, those conditions were retained for the rest of the analysis period.

The results of Analysis 4 show the costs of achieving the improved conditions compared to the current levels of budget available for each of the road types (i.e. not the spends from the current budget shown in Analysis 1). The costs are summarised in Table 11 and Figure 41 shows the spend in each year on each road type as the percentage of the allocated funding derived from the breakdown of the current budget level used in Analysis 1.

More than the current budget was needed in year 1 (and again in years 5 and 8) to achieve the target condition for rural A-roads but over the first 10 years of the analysis period the total cost was the same as the current budget and the spend over years 11 to 30 was less than the current budget yet the roads are in better condition. To achieve the target condition for urban A-roads less than the current budget was needed over the entire analysis period. With the current Treatment Strategies, in year 7, for urban A-roads, no maintenance was required to meet the required condition.

For B-roads and C-roads, the spend was approximately four times the current budget in year 1 and between 2.4 and 3 times the current budget over years 1 to 10 but smaller increases were needed over years 11 to 30 to achieve the target condition and then retain that condition.

For Motorways, only a small percentage of the current budget was needed to achieve and maintain the target condition.

The target condition for U-roads was the biggest improvement over the initial condition of all the road types. The cost in year 1 for rural U-roads was more than 2.7 times the current budget level and more than 1.7 times the current budget over years 1 to 10. However, the spend over years 11 to 30 was similar to the current budget level for years 11 to 30 of the analysis period. The condition improvements for urban U-roads required higher spends (compared to the current budget) throughout the analysis period (more than 3.8 times the current budget in year 1 and more than double the current budget over years 1 to 10) The increase in spend over years 11 to 30 was lower but was 1.6 times the current budget for this road type.

Over the entire network, with the specified target conditions for the road types, the significant improvements in condition required an increase in spend, compared to the current budget level, over the first 10 years of the analysis period but the increase was less in years 11 to 30.

Although this analysis was to achieve the specified target levels, the results also show the potential reduced indirect costs from improved carriageway condition achieved by the increased maintenance funding at the start of the analysis period with a smaller overall increase needed in later years. The use of other performance targets and Treatment Strategies may enable the level of these increased costs to be reduced while maintaining the level of benefits.

Figure 42 shows the condition impacts for Analysis 4 for each road type. The composition of the impacts and their variation through the analysis period are similar to those seen for Analysis 1 (see Figure 31). Figure 43 shows the percentage of the current budget for each treatment (Surface Dressing, Moderate Overlay and Deep Inlay) needed for A-roads in Analysis 4. For urban and rural A-roads, less Surface Dressing was needed than would be possible with the current budget allocation. A significantly higher budget would be needed for Moderate Overlay treatments on rural A-roads and a budget similar to the current budget allocation would be sufficient in all years except years 1 and 7 on urban A-roads. The budget needed for strengthening the carriageways (as shown by the Deep Inlay treatment) was very variable. For rural A-roads there was a periodic requirement for extra spend approximately every four years but in all years, more than the current budget level was needed. For urban A-roads, no Deep Inlay treatments were needed in years 1 to 4 or in some years through the analysis period. Only in occasional years was more than the current budget needed.

Figure 44 and Figure 45 show the condition impacts of Analysis 4 compared to Analysis 1 again reflected the differences in the condition of each of the road types. Only for urban A-roads, in Analysis 4, was the condition worse than in Analysis 1 and the vehicle operating costs and time costs were therefore higher in Analysis 4. The carbon (from fuel) costs result from the vehicle fuel consumption and this varies with vehicle speed, which is influenced by carriageway condition. For urban A-roads, the poorer condition still resulted in high carbon costs in Analysis 4 compared to Analysis 1 while the poorer conditions of urban B-roads, C-roads and U-roads did not lead to higher carbon (from fuel) costs in Analysis 4.

Table 11: Spend in Analysis 4 compared to the current budget level (undiscounted costs)

Road Type	Year 1 spend (%)	Year 11 spend (%)	Total spend over years 1 to 10 (%)	Total spend over years 11 to 30 (%)
A-roads (R)	144	88	100	91
A-roads (U)	101	47	66	53
B-roads (R)	396	211	247	204
B-roads (U)	452	249	284	239
C-roads (R)	386	219	261	205
C-roads (U)	396	274	294	255
Motorways (R)	5	5	4	5
Motorways (U)	6	3	4	3
U-roads (R)	271	84	176	107
U-roads (U)	386	173	203	160
Totals	**270**	**128**	**168**	**129**

(R) – Rural (U) – Urban

5.5.5 Analysis summary

Review of all the Base Analyses showed the changes in funding and the use of the performance targets resulted in carriageway conditions and indirect costs in line with expectations and provided further confidence in the reliability of the individual models in the tool and the overall results from HMAT.

The Base Analyses of the national network represent the use of the best model data available after the development and demonstration of the HMAT model. Detailed review of the results from the Base Analyses however suggests that the data is still not fully optimised. Further work is required to improve the representation of a national strategy for managing the highways asset.

However, the tests undertaken within the scope of this project confirm previous evidence that investing in highways maintenance provides good value for money. Comparisons of the results from Analysis 1 with those from Analyses 2, 3 and 4, shown in Table 10, indicate a return of between £2.70 and £4.30 for every £1 spent on direct maintenance works costs (using discounted costs).

Compared to the use of the current budget level (Analysis 1), the overall results of the Base Analyses are similar for the short term changes in budget (i.e. Analyses 2 and 3) but there are apparent higher returns from achieving significant improvements in carriageway condition (Analysis 4).

The analyses show the extra costs (compared to continued use of the current budget levels) of achieving the improved condition vary by road type but the longer term extra costs of retaining the improved condition (for years 11 to 30 of the analysis period) are lower than the costs over years 1 to 10 to achieve the target conditions.

6 Sensitivity tests

Following the Base Analyses (Analyses 1, 2, 3 and 4), seven tests were used to show the sensitivity of the Base Analyses to the use of different values of key data elements. The tests are summarised in Table 12. Appendix C provides more detail on these tests and Figure 9 shows the BCR values for the Base Analyses and the sensitivity tests.

Table 12: Summary of sensitivity tests of the national network

Sensitivity Test	Description	Analyses	Analysis period (years)
A	Appraisal periods	1 and 2	60, 40, 30 and 20
	Appraisal periods	1 and 3	60, 40, 30 and 20
	Appraisal periods	1 and 4	60, 40, 30 and 20
B	Low and high traffic growth	1 and 4	30
C	Low and high works costs	1 and 4	30
D	Treatment strategies in Analysis 1 in reverse order	1 and 4	30
	Treatment strategies proposed by County Council	1 and 4	30
	Reversal of the change in Analysis 3 treatment strategies to the County Council strategies	1 and 4	30
E	Lower and higher condition impacts	1 and 4	30
F	Lower and higher roadworks durations	1 and 4	30
G	Revised budget allocations	1 and 4	30

In Figure 9 the Base Analyses are shown and the levels of the BCR values for the comparisons between Analysis 1 and Analyses 2, 3 and 4 are shown to ease comparisons with each of the sensitivity tests. The BCR values are also shown in Table 47.

The results from Sensitivity Test A show the increased benefits from the longer analysis periods and the other tests show the changes to the BCR values caused by the adoption of the revised data.

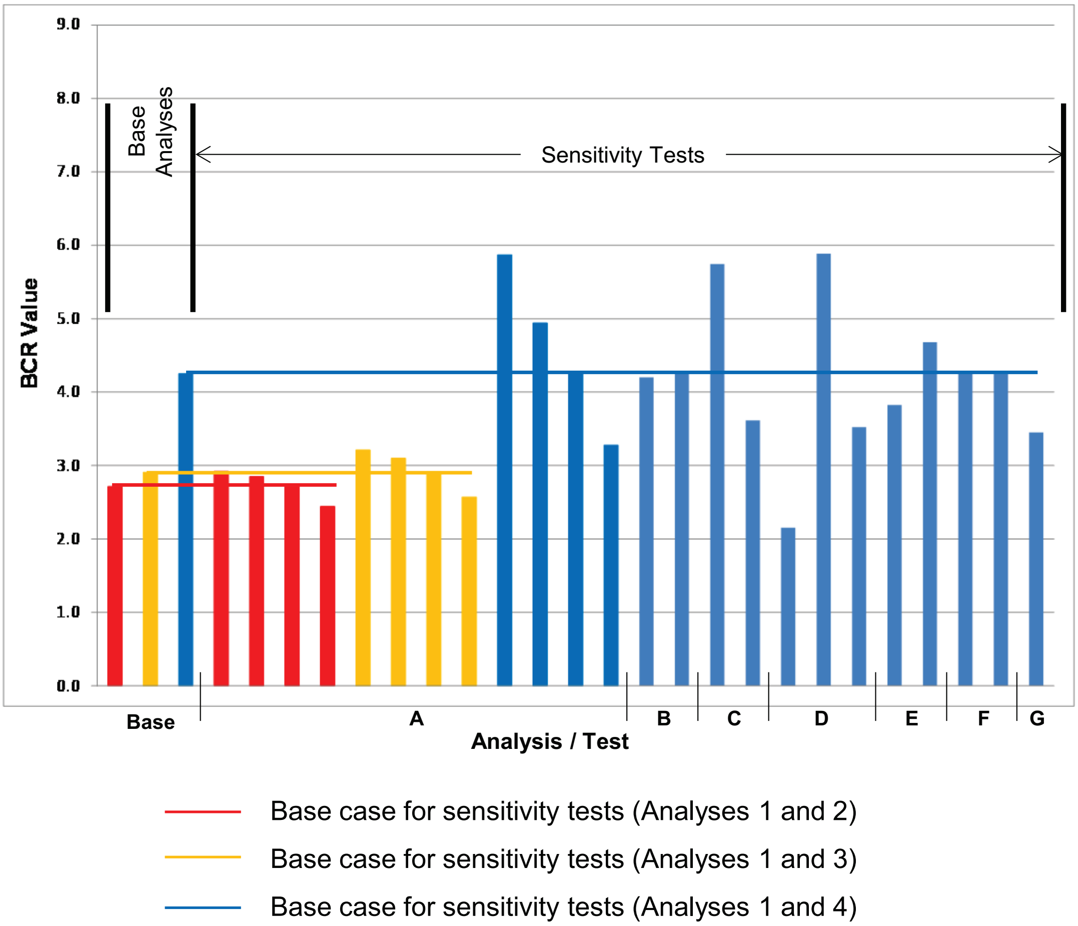


Figure 9: BCR values for the Base Analyses and Sensitivity Tests

7 Summary

The HMAT model development and testing included demonstrating the model with example data. Analyses of the national road network (i.e. local roads in England excluding London) and the carriageway maintenance carried out on that network used data provided from a survey of Local Authorities with statistics for the national network provided by DfT. HMAT was used with the new dataset to examine the effects of different levels of maintenance funding and to assess the potential levels of benefit from carriageways maintenance.

Analyses have been carried out to show the effects of using the new Local Authority data followed by limited sensitivity testing of some of the key data items used by the model. The aims of the base analyses and the sensitivity testing were to provide further assurance in the model behaviour, using representative data for the network, and to demonstrate, with the same data, the use of the HMAT model to assess the wider benefits from changes in road maintenance funding. The analyses were not intended to identify the appropriate level of maintenance funding for the local road network in England as this will require further investigation, using HMAT with the data collected for the national network, and possible variations in the levels of funding.

The Base Analyses represent the use of the best model data available after the development and demonstration of the HMAT model. Comparisons of the results from Analysis 1 with those from Analyses 2, 3 and 4, shown in Table 10, indicate a return of between £2.70 and £4.30 for every £1 spent on direct maintenance works costs (using discounted costs). The results from Analysis 4 support the case for improving the carriageway condition of the network and retaining that condition in the long term but the best target conditions to use on the different road types need further investigation.

The results from the analyses have shown that HMAT is a tool that is capable of examining the direct and indirect costs associated with road maintenance. The results show the behaviour of the model is consistent with expectations but care is needed in selecting the data for the analyses. Nevertheless, the results of the analyses have already shown there are potential savings from reduced indirect costs by increasing the direct maintenance spend above the current budget limits. The data collected from the survey of Local Authorities and used for the analysis of the national network (see Appendix B and Section 5.4) was the best data available in the project for the analysis of the national network. However, it was still a relatively small sample and a wider set of data should be collected to enable the variability across the national network to be examined more comprehensively. Further sensitivity analyses will help to more fully understand the variability in the results caused by the options provided for the model data (e.g. rules in the Treatment Strategies that show how maintenance will be carried out).

There will in the future be the option to modify the rules and algorithms in the model but that should wait until more experience with using the model has been gained.

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Appendix A. Descriptions of the HMAT Modules

A.1 Standard Inputs Module

A.1.1 Overview

The Standard Inputs module captures key information that is used in a number of modules in the model. It ensures that the data needs to be entered once only and helps provide a framework for data to be input in other modules. Some data that may be expected to be entered in this module is entered into the HMEP Toolkit. To avoid changing that toolkit, that data will continue to be entered there. The standard inputs are:

- Road types – the model can accommodate up to 100 road types but 10 types (A, B, C, Motorways and U-roads each of which can be rural or urban) have been adopted to represent the national local road network.
- Average maintenance scheme length for a road (see Table 45)
- Treatment type information including the treatment name (e.g. surface dressing) for use in the HMEP Toolkit (see Table 38) and the carbon consumption for use in the Treatment Impact Analysis module (see Section A.6)
- Road condition information (see Table 36 and Table 37).

A.1.2 Road Conditions

For the purpose of this model, the condition of all the road types is defined by the Carriageway Condition Index (CCI) and it is derived (outside of the model) from either SCANNER or visual condition data. The condition for Motorways, A, B and C-roads is typically based on SCANNER data while that of U-roads is from visual condition data (e.g. Detailed Visual Inspections [DVI] and Coarse Visual Inspections [CVI]).

In England, the CCI is generally described in the ranges by five bands: Very Good (VG), Good (G), Fair (F), Poor (P) and Very Poor (VP) condition. Those bands have been adopted as the base condition bands in the HMEP Toolkit (HMEP, 2012) but the number of bands can be changed.

The SCANNER and visual condition data was transformed into the CCI values for condition projections and definition of the start condition of the network in the HMAT model.

During the development of HMAT, data was sought from five Local Authorities to better represent the condition of the road network and that data was used to demonstrate analyses with the model. Following development of the model, a wider survey of Local Authorities provided data that was used to derive the set of data for the condition of the network at the start of the analysis period. The data was used in the application of HMAT to the national (excluding London) local road network in England.

A.1.3 Comment on key assumptions

One key assumption was made related to this aspect of model development. The assumption is noted and commented on in Table 13.

Table 13: Key assumptions related to the standard inputs module

Assumption	Comment
All analyses use carriageway length so no differences between lanes are modelled	On roads with more than one lane in a given direction, there is usually considerably greater deterioration in the nearside lane due to the impact of heavy vehicle traffic. On some roads (e.g. approaching ports) there might also be significant differences in the conditions in each direction. Neither effect is modelled given the very significant increase in complexity, from different deterioration models and traffic distribution models that would be required.

A.2 Activity Allocation Module

A.2.1 Overview

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.

When considering how to apply budget changes across its range of maintenance activities, a highway authority will consider the impact on its overall strategic objectives. This is usually set out in a corporate plan and stated as a number of asset management, or maintenance, drivers for the road network.

When prioritising activities within constrained budgets, a Local Authority will also consider the road type (e.g. A-roads, B-roads etc.). For example, with changing budgets, it is likely that the change to the budget for B-roads will be different to the change for the more strategic A-roads on the network.

Activities are usually defined in published budgets at a fairly coarse level of definition. For example, structural maintenance might be applied to both bridges and carriageways and there is a range of treatments (e.g. surface dressing, resurfacing, overlay etc.) which are applied to carriageways. Some of the treatments will affect only the surface of the carriageway while others provide a new, stronger, carriageway. During times of budget constraint, Local Authorities will not only vary the relative spend across activities and road types, but also within an activity type by varying the proportion of budget used for different treatment types.

The application of asset management, or maintenance, drivers, road type and treatment type information to derive the allocation across the different activities is the purpose of the Activity Allocation module.

A.2.2 Overall approach

The list of activities which make up the overall maintenance investment was identified. Typically, these will be the line items in the published maintenance budget. As the level of maintenance spend changes, so too might the allocation of spend to different activities. By defining envelopes of the ranges of budgets that might be applied in any year, the proportion of the budget available for each activity can be specified within lower, mid, and upper budgets. This aims to reflect the fact that at low levels of budget, high priority activities (e.g. a safety driven activity) will probably be protected and represent a higher overall proportion of the budget than at higher levels of budget, when other, more discretionary activities (e.g. graffiti removal and vegetation control) will also be funded.

For each of the three budget levels which define the envelopes, the user also enters information on maintenance drivers, road types and treatment types.

A.2.3 Maintenance drivers

A review of various Local Authority corporate/asset management plans, WebTAG and Scottish Transport Appraisal Guidance (STAG) (Transport Scotland, 2008) objectives was undertaken to determine whether there is any commonality in which maintenance drivers are the most relevant. A summary of the maintenance drivers for the different authorities and sources is shown in Table 14.

Table 14 suggests that the most common maintenance drivers across the different Local Authorities are safety, economy, environment and accessibility. These also appear as criteria in the WebTAG and STAG guidelines. Whilst each Local Authority will have different specific needs, the analysis suggested that there are some common themes which are repeated and some similar themes which are labelled differently. For example, air quality could be considered to overlap with the sustainability, environment and quality of life drivers.

HMAT has been designed to assess the overall economic impact of different levels of maintenance investment and so, in itself, the economy driver was not seen as appropriate for inclusion as a separate driver. From the range of themes identified, six default maintenance drivers were identified as common drivers for maintenance funding allocation by Local Authorities:

- Safety
- Accessibility
- Condition
- Reliability
- Customer Service
- Environment

In the HMAT model, for each maintenance activity, the user identifies the relative contribution of that activity to each of the six drivers. Note that there is no 'correct' approach for these definitions and it is for the user to define the relative contributions based on experience and subjective interpretation of the local context. Note also that the relative contribution can be varied for three budget levels (lower, mid and upper), to reflect the fact that, for example, road reconstruction projects might have a high safety driver at low levels of overall investment, but at higher levels of investment, more road reconstruction projects might be selected that address other aspects (e.g. network reliability concerns). It is not necessary to vary the drivers with budget level and as a starting point, it might be appropriate to define the contribution to each driver once for each activity and use that allocation for all budget levels.

Table 14: Local Authority maintenance drivers

Maintenance Drivers	DfT WebTAG	Scottish Transport Appraisal Guidance	Torbay Council	Surrey County Council	Coventry City Council	Sheffield City PFI	North Yorkshire County Council	Slough Borough Council	London Borough of Hammersmith and Fulham
Safety	✓	✓	✓	✓	✓	✓	✓	✓	✓
Economy	✓	✓		✓	✓		✓		
Environment	✓	✓		✓	✓		✓	✓	
Condition					✓				
Accessibility	✓	✓			✓	✓	✓	✓	
Serviceability			✓						✓
Sustainability			✓						✓
Customer Care									✓
Integration	✓	✓			✓				
Quality of life						✓	✓		
Congestion						✓	✓	✓	
Efficiency							✓		
Air quality						✓		✓	
Community								✓	
Reliability									

Note: Local Authorities were chosen to represent the range of Authorities (i.e. County Council, City, Borough and PFI) across England.

Source: Refer to Section 8.

The use of the maintenance drivers enables the overall budget contribution to each of the maintenance drivers to be seen and therefore show how the qualitative impacts may be affected by different maintenance budgets.

A.2.4 Road types and treatment types

For each of the budget envelopes, the user defines how the budget is allocated across the different road types. For the carriageway related activities, the proportion of the budget allocated to each of the user defined treatment types is also defined by the user. As for the maintenance drivers, both of these definitions should be determined by the user based on experience of the network being analysed and the objectives for the operation of the network. The definitions are needed so that the budget allocation can be disaggregated to the level of detail needed by the HMEP Toolkit (HMEP, 2012).

A.2.5 Comment on key assumptions

Two key assumptions were made related to this aspect of model development. Each assumption is noted and commented on in Table 15.

Table 15: Key assumptions - Activity Allocation module

Assumption	Comment
The proportional cost allocation to maintenance drivers is the same for budgets within a budget envelope and is not interpolated (unlike the activity budget proportions, road and treatment type proportions).	There is no 'theoretically correct' approach to adopt for the activity allocation module. The adopted approach aims to reflect reasonably good practice within a road administration. In designing this module, the aim has been to strike a balance between the complexities of managing activities across a road network while keeping the approach relatively simple to use in the model.
Performance based analyses generate the carriageway budget required. There is no need to factor that budget back to the overall maintenance budget.	The maintenance drivers are described to show how the carriageway budget can be derived from the total maintenance budget. The design does not allow the total maintenance budget to be generated from the carriageway budget.

A.3 Traffic Projection Module

A.3.1 Overview

Traffic growth rates, operating cost, user delay cost and vehicle emissions vary depending on the vehicle type. This module requires the user to enter the relevant data to enable all such calculations to be undertaken in the model.

A.3.2 Vehicle types

Based on the HDM-4 study undertaken for the local English road network (WSP, 2010), the study on the Scottish local road network (Parkman et al, 2012) and the RAC Foundation study (Gould et al, 2013), it was understood that there are significant differences in the economic vehicle operating costs of different vehicle types and the variation in the costs with carriageway condition. This is specifically relevant for goods vehicles where it was found that there are significant cost differences between vehicles with 3-axles, and 4-axles and more.

The five typical vehicle types used in the model fit the WebTAG differentiation of vehicle types:

- Cars including cars, taxis and motorbikes
- Light Good Vehicles (LGV)
- Ordinary Good Vehicles type 1 = Rigid 3-axle + Articulated 3-axle (OGV1)
- Ordinary Good Vehicles type 2 = Rigid 4-axle + Articulated 4, 5 and 6-axle (OGV2)
- Buses and coaches (PSV)

The traffic projection module uses these five categories of vehicle types to support the Condition Impacts and Treatment Impacts modules (as described in Section A.5 and Section A.6). Flexibility to define different vehicle types to these five is not allowed as those analysis modules depend on data in look-up tables which has been provided for that set of vehicle types.

Traffic growth is entered for each vehicle type and can either be input separately for each road type or be entered for the network in its entirety. Default traffic growth rates have been provided from the National Traffic Model (NTM) for traffic growth until 2040. Clearly, the prediction of future traffic so far into the future has a high degree of uncertainty. However, by allowing flexibility to define the traffic growth rate for each year of the analysis period, the effect of other assumptions can be tested.

Differentiation by engine type (electric, petrol, diesel) is derived based on data provided in WebTAG (DfT, 2014).

A.3.3 Comment on key assumptions

Four key assumptions were made related to this aspect of model development. Each assumption is noted and commented on in Table 16.

A.4 Treatment Analysis and Condition Projection Module

A.4.1 Overview

As stated in Section 3.3, the HMEP Lifecycle Planning Toolkit (HMEP, 2012) is the basis for the predictions of treatments and the impacts on road conditions. It has been incorporated unchanged within the model for consistency with other analyses and to allow for ease of update should future enhancements be released in the future. The inputs and setup required for the toolkit are as described in the guidance for that toolkit.

A.4.2 Set up requirements

The HMEP Toolkit is flexible in terms of how many asset types and condition bands it can analyse. The default setup is for a carriageway analysis and for five condition bands. The road type and condition band definitions to be used in an analysis with this model are specified in the Standard Inputs module, and that information is used in the HMEP module.

Table 16: Key assumptions - Traffic projection module

Assumption	Comment
Carriageway condition does not affect the distribution of vehicles on a road type or between road types (i.e. traffic for a road type is smoothed over the length of the road type irrespective of condition).	With marginal changes in condition, this is a reasonable assumption. As road conditions deteriorate and there becomes a greater difference in condition between the good and poor parts of a network, this assumption may not hold. However, any more sophisticated analysis would need to be based on quantifiable evidence which has not been found in the literature.
Carriageway condition is assumed to represent the whole carriageway (although SCANNER data for Principal and other Classified roads is collected by lane) so the distribution of vehicles across lanes will not be needed.	For Principal roads such as dual carriageways, this assumption is quite coarse. However, to analyse the performance of each lane would be a significant increase in complexity for the model. Overall, dual carriageways only represent a small proportion of the local road network but may represent a significant proportion in some local areas.
In practice, a range of traffic flows will exist on each road type but it is assumed the representative AADT is consistent for each road type.	As for other assumptions on traffic, this is a starting point. Sensitivity testing could be carried out to establish the significance of the assumption by considering different traffic levels (veh-km) and investigating the effect on the treatment impact analysis module outputs – which are the only outputs affected by this assumption.
Vehicle types used in the model have been identified based on the significant differences in economic costs of different vehicle types (and consistent with earlier HDM-4 analyses of the local road network (WSP, 2010 and Parkman et al, 2012).	See main text for discussion on this aspect.

The expectation is that the defaults proposed in the Standard Inputs module for the national network will be used. If changes are made to these inputs, by introducing a new road type, or by changing the number of condition bands (or the basis of their derivation), then more experience will be needed to establish a robust model set-up. This is because the impacts model has derived standard look-up data tables based on the standard road types and condition bands, and, if these are changed, validation of each aspect of the impacts model will be needed.

The length of each road type in each condition band is specified before moving to other worksheets to complete other more detailed setup requirements for the HMEP Toolkit as described in that guidance (HMEP, 2012).

A.4.3 Compatibility with existing Local Authority approaches

It is noted that the HMEP Toolkit is for reasonably complex strategic analyses of road network maintenance requirements under different budget scenarios. It adopts a tried and tested probabilistic modelling approach. Arguably, for the assessment of the economic benefits of maintenance, the toolkit is more advanced than is required and a simpler analysis module could be derived. However, the advantages of working with recently developed industry led HMEP techniques as far as possible led to the conclusion that this remained the most appropriate solution.

A.4.4 Testing the appropriateness of the HMEP Toolkit

The toolkit was tested to establish the credibility of its outputs and ascertain how far it will need to be calibrated to each specific local road network or nationally. This testing was completed at an early stage in the project with different budget scenario definitions but the results are still appropriate for the final developed model. In summary, the tests showed that:

- Using the national condition information currently available, the predictions of performance of the network using the HMEP Toolkit give plausible results. The predicted steady state expenditure requirements suggest long term budget requirements (i.e. total spend over analysis period divided by number of years in analysis period) not dissimilar from current Local Authority spend in England. No anomalous behaviour is seen in the results (e.g. reduced budgets suggest conditions will deteriorate).
- Refinement of the HMEP Toolkit will be required in order for it to reflect more closely the realistic performance of the local road network. In particular, the establishment of performance targets and treatment strategies which are used to derive the steady state predictions will need to be calibrated, particularly to address the significant changes in network conditions predicted by the toolkit in the early years of the analysis period. Further use of the toolkit showed refinements of the HMEP Toolkit setup (e.g. altering default setup parameter values within the toolkit) enabled the analyses required in this project to be completed.
- With budget variations of ±20%, it has been shown that there are no 'tipping-points' evident where the condition of the network becomes exponentially divergent to conditions expected. Changes are shown to be far more gradual for the budgets analysed. Using the default setup, it could therefore be concluded that the tipping point for condition projection assumptions will be outside the ranges of budget variation considered in this project.

A.4.5 Comment on key assumptions

Six key assumptions were made related to this aspect of model development. Each assumption is noted and commented on in Table 17.

Table 17: Key assumptions - Treatment Analysis and Condition Projection module

Assumption	Comment
Default data required by the HMEP Toolkit could be sourced from the HMEP User Guidance where appropriate.	The toolkit has been unchanged and incorporated for use within the model of impacts on road users and society, to allow for ease of update and for consistency with existing analyses.
Wherever possible no changes are made to the HMEP Toolkit process and algorithms.	No changes have been made, for the reasons stated in the first assumption.
The effect of any future utilities work is not accounted for in model projections of road condition.	Utilities work is not predictable but is often one of the major reasons that (particularly urban) road networks become rougher and uneven. Roughness is the defect which impacts on road users in terms of costs and perception. However, there is no ability to predict utility work with a generic toolkit so if these effects need to be considered it must be outside of the HMEP toolkit.
The projections assume no significant change to traffic levels or environmental effects during the analysis period beyond that already assumed inherent in the definition of the transition matrices.	The HMEP Toolkit is a probabilistic model which predicts future conditions based on the current conditions on the network. It includes no relationships which relate deterioration to causal factors (e.g. traffic, environment). Such a detailed approach would be inappropriate for the overall, strategic approach required for this study. Consideration of specific effects could be made based on user judgement and calibration of the transition matrices for various user defined scenarios.
Network length and length of each road type remain constant over the analysis period.	From time to time network improvements might change the length of any network. Also, roads might be reclassified as a different road type or the local road network may be increased by de-trunking parts of the trunk road network. No account is taken of such changes in the model as in general, such changes are small (e.g. a network upgrade, or addition of a lane) for the purposes of the model outputs, and such changes are also usually not predictable for specification through the analysis period.
An average width can be used for all roads in a road type and that width remains constant over the analysis period.	The effect of differences in road widths and potential changes in road width are considered relatively marginal for the purpose of the analyses. The network may be split into more road types by assuming more than one width for a road type but this was not

Assumption	Comment
	considered necessary for the current state of development of the model. The effects on carriageway deterioration, maintenance costs and vehicle operating costs are small. Road width may impact on the cost of delays to traffic at roadworks but this effect is also considered a small part of the overall impacts.

A.5 Condition Impact Analysis Module

A.5.1 Overview

As road carriageway surfaces deteriorate, there are various impacts that can be quantified:

- Changes in unevenness result in variations in vehicle operating costs due to:
    - Fuel consumption
    - Consumption of lubricants
    - Wear and tyre on tyres and other parts
    - Depreciation of vehicle value
- Travel speeds change and so affect travel time costs
- Changes in fuel consumption lead to changes to the generation of CO_2 and other emissions

The Condition Impact Analysis module was designed to quantify these effects.

Road safety might also be compromised as carriageway condition deteriorates. Higher safety risks due to reductions in the skid resistance of surfaces might result in increased accident costs and these are described in Section 3.8 and Section A.7. Other potential safety related risks (e.g. vehicles swerving to avoid potholes) cannot easily be quantified and so are not captured within the model.

A.5.2 Approach

In general, for countries where roads have historically been built and maintained to deliver smooth travel over the life of the carriageway, 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). Consistent with this general view, the DfT WebTAG requirements for assessment of vehicle operating costs give no guidance on the impact of road roughness and are based only on travel speed, alignment and distance travelled.

Section 3.6 has described the approach using HDM-4. 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 the 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^2 in 3m wavelength Longitudinal Profile Variance, LPV, at base ride quality levels of 4 mm^2 LPV).

A.5.3 Calibration of the model for local roads in England

A.5.3.1 Relating English local road conditions to road roughness

It was necessary to identify a transformation of existing and typical English local road condition data to the roughness parameter (IRI) used in HDM-4. The analysis which derived this transformation showed:

- The derivation is based on data from recent SCANNER surveys for the full English local road network and has been carried out for each road type separately
- The CCI from the SCANNER data was derived, and grouped into condition bands as defined in the HMEP Lifecyle Planning Toolkit (Very Good, Good, Fair, Poor and Very Poor)
- For each road type, a default transformation matrix of CCI to IRI has been produced and included within the HMAT model
- For U-roads, there was limited SCANNER data available. During the development of HMAT the distributions of the condition of C-roads were also used for U-roads. In the analyses of the national network, visual condition data was used to represent the condition of U-roads.
- For Motorways, the limited data available meant that the distributions for the A-roads were also used for Motorways

Given the approach adopted, care is needed if the network is to be analysed with a different number of condition bands or based on a different condition parameter. New transformations would need to be derived to be consistent with the default approach adopted for the model.

A.5.3.2 HDM-4 setup and integration with WebTAG requirements

A series of runs with HDM-4 were completed using the vehicle fleet information (Section A.3) and based on assumptions for required parameters to describe the vehicle types described in Section A.3. However, as far as possible, the approach was integrated with WebTAG requirements by, for example:

- Setting the cost of fuel to £1 per litre within HDM-4 and then using data from WebTAG Table A1.3.7 to factor this cost for application in the UK for each year of the analysis
- Applying the projected vehicle efficiency improvements (Table A1.3.10) in WebTAG (DfT, 2014) to the projected fuel consumption figures generated by HDM-4

The outputs of the HDM-4 runs are captured in a series of look-up tables of condition by vehicle type and the WebTAG requirements, where relevant, are applied separately. Adopting such an approach allows for straightforward future updates:

- If adapted HDM-4 analysis runs are required, they can be completed and inserted in place of the current look-up tables
- If WebTAG is updated, the relevant updated WebTAG tables can be inserted into the model in place of the existing WebTAG tables

A.5.4 Comment on key assumptions

Six key assumptions were made related to this aspect of model development. Each assumption is noted and commented on in Table 18.

Table 18: Key assumptions - Condition Impacts module

Assumption	Comment
The HDM-4 model typically requires the relationships built into the model to be calibrated. Calibration coefficients from the earlier study of the impacts of maintenance (WSP, 2010) are used where these are available and it is assumed that these are appropriate for the UK local road network.	The approach to calibration has been described in this Section.
The vehicle operating costs analysis assumes that traffic is distributed evenly over the network. In reality it is likely that the distribution of traffic is skewed towards the parts of network in very good and good condition.	This effect could be assessed by carrying out some sensitivity testing but would require minor modification to the model as currently designed. The assumption is considered the most appropriate first step in understanding the effect of carriageway conditions on vehicle operating costs.
The vehicle operating costs analysis will not make use of congestion modelling available in HDM-4. Therefore the impacts of congestion will not be reflected in the outputs, only the impact of carriageway roughness on vehicle operating costs. No account is taken of any impact of congestion on the vehicle operating costs relationships.	Congestion is a significant issue on many parts of the network. Congestion increases vehicle operating costs due to increased stop/start conditions and vehicle idling (although this will be somewhat exacerbated with more modern vehicle designs). Introducing congestion effects into the vehicle operating cost model would represent a significant increase in complexity and data requirement. Assuming road surface conditions have only a marginal effect on travel patterns, it is

Assumption	Comment
	considered reasonable to adopt the proposed approach and assume that congestion effects will not change due to levels of maintenance investment.
Calculations of the mass of CO_2 produced from the fuel use analysis assume that perfect combustion occurs (i.e. all the fuel is burned with no by-products). In practice, combustion includes Hydrocarbon and other by-product emissions (e.g. Carbon Monoxide [CO]), but this effect is much less than 1%. After time the Hydrocarbons and CO degrade to CO_2 in the atmosphere.	The assumption is considered the best reasonable approach and the effect identified is only considered marginal.
The fuel use analysis assumes that the fuel consumption model used in HDM-4 is based on a vehicle with comparable fuel consumption characteristics to the baseline (2010) vehicle in WebTAG (DfT, 2014).	This assumption would need further detailed review to provide more assurance on its level of significance. HDM-4 is based on a wide range of international studies which were collated in the mid-1990s. Therefore they are based on vehicle types of around, say, 20 years older than the average age of the fleet of cars on the UK road network. However, the DfT data is based on the most recent updates in UK (Boulter et al, 2009) and so are significantly more up to date.
Not all vehicles can be modelled as both petrol and diesel fuel types in HDM-4. For example a car is set as petrol fuel type but the HMAT tool requires data for a petrol and diesel cars in order to undertake a full analysis. The HDM-4 output data was used to derive consumption data for both fuel types using the values for energy content of transport fuels (Bennett and Greenwood, 2003). The created look-up table therefore contains reliable look-up data for both fuel types for all vehicles.	This assumption is considered robust in deriving consistent fuel consumption data for different fuel types over lengths of different condition. The user should also note that electric vehicle fuel consumption has only been related to distance travelled and no attempt has been made to fit the HDM petrol/diesel model to varying rates of fuel consumption depending on road condition for vehicles with these engine types.

A.6 Treatment Impact Analysis Module

A.6.1 Overview

As a result of the treatments undertaken on the network there are various impacts that could be quantified:

- Embodied carbon from the maintenance activity

- Costs of delays experienced by road users and society, expressed as costs for:
    - Additional time delay due to roadworks.
    - Change in accidents due to roadworks.
    - Change in carbon costs due to roadworks.

The Treatment Impact Analysis Module was designed to quantify these effects.

A.6.2 Approach

The treatments predicted by the model result in the lengths of carriageway to be maintained. This maintenance can be translated into a number of schemes based on an average scheme length for each road type. When more maintenance is undertaken it impacts users by creating more disruption on the network and if lower-cost maintenance options that require more frequent interventions are chosen over more comprehensive treatments that can compound the additional maintenance experienced when assessed over the long analysis period. Therefore, there is a trade-off to be made between the costs and effects of maintenance (i.e. improving condition) and the additional impacts of the maintenance (e.g. delays).

A.6.3 Measuring delays

The software package Queues and Delays at Roadworks (QUADRO) is an approved approach for measuring the impacts of delays at locations where roadworks are experienced (DfT, 2002).

A series of runs of QUADRO using the ten default road types and five vehicle types were used to create a look-up table of costs for use in HMAT. For each road type a default closure was assumed which was modelled under a range of traffic levels and different HGV proportions for each traffic level. The closures were modelled for twenty-four hour closures, off-peak only closures and night closures (due to the different costs associated with each closure type as a result of the different traffic levels experienced during a twenty-four hour period).

The modelled closures resulted in costs for each of the five vehicle types (cars, LGV, OGV1, OGV2 and PSV) normalised for 'per hour per vehicle' for each of the different closure periods and traffic levels.

The output look-up tables derived from the QUADRO runs show the costs by road type, closure type, HGV proportion and traffic flow. Adopting this approach allows for future updates:

- If further QUADRO runs are required, they can be completed and inserted in place of the appropriate look-up tables generated to date.
- If a new version of QUADRO is released, the tables can be updated.
- QUADRO runs can be undertaken if representations of the network by different road types or traffic on the network by different vehicle types are required.

A.6.4 Measuring embodied carbon

The tool used to determine the embodied carbon for the maintenance treatments was the asphalt Pavement Embodied Carbon Tool (asPECT) (Wayman et al, 2011). The tool takes account of the CO_2e (carbon dioxide equivalent) impact of building or maintaining a road, following the requirements laid out in BSI PAS 2050:2008 (British Standards Institution, 2008) and has a clear set of rules that have been implemented to determine the carbon emissions associated with bitumen bound mixtures (Wayman et al, 2011). The protocol clauses within the software have been endorsed by the Highways England, Mineral Products Association (MPA), Refined Bitumen Association (RBA), Association of Directors of Environment, Economy, Planning and Transport (ADEPT) and TRL.

Within this tool the CO_2e content of individual asphalt mixtures is calculated through a summation of the:

- Cradle-to-gate CO_2e from each material.
- Transport from the factory gate to the plant.
- CO_2e from the energy used to produce the asphalt at the mixing plant (excluding that used for heating and drying).
- CO_2e from the process of heating and drying the mixture and ancillary materials.
- Transportation to site.
- Energy from laying and compacting.
- CO_2e from additional materials used on site.

Runs of the asPECT tool were completed for six treatment types. For each treatment type, the mixture and associated treatment data (e.g. depth planed out, recycled content) were assumed for modelling.

The modelled treatments resulted in quantities of carbon for each of the five treatment types normalised for 'kg $CO2_e$ per m^2'.

The outputs from the asPECT runs resulted in values that can be entered as inputs to the HMAT model. If adapted treatment types are required, asPECT can be used to generate a specific carbon quantity for the new treatment, or make use of a suitable value from the six treatment types analysed to date. It is recommended that a specific value is calculated for each treatment so that the model can accurately calculate the impacts from the different funding analyses as closely as possible.

A.6.5 Comment on key assumptions

Eight key assumptions were made related to this aspect of model development. Each assumption is noted and commented on in Table 19.

A.7 Accident Analysis Module

A.7.1 Overview

The purpose of this module was to establish the predicted safety impacts in terms of accidents from two specific sources:

- Changes in skid resistance on the network due to changes in road surfacing budgets
- Changes in lighting availability due to changes in lighting budgets

Table 19: Key assumptions - Treatment Impacts module

Assumption	Comment
Closures are 1 by 1 lane closures on D2AP and D2M (i.e. 1 lane remains open in each direction during maintenance). No other numbers of lanes were used for dual carriageways.	Multi-lane dual carriageways with more than 2 lanes per carriageway make up only a very small part of the local road network. Although other closures will be experienced on networks these were deemed to be suitable representative closures for these road types. The time difference between a contraflow and lane closure when modelled is small when the same number of lanes remain open in each direction.
Closures are shuttle working on S2AP.	On single carriageways a shuttle working (i.e. traffic-light controlled) closure was deemed the most representative for local roads. Lane closures with lanes open in each direction are unusual on local roads due to the lack of road space required for a safe working zone.
Closure lengths are as specified for default scheme lengths.	Closure lengths and scheme lengths represent the same thing. Long closure tapers are not often used on local roads.
Vehicle proportions are derived from national traffic count data shown in Appendix B of the HMAT Specification.	Default proportions were assumed from national traffic count data. For varying the HGV proportion in QUADRO, the non-HGV proportions were applied to the remainder of the traffic flow where appropriate.
Diversions, or alternative routes, around maintenance sites, are assumed to be on an S2AP road of a lower class road type (e.g. the alternative route for an A-road is a B-road).	All alternative routes for closures in QUADRO were assumed to be on single-carriageway roads to represent the network available when modelling Local Authority roads.
Treatment descriptions including binder content, depth of treatment, recycled content etc. are typical for local roads based on expert opinion and are specified in the HMAT data.	This is considered the best reasonable approach for modelling generic (not proprietary) treatments at a network level.
Carbon calculations are carried out using asPECT defaults for the installation plant, average haulage figures (Mineral Products Association, 2011) and fuel oil consumed at the average European rate for firing the asphalt plant.	The model does not represent actual maintenance schemes. No locational information is held in the model and so specific distances from the maintenance works to the nearest plant etc. cannot be determined. A representative value was seen as the best approach. The same is true for determining plant fuel use.
Polymer Modified Binders (PMB) are used in 15% of treatments (excluding surface dressing	This is considered the best reasonable approach for modelling generic (not proprietary)

Assumption	Comment
and micro asphalt), based on expert views of the typical proportion of maintenance using PMB.	treatments at a network level.

The analyses are based on broad, conceptual principles which are applied at an aggregated network level (i.e. network level funding changes translated directly into predicted summary changes at the network level) rather than using any more detailed condition projection model (e.g. impact of funding on different types of street-lighting maintenance resulting in different conditions of the lighting asset).

A.7.2 Skid Accident Analysis

A.7.2.1 Review for Scotland

For the Scottish study (Parkman et al, 2012), the literature for evidence of a relationship between skid resistance and accidents was reviewed for development of an appropriate model. The review confirmed that the relationship between skid resistance, site accident risk rating and skidding accident rates is well established in the UK. The evidence is re-presented in this section with a focus on English local road issues.

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 and 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 for UK, Viner, Sinhal and Parry (2005), showed 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 increased accident rates. However, there was no established model for network level use. Also, it is noted that many Local Authorities do not collect skid resistance data, and those that do collect the data do not have it for a large proportion of the network, so analyses in such contexts are not possible.

A.7.2.2 Model development

Using models proposed in the most recent unpublished TRL study (Coyle and Viner, 2009) and a number of related assumptions, a model has been derived for use on the English local road network.

It is necessary first to demonstrate that resurfacing investment on the network to date has been shown to have a positive effect in reducing skid resistance. Assuming this is the case, the change in funding and the related change in the proportion of the network with poor skid resistance are required to be specified by the user for the network to be analysed.

The model also requires the accident data for the network so that a prediction of the change in accidents with resurfacing investment can be generated. The prediction is based on evidence from the English local road network. At the network level, without the ability to discriminate between different categories of road by accident risk (e.g. junction approaches, straight sections of road etc.), it was estimated that the data suggests accident risk increases by the ratio of 12.5/7.5 (i.e. an increase of 66%) when moving from the population with acceptable skid resistance (i.e. a positive SCRIM deficiency) to the population with unacceptable skid resistance (i.e. a negative SCRIM deficiency). This value has been established as a default setting within HMAT but which can be changed if better information becomes available.

A.7.3 Lighting Accident Analysis

A.7.3.1 Review for Scotland

For the Scottish study (Parkman et al, 2012) a review was carried out of the impact of maintenance on lighting and any potential impacts on users. It showed that recent research on lighting costs, technologies and accident statistics had 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 the 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).

The TRL cost analyses (Crabb, Beaumont, Steele, Darley, & Burtwell, 2005) showed that a 22% energy saving can be achieved through 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.

A.7.3.2 Model development

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 Highways England 2012 cost-benefit recommendation in reverse). HMAT uses this assumption and further assumes it is also applicable on a pro rata basis for any partial reduction in lighting maintenance.

A.7.4 Comment on key assumptions

Five key assumptions were made related to this aspect of model development. Each assumption is noted and commented on in Table 20.

Table 20: Key assumptions elated to the accident analysis module

Assumption	Comment
Changes in the predicted accidents due to skidding and lighting are assumed to be independent of each other and of other effects predicted in other modules. They are calculated for each year by considering the budget in comparison with the budget for the accident data provided. There is no cumulative effect with increasing time, nor is there, for example, an increase in skid related accidents due to the effect of any increase in lighting related accidents or change in predicted speeds due to carriageway maintenance on the network.	The models are conceptually simple and a first attempt to identify the impacts on accidents of maintenance investment strategies. Longer term research is required to establish more detailed models based on empirical evidence on the network.
A specified percentage reduction in the lighting budget translates to the same percentage reduction in the amount of available lighting on the network.	This is a very simplistic assumption but is the only reasonable approach that can be considered without more complex models, as noted in Section A.7.3.2. The user can amend the change in number of accidents resulting from budget changes.
Current night-time road accidents are evenly distributed across the lit network irrespective of condition or road type.	There are accident 'blackspots' on any network and accidents are clustered where a number of hazards promote a high risk. However, without more detailed knowledge of the distribution of accidents across a network and a more complex model, this is the only logical approach that can reasonably be considered.
Based on the work of Crabb et al (2009) and the Highways England cost-benefit recommendation used in 2012, it is assumed that a 10% increase in accidents is predicted when lights are switched off.	A Local Authority that considers reducing lighting availability will aim to minimise the impact on the road user. The reasons for the original implementation of a lighting scheme may be more than night-time accident reduction, and there may have been changes in travel patterns since implementation. The initial assumption is reasonable but can be refined by assuming progressive increases in the risk of more accidents with reductions in expenditure.
There are limitations on applicability of both the skid accident and lighting accident models.	For the skid accident model, the model is not extrapolated beyond the ranges of investment / network performance as defined by the user (see Section A.7.2.2). If the skid resistance or funding falls outside these ranges, then the

Assumption	Comment
	level of accidents is assumed to be the same as the limit of the range. For the lighting model, no reduction in accidents is predicted by any increase in funding above the current budget level. The model is only applied for budget constraints. The user needs to enter the accidents related to the current budget level and if the current budget level changes when conducting analyses in future years, then the accident data will also need updating.

A.8 Job Impacts Analysis Module

A.8.1 Adopted approach

To estimate the impacts of maintenance funding on levels of employment, data from the Construction component of the Annual Business Survey (Office of National Statistics, 2012) was extracted in terms of estimates for turnover, GVA and employment in the industry for the purpose of benchmarking GVA and employment created by a given level of expenditure in a road maintenance project. The current metrics for the Construction Industry are as shown in Table 21.

Table 21: Values of current indicators from Annual Business Survey

Construction Indicators	Value
Gross Value Added	£72.581bn
Employment	1.298mn
Turnover	£189.799bn

The figures from Table 21 translate into benchmark figures of:

- £55,918 in GVA per job (Total GVA/Employment)
- £146,224 Turnover per job (Total Turnover/Employment)
- GVA:Turnover Ratio of 38.24%

The Annual Business Survey (previously the Annual Business Inquiry Part 2) is the main structural business survey conducted by the Office for National Statistics. It collects financial information for about two-thirds of the UK economy, covering forestry and fishing, production, construction, motor trades, wholesale, retail, catering and accommodation, property, service trades and agriculture in part. The financial variables covered include turnover, purchases, employment costs, capital expenditure and stocks.

Approximate Gross Value Added (aGVA) is calculated as an input into the measurement of Gross Domestic Product.

A benchmark case for this approach was the Centro RCS Report. Using data for the construction industry from the Annual Business Survey 2011, extracted using the appropriate Standard Industrial Classification codes, the approach was applied to compute benchmark values for construction-stage job creation and GVA for the Dudley area due to direct maintenance activities.

A £27,304,017 difference in expenditure between the 'Do Minimum' and 'Do Something' analyses for that study over a 46-year period was calculated, and the Annual Business Survey overall metrics for the industry from 2011. The expenditure was predicted to produce 202 construction-stage jobs (approximately 4 per annum) and £10.1m GVA at that time. These results were considered plausible and the approach has been replicated for the HMAT model.

A.8.2 Comment on key assumptions

One key assumption was made related to this aspect of model development. Each assumption is noted and commented on in Table 22.

Table 22: Key assumptions - Job Impacts module

Assumption	Comment
Jobs and GVA assessment are based on the total maintenance allocation for the road network and take no account of local economic context which might vary by proportion of road type (e.g. urban versus rural) and level of traffic etc.	As noted in Section A.7.1, it is not feasible to estimate the local variation in the impacts without significantly more data and more in depth study.
Variation in carriageway condition may change the traffic carried by a road and therefore impact the level of economic activity in an area.	These second order effects are not considered in HMAT.

A.9 Aggregated Outputs Module

A.9.1 Overview

Following the completion of analyses using the HMAT model, various impacts can be viewed and compared, primarily grouped into direct and indirect costs. There are also different metrics that can be generated from the results of the individual analyses.

The Aggregated Outputs Module (AOM) has been designed to display the results from up to ten individual analyses in one collective table. The AOM is separate from the HMAT model and results files from HMAT analyses are loaded into the AOM.

A.9.2 Approach

In general, one analysis will not provide a decision maker with sufficient information to make an informed decision on the level of road maintenance investment. A number of different analyses will be needed to understand the impacts of different maintenance strategies.

In the AOM, one analysis is selected as the base case and the other options are compared with that base case. Within the AOM, the base case can be changed at any time. In addition to comparing the calculated quantitative results from the individual analyses, when multiple analyses (or strategies) are compared, the Net Present Value can be determined between the analyses to provide a measure of the economic benefits or costs of the different analyses. Analyses in this project and described in Section 5 and Appendix C use a Benefit-Cost Ratio (BCR) to describe the overall analysis results. This BCR is the change in indirect costs achieved by £1 of direct works cost. Both the direct and indirect costs are shown in the AOM outputs but the BCR is not currently included.

As well as comparing the quantitative results, the qualitative impacts from the different analyses should be recorded in an effort to align with current project appraisal guidelines (DfT, 2014) and help ensure all inputs are considered when comparing options.

The overall comparison results from the Aggregated Outputs Module will allow the effects of the road maintenance budget and strategy to be demonstrated within the framework of the analysis described in this report.

A.9.2.1 Quantitative analysis results

The Aggregated Outputs Module uses outputs from all modules to compare between analyses:

- Direct costs:
    - Road maintenance costs.
- Indirect costs:
    - Road condition impacts.
        - Vehicle operating costs
        - Value of time
        - Carbon (from fuel)
    - Road works impacts.
        - Accidents
        - Carbon (from fuel)
        - Time
    - Accident impacts.
        - Number of accidents
        - Accident costs
    - Carbon impacts (embodied).
        - Carbon quantity
        - Carbon cost
    - Job impacts.
        - Jobs
        - Gross value Added (GVA)

Summary economic statistics show:

- Works (direct) costs changes between analyses.

- Non-works (indirect) costs changes between analyses.
    - Excluding Carbon Impacts and Job Impacts
    - Including Carbon Impacts and Job Impacts
- Net Present Value (NPV) between the selected base analysis and all other analyses.

For the impacts described in the analyses used to demonstrate the model and described in Section 5 and Appendix C, the Non-works Costs used are Excluding Carbon Impacts and Job Impacts.

A.9.2.2 Qualitative analysis results

The qualitative outputs require user input to show the level of impact between the analyses. The outputs summarise the impacts against the four main criteria of:

- Economy.
- Environmental.
- Social.
- Public accounts.

For some of the sub-criteria within each criterion, there is limited potential for road maintenance funding to have an impact and this should be recorded where appropriate.

Within the Aggregated Outputs Module the user also has the option to record the key qualitative impacts when comparing the analyses. The table for entering this information also includes advice on what might be suitable inferences to make from the available analysis data. These impacts can be used as supporting evidence for appraisal decisions. Figure 10 shows an example of how the tables could be completed.

Description of scenarios:		This commentary provides qualitative discussion around Scenario 1 ('current budget'), Scenario 3 (10% increase years 1 to 10, same total spend) and Scenario 4 (20% increase years 1 to 10, same total spend). N.B. These are example comments as setup requires further refinement and calibration before conclusions can be drawn.
Impacts		Summary of key impacts
Economy	Business users & transport providers	Scenario 4 has lowest costs for value of time and condition impacts, which are borne as costs by business users and transport providers.
	Reliability impact on Business users	Scenario 4 causes most disruption due to road works (shown in road works impact time values) but this small compared with the value of time savings generated by improved road conditions. Also, the increased investment overall (as reflected by the increased allocation in particular for relaibility, accessibility and customer service drivers) will result in increased investment in activities such as bridge maintenance or drainage (effects not quantified) and therefore reduce the risk of disruption due to extreme weather of unforseen structural failures.
	Regeneration	Regeneration is not considered applicable in terms of variation under these budget scenarios.
	Wider Impacts	(Statements as exampled above could be made for each qualitative criteria once an analyst is satisfied the results are ready for reporting).
Environmental	Noise	
	Air Quality	
	Greenhouse gases	
	Landscape	
	Townscape	

Figure 10: Example qualitative impacts

A.9.3 Comment on key assumptions

Three key assumptions were made related to the development of the AOM. Each assumption is noted and commented on in Table 23.

Table 23: Key assumptions - Aggregated Outputs Module

Assumption	Comment
A maximum of ten analyses can be compared in one version of the Aggregated Outputs Module.	If comparisons of more than ten analyses are required, multiple copies of the Aggregated Outputs Module must be made. The same base analysis can be copied into each version of the Aggregate Outputs Module (each with up to nine alternative analyses). This will ensure that all alternative analyses are compared against the same base case, even across multiple copies of the Aggregate Outputs Module.
The Aggregated Outputs Module does not know if the analyses requested for comparison are directly comparable.	Summary statistics from analyses loaded into the Aggregate Outputs Module provide a view of the differences between the analyses (e.g. analysis period, start year, number of road types). This information can help make comparisons between different analyses.
The analyses cannot be used to automatically make any judgements on the qualitative impacts.	The costs attributed to maintenance drivers through the analysis period provide some indication of the impacts on some of the qualitative sub-criteria (e.g. a reduction in the environment budget may have an effect on biodiversity and water environment). However, it is for the user to enter descriptions on the levels of qualitative impacts between the different analyses.

Appendix B. Data used in the national network analyses

This Appendix summarises the data used in this project for the analysis of maintenance funding of the national local road network in England (excluding London). Using the data derived from the wider survey of Local Authorities and analysis of the results from the demonstration analyses for the same network, the following data used in the demonstration analyses has been modified:

- Carriageway widths
- Maintenance treatment costs
- Maintenance treatment strategies
- Budget allocation constraints
- Initial network condition
- Maintenance works data

B.1 Road Type

The road types used for the national analyses are shown in Table 24. The demonstration analyses used 10 road types (5-Rural and 5-Urban), including Motorways (Urban and Rural). None of the Authorities that provided data have Motorways in their local road network but this road type was needed in the analysis of the national network to provide complete coverage. For the 8 other road types, 8 Authorities use 8 road types either the same or that can be directly mapped to the road types in the demonstration analyses. Some Authorities are predominantly urban but the data provided did not prevent the use of the proposed classification into rural and urban for each road type.

The Local Authority data showed no regional or Authority type variation in the approach to definition of road types.

Table 24: Road Types

Road Type
Motorway (R)
Motorway (U)
A-roads (R)
A-roads (U)
B-roads (R)
B-roads (U)
C-roads (R)
C-roads (U)
U-roads (R)
U-roads (U)

(R) – Rural (U) – Urban

Source: Analysis of returned Local Authority data

The road types used in the demonstration analyses continued to be used in the analysis of the national network. Much of the other model data is defined by road type so road type was not varied in the sensitivity testing. The network length, by road type, used for the analyses of the national network is shown in Table 25**.**

Table 25: Network length by road type

Road Type	Carriageway Length (m)
A-roads (R)	20,336,000
A-roads (U)	9,674,000
B-roads (R)	15,236,000
B-roads (U)	4,139,000
C-roads (R)	54,480,000
C-roads (U)	9,078,000
Motorways (R)	41,150
Motorways (U)	41,150
U-roads (R)	83,379,000
U-roads (U)	86,979,000

(R) – Rural (U) – Urban

Source: DfT Road Transport Statistics (DfT, 2014a) Tables 0202a and 0202b

B.2 Carriageway Widths

The carriageway widths used in the demonstration analyses were derived from averages of the widths provided by the example data provided by the five Local Authorities. The widths used for the national network were length weighted averages of the new data provided by the wider range of Local Authorities, to enable those Authorities with more Urban (or Rural) roads to have a bigger influence on the national values.

Table 26 summarises the length weighted average widths used in the national analyses but the sensitivity analysis included the effects of wider and narrower carriageways.

B.3 Traffic

Traffic for the network is input into HMAT as part of the network definition. The traffic for the national network has been provided centrally by DfT as data from individual Authorities is of little use for the national analyses. The traffic flows used for the start of the analysis period are shown in Table 27 and the traffic growth rates used for the analysis period taken from the National Transport Model are shown in Table 28.

As part of the sensitivity analyses, alternative (higher and lower) growth rates were used to test the effects of different levels of traffic over the analysis period. The rates to be used in the testing were based on high and low rates included in the WebTAG data tables.

Table 26: Carriageway widths[5] (m)

Road Type	Average Width[6] (m)
A-roads (R)	8.1
A-roads (U)	8.6
B-roads (R)	6.4
B-roads (U)	7.3
C-roads (R)	5.4
C-roads (U)	6.9
Motorways[7] (R)	11.0
Motorways[8] (U)	11.0
U-roads (R)	4.4
U-roads (U)	6.3

(R) – Rural (U) – Urban
Source: Analysis of returned Local Authority data

Table 27: Initial traffic flows

Road Type	Vehicle Class (used for OGV1:OGV2 splits)	Traffic Flows (annual thousand veh. km)				
		Cars and bikes	Motor-bikes	Light vans	Goods vehicles	Buses and coaches
A-roads (R)	Built-up Principal	55,285,782	613,588	9,663,396	3,377,652	466,001
A-roads (U)	Built-up Principal	41,320,218	366,386	6,261,581	1,352,079	626,569
B-roads (R)	Other	13,163,344	211,340	2,691,866	379,842	76,981
B-roads (U)	Other	8,587,512	151,919	1,422,909	141,534	161,635
C-roads (R)	Other	15,467,246	257,291	2,876,243	345,298	100,827
C-roads (U)	Other	10,851,672	183,046	1,753,942	150,893	202,291
Motorways (R)	Motorway	724,550	4,441	102,923	35,353	4,806
Motorways (U)	Motorway	724,550	4,441	102,923	35,353	4,806
U-roads (R)	Other	14,689,875	257,955	2,452,342	266,898	103,005
U-roads (U)	Other	47,026,071	768,567	7,748,149	557,394	758,153

(R) – Rural (U) – Urban
Note: These traffic flows are for year 0, before the start of the analysis period.
Source: data request from DfT Road Transport Statistics

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[5] Carriageway widths provided by Local Authorities were mapped on to the default road classification using the road classifications given in Table 24

[6] Average width was determined on a length weighted basis using the supplied lengths of the road classifications in each authority. Norfolk and Northampton were excluded from the average width calculations because no lengths were provided for the road classifications for those authorities.

[7] No data was provided by Local Authorities for Motorways. A standard width was assumed.

Table 28: Annual traffic growth rates (%)

Vehicle Type	Analysis Period (Years)						
	1	2-6	7-11	12-16	17-21	22-26	>27
Cars	0.75	1.70	1.72	0.98	0.82	0.66	0.00
Motorbikes	0.75	1.70	1.72	0.98	0.82	0.66	0.00
Light Goods Vehicles	1.33	2.74	2.41	2.11	1.76	1.55	0.00
Goods Vehicles	-0.90	1.08	0.61	1.01	0.83	1.03	0.00
Buses and Coaches	0.89	0.00	-0.89	0.00	0.00	0.00	0.00

Source: National Traffic Model

B.4 Budget Allocation

In HMAT, the total maintenance budget is allocated to various maintenance activities (e.g. carriageway maintenance). In the demonstration analyses the allocations adopted were based on an analysis of breakdowns reported by Local Authorities in annual Authority reports. HMEP does not include an allocation of the total maintenance budget and the pro-forma used to collect the HMAT data for the national network did not ask for this information.

As there was no new data to support changing the allocations from those used in the demonstration analyses, those allocations were also used in the national network analyses. The effect of different allocations is to change the percentage of the total budget used for carriageway maintenance and for each maintenance treatment on each road type.

The allocation of the total budget to different maintenance activities may change for different levels of the total budget. To reflect this in the analysis of the national network, the 3 bands of budget level shown in Table 29 were adopted.

Table 29: Budget envelope limits

Envelope	Budget limit (£k)
Lower	2,299,350
Mid	4,629,267
Upper	6,976,101

Source: Proposed by project team

HMAT (and the HMEP Toolkit) further breaks down the carriageway budget by limiting the budget for treatment types and road types. These limits are often set to meet the local needs for an Authority so the analyses provided by Authorities as part of the new data did not, necessarily, reflect the general allocations that should be used in national network analyses.

The data provided by the Local Authorities was therefore used to guide the budget allocation limits applied in the analyses but the allocations were changed as the analyses were developed (e.g. to achieve required levels of carriageway condition). The allocations proposed by the Authorities were used to guide the acceptability of the allocations adopted.

The allocations used to break down the overall maintenance budget for the national network are shown in Table 30 and the current budget breakdown is shown in Table 31.

The limits on the breakdown of the carriageway maintenance budget, in each of the 3 bands of overall budget level, used for the analysis of the national network are shown in Table 32 for road types and Table 33 for maintenance treatment types. The breakdown of the current budget available for each maintenance treatment type on each road type, and used in the analyses of the national network, is shown in Table 34 and Table 35.

Table 30: Activity Allocations

Activity	Total Budget (%)	Maintenance Drivers (%)					
		Safety	Accessibility	Condition	Reliability	Customer Service	Environment
Reconstruction (capital)	13	20	10	0	40	30	0
Structural (capital)	20	15	0	65	0	10	10
Bridge (capital)	3	30	10	20	0	30	10
Road Safety (capital)	2	90	0	0	0	10	0
Lighting (capital)	2	60	0	0	20	20	0
Planning, policy & strategy (revenue)	17	10	0	40	0	20	30
Structural - roads (revenue)	9	15	0	65	0	10	10
Structural -skid (revenue)	1	90	0	0	0	10	0
Structural - bridges (revenue)	1	30	10	20	0	30	10
Environment (revenue)	18	20	0	0	0	40	40
Lighting (revenue)	10	50	0	0	20	30	0
TM & Road safety (revenue)	4	90	0	0	0	10	0

Source: Proposed by project team

Table 31: Current budget breakdown

Activity	Budget (£k)	HMAT Condition Analysis	Carriageway Maintenance Budget (£k)
Reconstruction (capital)	601,805	Carriageway	1,944,292
Structural (capital)	925,853		
Structural - roads (revenue)	416,634		
Structural -skid (revenue)	46,293	Skid	46,293
Road Safety (capital)	92,585	None	0
Planning, policy & strategy (revenue)	786,975		
Bridge (capital)	138,878		
Structural - bridges (revenue)	46,293		
Environment (revenue)	833,268		
Lighting (capital)	92,585		
Lighting (revenue)	462,927		
TM & Road safety (revenue)	185,171		
Total	**4,629,267**		**1,990,585**

Source: Analysis of [a] Local Authority capital/revenue expenditure and receipts in England: 2012 to 2013 final outturn (Department for Communities and Local Government 2012) and [b] Annual Local Authority Road Maintenance survey 2013 (ALARM 2013))

Table 32: Road type budget allocations

Road Type	Budget Breakdown (%)		
	Lower Envelope	Mid Envelope	Upper Envelope
A-roads (R)	34	22	20
A-roads (U)	16	11	8
B-roads (R)	6	4	4
B-roads (U)	1	1	1
C-roads (R)	12	14	17
C-roads (U)	2	2	2
Motorways (R)	1	1	1
Motorways (U)	1	1	1
U-roads (R)	13	22	23
U-roads (U)	14	22	23

(R) – Rural (U) – Urban
Source: Proposed by project team

Table 33: Treatment type budget allocations

Treatment Type	Budget Breakdown (%)		
	Lower Envelope	Mid Envelope	Upper Envelope
Surface Dressing	30	10	15
Micro Asphalt	20	10	10
Moderate Overlay	20	20	25
Moderate Inlay	15	20	20
Deep Inlay	10	20	15
Reconstruction	5	20	15

Source: Proposed by project team

Table 34: Budget Allocations (Current budget)

Road Type	Treatment	Budget constraints (£k)	Total (£k)
A-roads (R)	Surface Dressing	43,793	437,929
	Micro Asphalt	43,793	
	Moderate Overlay	87,586	
	Moderate Inlay	87,586	
	Deep Inlay	87,586	
	Reconstruction	87,586	
A-roads (U)	Surface Dressing	21,896	218,964
	Micro Asphalt	21,896	
	Moderate Overlay	43,793	
	Moderate Inlay	43,793	
	Deep Inlay	43,793	
	Reconstruction	43,793	
B-roads (R)	Surface Dressing	7,962	79,623
	Micro Asphalt	7,962	
	Moderate Overlay	15,925	
	Moderate Inlay	15,925	
	Deep Inlay	15,925	
	Reconstruction	15,925	
B-roads (U)	Surface Dressing	1,991	19,906
	Micro Asphalt	1,991	
	Moderate Overlay	3,981	
	Moderate Inlay	3,981	
	Deep Inlay	3,981	
	Reconstruction	3,981	

(R) – Rural (U) – Urban
Source: Analysis of budgets and allocations

Table 35: Budget Allocations (Current budget) (Continued)

Road Type	Treatment	Budget constraints (£k)	Total (£k)
C-roads (R)	Surface Dressing	27,868	278,682
	Micro Asphalt	27,868	
	Moderate Overlay	55,736	
	Moderate Inlay	55,736	
	Deep Inlay	55,736	
	Reconstruction	55,736	
C-roads (U)	Surface Dressing	3,981	39,812
	Micro Asphalt	3,981	
	Moderate Overlay	7,962	
	Moderate Inlay	7,962	
	Deep Inlay	7,962	
	Reconstruction	7,962	
Motorways (R)	Surface Dressing	1,991	19,906
	Micro Asphalt	1,991	
	Moderate Overlay	3,981	
	Moderate Inlay	3,981	
	Deep Inlay	3,981	
	Reconstruction	3,981	
Motorways (U)	Surface Dressing	1,991	19,906
	Micro Asphalt	1,991	
	Moderate Overlay	3,981	
	Moderate Inlay	3,981	
	Deep Inlay	3,981	
	Reconstruction	3,981	
U-roads (R)	Surface Dressing	43,793	437,929
	Micro Asphalt	43,793	
	Moderate Overlay	87,586	
	Moderate Inlay	87,586	
	Deep Inlay	87,586	
	Reconstruction	87,586	
U-roads (U)	Surface Dressing	43,793	437,929
	Micro Asphalt	43,793	
	Moderate Overlay	87,586	
	Moderate Inlay	87,586	
	Deep Inlay	87,586	
	Reconstruction	87,586	

(R) – Rural (U) – Urban
Source: Analysis of budgets and allocations

B.5 Condition Bands

Although the Local Authorities used different numbers of condition bands, all Authorities that provided data use the same number of condition bands for all road types in the Authority. One Metropolitan Authority uses 3 bands and 4 Authorities (Cities and Metropolitan Boroughs) use 4 bands. All other Authorities, use the same 5 bands (Very Good, Good, Fair, Poor and Very Poor) used in the demonstration analyses and shown in Table 36.

Table 36: Carriageway condition bands

Condition Band
Very Good (VG)
Good (G)
Fair (F)
Poor (P)
Very Poor (VP)

Source: Analysis of returned Local Authority data

In preparation of the data for the demonstration analyses, network condition data from the five Local Authorities that used 3 or 4 bands was mapped on to the 5 bands. The network condition from Authorities using 3 or 4 condition bands in the new Local Authority data was mapped in the same way. There were strong reasons to continue the use of the 5 condition bands used in the demonstration analyses:

- SCANNER data to be used in the national analyses for all roads except U-roads is available in the 5 condition bands.
- All the local Authority data provided could be considered in the development of the base data for the national analysis.
- The HMEP Toolkit uses 5 condition bands in its default description of network condition
- Transition matrices are used in the HMEP Toolkit to project network condition. These matrices have been developed around the 5 condition bands. In the new Local Authority data, few Authorities have made any changes to the HMEP matrices (those Authorities not using 5 bands have had to change the matrices but the changes appear to be little more than the aggregation of adjacent cells in the matrices).
- The existing Local Authority SCANNER condition data for road types other than U-roads can be used to more easily develop represntations of network condition to use in other analyses.

The 5 condition bands used in the demonstration analyses and used by 7 Authorities in the new data have been used for the national data.

B.6 Initial carriageway condition

The carriageway condition for the national network at the start of the analysis period was given by the 2013/14 SCANNER data for Motorways, A-roads, B-roads and C-roads using the condition bands shown in Table 36.

For U-roads, there is little SCANNER data available so the condition was derived from the conditions of U-roads provided in the new Local Authority data. The percentage of the network in each band was the length weighted average of the data provided by the Local Authorities, normalised to 100% for the total network.

The condition distribution for the national network at the start of the analysis period is shown in Table 37.

Table 37: Initial network condition

Road Type	Condition Bands				
	VG	G	F	P	VP
A-roads (R)	31.5%	43.3%	19.4%	5.0%	0.8%
A-roads (U)	30.8%	37.3%	20.9%	8.8%	2.1%
B-roads (R)	21.4%	46.0%	25.1%	6.2%	1.2%
B-roads (U)	27.8%	39.9%	21.6%	8.2%	2.6%
C-roads (R)	21.5%	40.4%	28.0%	8.2%	1.9%
C-roads (U)	35.2%	35.1%	19.2%	7.6%	2.9%
Motorways (R)	64.3%	21.1%	9.4%	4.0%	1.3%
Motorways (U)	39.3%	31.8%	16.6%	10.1%	2.3%
U-Roads (R)	23.9%	17.7%	29.2%	15.9%	13.3%
U-Roads (U)	35.5%	20.9%	25.3%	9.5%	8.8%

(R) – Rural (U) – Urban
Source: Analysis of SCANNER data and returned Local Authority data

B.7 Treatments

The demonstration analyses used 6 maintenance treatments to show the effects of different funding levels. These treatments are those provided with the HMEP Toolkit and have generally been adopted by Authorities using the HMEP Toolkit (and providing data for HMAT). Table 38 shows the names of treatments used in the demonstration analyses which continued to be used for the national network analysis.

B.8 Treatment Effects

Review of the Local Authority data showed no variation in the effect of the same treatment on different road types.

Interpreting the effects of treatments has clearly not been consistent across the different Authorities and could not be explained without further consultation with the Authority (e.g. when applying a surfacing treatment the data showed the effect was to move Very Poor condition to Very Good condition while others showed the effect of the same treatment was to improve the condition by one condition band).

Table 38: Maintenance treatments

Maintenance Treatment
Surface dressing
Micro Asphalt
Moderate Overlay
Moderate Inlay
Deep Inlay
Reconstruction

Source: Analysis of returned Local Authority data

In general, the effect of surfacing treatments was assumed to improve the condition by one condition band (e.g. from Poor to Fair) and the effect of a structural treatment was assumed to move the condition two bands. It is also reasonable to assume a full reconstruction would move the condition from any band to Very Good condition.

Increasing the improvements in condition resulting from use of each of the maintenance treatments by a further band is a big assumption of the improvement and when applied would need to be accompanied by changes to the maintenance strategies that define at what level and how much of the condition is treated each year. Although possible to carry out, it was considered unlikely that changing the effect of a surfacing treatment to no change in the condition band and the effect of structural treatments to an improvement of only one band would show any useful analysis results and may lead to a misunderstanding of the results obtained.

The sensitivity testing did not therefore include any change in the Treatment Effect matrices. The Treatment Effects used for the analysis of the national network are shown in Table 39 and Table 40.

B.9 Treatment Costs

Local Authorities provided outturn costs for the treatments used in their analyses and these were mapped to the treatments to be used for the national network (as in Table 38). The costs were adjusted for the base year of the analyses in this project (i.e 2014).

In the Local Authority data, four Authorities (of all types and from all Regions) provided the same treatment cost for all road types but the other Authorities showed variations in the cost of the same treatment with road type. Only two County Councils and one Metropolitan Borough showed any variation in treatment cost with the carriageway condition being treated.

For the national analyses, unit treatment costs were varied with road type but no variation was included for the effect of the carriageway condition being treated.

To derive the costs for the treatments, for the road types to be adopted for the national network, the costs provided by the Authorities for each treatment were averaged for the national network and for each region. Where possible, length weighted averages were used to reduce the impact of a treatment cost for a treatment on a road type from an Authority with only a short length of the road type in that Authority (e.g. rural roads in an urban Authority). The costs used for the analysis of the national network are shown in Table 41.

Table 39: Treatment effects on condition

Road Type	Treatment	Condition Band				
		VG	G	F	P	VP
A-roads (R)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG
A-roads (U)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG
B-roads (R)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG
B-roads (U)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG
C-roads (R)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG
C-roads (U)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG

(R) – Rural (U) – Urban

Table 40: Treatment effects on condition (continued)

Road Type	Treatment	Condition Band VG	G	F	P	VP
Motorways (R)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG
Motorways (U)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG
U-roads (R)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG
U-roads (U)	Surface Dressing	VG	VG	G	F	P
	Micro Asphalt	VG	VG	G	F	P
	Moderate Overlay	VG	VG	VG	G	G
	Moderate Inlay	VG	VG	VG	G	G
	Deep Inlay	VG	VG	VG	G	G
	Reconstruction	VG	VG	VG	VG	VG

(R) – Rural (U) – Urban
Source: Analysis of returned Local Authority data

The regional values from the Local Authority data were compared to the national values to indicate the levels of difference in the costs to use in sensitivity testing for the national network.

B.10 Treatment Strategies

The demonstration analyses showed the importance of Treatment Strategies in determining the type and amount of maintenance carried out on the network. The strategies adopted in the demonstration analyses were shown to lead to a move to network condition being split between Very Good and Very Poor in budget analyses and strategies needed to be applied iteratively to achieve the steady state (in all condition bands) on the network.

Table 41: Maintenance treatment costs

Road Type	Treatment	Treatment Cost (£/m2)	Treatment	Treatment Cost (£/m^2)
A-roads (R)	Surface Dressing	6.09	Moderate Inlay	21.89
	Micro Asphalt	8.77	Deep Inlay	35.70
	Moderate Overlay	25.48	Reconstruction	54.09
A-roads (U)	Surface Dressing	6.07	Moderate Inlay	22.36
	Micro Asphalt	8.51	Deep Inlay	34.06
	Moderate Overlay	23.12	Reconstruction	53.76
B-roads (R)	Surface Dressing	6.22	Moderate Inlay	21.44
	Micro Asphalt	8.96	Deep Inlay	33.95
	Moderate Overlay	23.61	Reconstruction	54.33
B-roads (U)	Surface Dressing	6.04	Moderate Inlay	21.36
	Micro Asphalt	8.64	Deep Inlay	32.99
	Moderate Overlay	22.49	Reconstruction	53.27
C-roads (R)	Surface Dressing	6.78	Moderate Inlay	20.72
	Micro Asphalt	8.67	Deep Inlay	33.17
	Moderate Overlay	22.61	Reconstruction	53.73
C-roads (U)	Surface Dressing	6.59	Moderate Inlay	20.84
	Micro Asphalt	8.40	Deep Inlay	31.37
	Moderate Overlay	22.13	Reconstruction	52.17
U-roads (R)	Surface Dressing	6.53	Moderate Inlay	19.25
	Micro Asphalt	9.02	Deep Inlay	31.38
	Moderate Overlay	20.66	Reconstruction	48.45
U-roads (U)	Surface Dressing	5.85	Moderate Inlay	19.99
	Micro Asphalt	8.68	Deep Inlay	31.04
	Moderate Overlay	21.24	Reconstruction	47.79

NB. The A-roads treatment types and costs were also used for Motorways
Source: Analysis of returned Local Authority data

There were, therefore, a number of issues associated with choosing the strategies to adopt for the national network:

- The way strategies are defined requires a level of understanding of the way they are applied. The variability in the treatment strategy data provided by Local Authorities raised questions about the reliability and suitability of the data for use in analyses of the national network (e.g. the order in which the model applies the treatments each year on each road type and the amount of treatment each year).
- In HMAT (and HMEP) Treatment Strategies may vary with road type but many of the Authorities providing data showed no variation had been included in the analyses of the local networks.
- There was considerable variation in the percentages of the network treated in the treatment strategies adopted by Authorities in the data returned.
- The Treatment Strategy may need to change during the analysis period to achieve the aims of the analysis. Few Authorities showed any change during the period and the reasons for any change was not clear from the data (e.g. if the

changes were made to achieve specific performance targets or if significant budget changes during the analysis period allowed different strategies to be adopted).

Table 42: Treatment strategies

Strategy Name and Road Type	Step	Treatment	Condition Band	Percent Treated	Condition Band VG	G	F	P	VP
Strat&Main A-roads and Motorways	1	Surface Dressing	F	20%			20%		
	2	Micro Asphalt	F	20%			20%		
	3	Moderate Overlay	F	15%			15%		
	4	Moderate Inlay	P	45%				45%	
	5	Deep Inlay	P	30%				30%	
	6	Deep Inlay	VP	45%					45%
	7	Reconstruction	VP	20%					20%
Secondary B-roads	1	Surface Dressing	F	20%			20%		
	2	Micro Asphalt	F	20%			20%		
	3	Moderate Overlay	F	10%			10%		
	4	Moderate Inlay	P	20%				20%	
	5	Deep Inlay	P	25%				25%	
	6	Deep Inlay	VP	20%					20%
	7	Reconstruction	VP	15%					15%
Link C-roads	1	Surface Dressing	F	12%			12%		
	2	Micro Asphalt	F	12%			12%		
	3	Moderate Overlay	F	12%			12%		
	4	Moderate Inlay	P	35%				35%	
	5	Deep Inlay	P	20%				20%	
	6	Deep Inlay	VP	25%					25%
	7	Reconstruction	VP	25%					25%
Local U-roads	1	Surface Dressing	F	15%			15%		
	2	Micro Asphalt	F	15%			15%		
	3	Moderate Overlay	F	10%			10%		
	4	Moderate Inlay	P	30%				30%	
	5	Deep Inlay	P	15%				15%	
	6	Deep Inlay	VP	20%					20%
	7	Reconstruction	VP	25%					25%

Source: Analysis of returned Local Authority data

The Treatment Strategies need to meet the aims of the analyses. It was not possible to simply define in advance of the analyses one or more strategies to use in the Base Analyses of the national network. The data provided by the Authorities was used when formulating the analyses for the national network, although the strategies from some Authorities were not included as they required further consultation with the Authority to understand why they had been adopted. Table 42 shows the Treatment Strategies used for the analyses of the national network. For each road type, the same strategy was applied for both rural and urban roads.

B.11 Maintenance works data

Maintenance treatment costs have been described in Section B.7 but three other treatment parameters are needed for the analysis of the impacts of maintenance funding that are caused by the amount of maintenance works carried out each year. None of the data for these aspects has been provided as part of the data supplied by Local Authorities.

The duration of maintenance works impacts on how long users are delayed at maintenance sites. Average rates of working for each treatment type on each road type are used to estimate the duration of the maintenance works from the amount of maintenance resulting from the budget allocation and maintenance strategy. The rates of working used for the analysis of the national network were obtained from rates used in other analyses of maintenance works. The values used are shown in Table 43.

Table 43: Rates of output for maintenance treatments

Road Type	Output Rates (sq.m/hr)					
	Surface Dressing	Micro Asphalt	Moderate Overlay	Moderate Inlay	Deep Inlay	Reconstruction
A-Roads (R)	189.57	139.50	81.67	114.00	88.50	49.50
A-Roads (U)	134.83	113.00	61.33	88.50	64.00	36.50
B-Roads (R)	189.57	139.50	81.67	114.00	88.50	49.50
B-Roads (U)	134.83	113.00	61.33	88.50	64.00	36.50
C-Roads (R)	189.57	139.50	81.67	114.00	88.50	49.50
C-Roads (U)	134.83	113.00	61.33	88.50	64.00	36.50
Motorways (R)	490.00	453.00	231.43	356.00	259.00	109.50
Motorways (U)	490.00	453.00	231.43	356.00	259.00	109.50
U-Roads (R)	189.57	139.50	81.67	114.00	88.50	49.50
U-Roads (U)	134.83	113.00	61.33	88.50	64.00	36.50

(R) – Rural (U) – Urban
Source: Project data analysis

Major factors in the delays to users at roadworks are the type of closure used (e.g. contra-flow, lane closure or shuttle working) and the time of day the closure is in place (e.g. all day, off-peak during the day, at night). HMAT uses default data to select the type of closure to be used for each type of maintenance treatment on each road type but the durations of closure per day are specified by the user. Table 44 shows the breakdown of the timing of maintenance works on each road type. There is no variation with treatment type. The new data provided by Local Authorities did not include any information on these splits of the maintenance timing so the values used are those used for the demonstration analyses derived from discussions with highway managers about current practice.

Table 44: Closures for maintenance works

Road Type	Delay Look-up	Maintenance closure split (%)		
		24hr closures	Off-peak closures	Night closures
A-roads (R)	A-Road Rural Single	20	10	70
A-roads (U)	A-Road Urban Single	40	10	50
B-roads (R)	B-Road Rural	50	50	0
B-roads (U)	B-Road Urban	50	50	0
C-roads (R)	C-Road Rural	50	50	0
C-roads (U)	C-Road Urban	50	50	0
Motorways (R)	M-way Rural	20	10	70
Motorways (U)	M-way Urban	40	10	50
U-Roads (R)	U-Road Rural	50	50	0
U-Roads (U)	U-Road Urban	50	50	0

(R) – Rural (U) – Urban
Source: Proposed by project team

Table 45: Average scheme lengths

Road Type	Average Scheme Length (C'way km)
A-roads (R)	1.59
A-roads (U)	1.05
B-roads (R)	1.82
B-roads (U)	1.15
C-roads (R)	1.38
C-roads (U)	0.99
Motorways (R)	1.59
Motorways (U)	1.05
U-roads (R)	1.04
U-roads (U)	0.45

(R) – Rural (U) – Urban
Source: Analysis of returned Local Authority data

The HMAT analysis calculates the total volume of work for each treatment type on each road type in each year. To translate that into the number of maintenance schemes that would be needed each year, HMAT uses an average scheme length for each road type (there is no variation in scheme length with maintenance treatment type). The data provided by three Local Authorities contained proposed values for scheme lengths and the averages of these have been used for the analysis of the national network. The values adopted are shown in Table 45.

B.12 Vehicle Operating Costs

Part of the impacts of road maintenance calculated in HMAT arise from the condition of the carriageway that affects the fuel consumption of vehicles, the speed of vehicles (and therefore the travel time on the network) and non-fuel vehicle operating costs (e.g. spare parts, oil consumption).

HMAT contains tables of unit values of fuel consumption and non-fuel vehicle operating costs for each vehicle type, road type, fuel type, vehicle speed and level of surface unevenness that were calculated from separate analyses using the HDM-4 model (see Section 10 of this report). These values are used to calculate the change in costs from the costs operating at base vehicle speeds on each road type for each vehicle type.

The base vehicle speeds used in the analysis of the national network are shown in Table 46.

Table 46: Base vehicle speeds (mph)

Road Type	Vehicle Type				
	Car	LGV	OGV1	OGV2	PSV
A-roads (R)	60	60	50	50	60
A-roads (U)	30	30	30	30	30
B-roads (R)	60	50	40	40	50
B-roads (U)	30	30	30	30	30
C-roads (R)	60	50	40	40	50
C-roads (U)	30	30	30	30	30
Motorways (R)	70	70	60	60	70
Motorways (U)	50	50	50	50	50
U-roads (R)	60	50	40	40	50
U-roads (U)	30	30	30	30	30

(R) – Rural (U) – Urban
Source: Proposed by project team

To assess the sensitivity of the results of the analyses of the carriageway condition impacts, the unit values of fuel consumption and non-fuel vehicle operating costs for each vehicle type, road type, fuel type, vehicle speed and level of surface unevenness were increased and decreased.

B.13 Employment

Based on data for the employment effects of maintenance funding taken from the Annual Business Survey, values used for the analyses were:

- £55,918 GVA per job

- £146.224 Turnover per job
- GVA:Turnover ratio of 38.24%

More details of the derivation of these values are given in Section 3.9 of this report.

Appendix C. Sensitivity tests on analyses of the national network

The effects of changes in some of the key model data values adopted for the national network were examined using Analysis 4 (performance target), compared with Analysis 1 (current budget), using the base national dataset with an analysis period of 30 years. The aims of the sensitivity tests were to assess the effects of changes to the model data on the overall benefits resulting from the increased maintenance funding and to demonstrate how the key model variables impact on the overall variations in costs. The aim was not to assess the sensitivity of the results to changes in relationships within the HMAT model as these were not changed.

Seven tests were used to examine the sensitivity of the Base Analyses as shown in Table 12.

Table 47 shows the summary impact on the BCRs from the sensitivity tests reported in this Appendix.

The analyses are described in more detail below.

C.1 Test A

New network, maintenance and condition data used in Analyses 1 and 2 with the new Treatment Strategies and Budget Allocation constraints with analysis periods of 20, 30, 40 and 60 years.

The Base Analyses showed Analyses 2, 3 and 4 gave a reduction over Analysis 1 of between £2.70 and £4.30 in the (discounted) indirect costs for every £1 of (discounted) works costs, using an analysis period of 30 years. This sensitivity test further examined the variation using the best data available during the HMAT development and demonstration.

To assess the changes in the benefits provided by analyses with different analysis periods, Analysis 1 (current budget), Analysis 2 (increased budget), Analysis 3 (reduced budget) and Analysis 4 (performance target) were repeated with the data used in the Base Analyses but for analysis periods of 20, 40 and 60 years.

Figure 11 shows the change in condition for Analysis 1 for the 60 years period for all road types except Motorways (these reach Very Good condition early in the analysis period). This shows the long term condition of each road type reached a steady level of condition after approximately 30 years. Some road types reached the steady condition sooner but after 20 years the conditions of urban B-roads, C-roads and U-roads are still deteriorating. Therefore, to represent the full changes in carriageway condition an analysis period of at least 30 years is needed.

Figure 3 shows the indirect impacts also become steady after approximately 30 years (after traffic growth has been limited). The results from this sensitivity test therefore indicate an analysis period of 30 years is sufficient to represent the long term effects of funding levels on the road network.

Table 47: Benefit-Cost Ratio (BCR) for each sensitivity analysis

Sensitivity Test	Analyses	Description	Analysis period (years)	BCR[1]
A	1 and 2	Analysis periods 20 to 60 years	60	2.9
			40	2.8
			30	2.7
			20	2.4
	1 and 3	Analysis periods 20 to 60 years	60	3.2
			40	3.1
			30	2.9
			20	2.6
	1 and 4	Analysis periods 20 to 60 years	60	5.9
			40	4.9
			30	4.3
			20	3.3
B	1 and 4	Low traffic growth	30	4.2
		High traffic growth		4.3
C	1 and 4	Low works costs	30	5.7
		High works costs		3.6
D	1 and 4	Reverse order rules	30	2.2
		County Council strategy		5.9
		County Council strategy (opposite change)		3.5
E	1 and 4	Low condition impacts	30	3.8
		High condition impacts		4.7
F	1 and 4	Low roadworks impacts	30	4.3
		High roadworks impacts		4.3
G	1 and 4	Revised budget allocations	30	3.5
	1	Revised budget allocations for the current budget analysis		7.0

[1] BCR = Change in discounted indirect costs per £1 change in direct maintenance works costs excluding the impacts of carbon and employment.

This analysis used the new treatment strategies and budget allocation constraints, to avoid the condition polarisation and to spend a high percentage of the maintenance budget, for Analyses 1, 2, 3 and 4 for all of the analysis periods of 20, 30, 40 and 60 years. The data represents the final dataset for the national network, as used in the Base Analyses, so shows the results of those funding options over the different analysis periods.

For Analysis 2 (increased budget) and Analysis 4 (performance target), the reduction in the overall indirect costs achieved by each extra £1 of directs maintenance costs, compared to Analysis 1 increased with the length of the analysis period. For Analysis 3 (reduced budget), the increase in indirect costs resulting from each £1 reduction in direct maintenance works costs, compared to Analysis 1 was also higher, the longer the analysis period. Table 47 summarises the changes in overall indirect costs for each £1 change in direct maintenance works costs (compared to Analysis 1) for Analyses 2, 3 and 4. Figure 15, Figure 16 and Figure 17 in Appendix D show the summary results for Test A.

The results from this Test support the use of the 30 years analysis period for the assessment of the effects of alternative levels of maintenance funding. The shorter period (compared with 60 years) reduces the run time of the model while still showing the potential level of benefits. A longer analysis period of 60 years can be expected to show the same effect as the 30 years period but with the costs and benefits increased.

Although the way the funding pattern is modelled is different in Analyses 2 and 4 the effects are similar in that they both represent the use of an increased budget at the start of the analysis period and then a lower budget for the remainder of the period. With a 30 years analysis period, compared with Analysis 1, Analysis 2 (increased budget) shows that each extra £1 of directs maintenance costs resulted in a reduction in the overall indirect costs of £2.70 while the adoption of the performance target resulted in a reduction of £4.30.

With the data used to represent the national network, Figure 40 (for Analysis 4) and Figure 6 (for Analysis 2) show that the performance target adopted in Analysis 4 resulted in better conditions than Analysis 2 for all the road types. The increased budgets in Analysis 2 were sufficient to improve the conditions of A-roads, compared to the condition at the start of the analysis period, but for all road types the increased budget did lead to better conditions, at the end of the analysis period, than continued use of the current budget (Analysis 1) as shown in Figure 5.

C.2 Test B

Higher and lower traffic growth rates were applied to Analyses 1 and 4.

The traffic growth rates used in the Base Analyses are given in Table 28. To assess the effect of uncertainty in the level of traffic through the analysis period, the traffic growth rates were modified. No changes were made to the initial levels of traffic, the vehicle type composition of the total flow or the distribution of the traffic across the road types in the network.

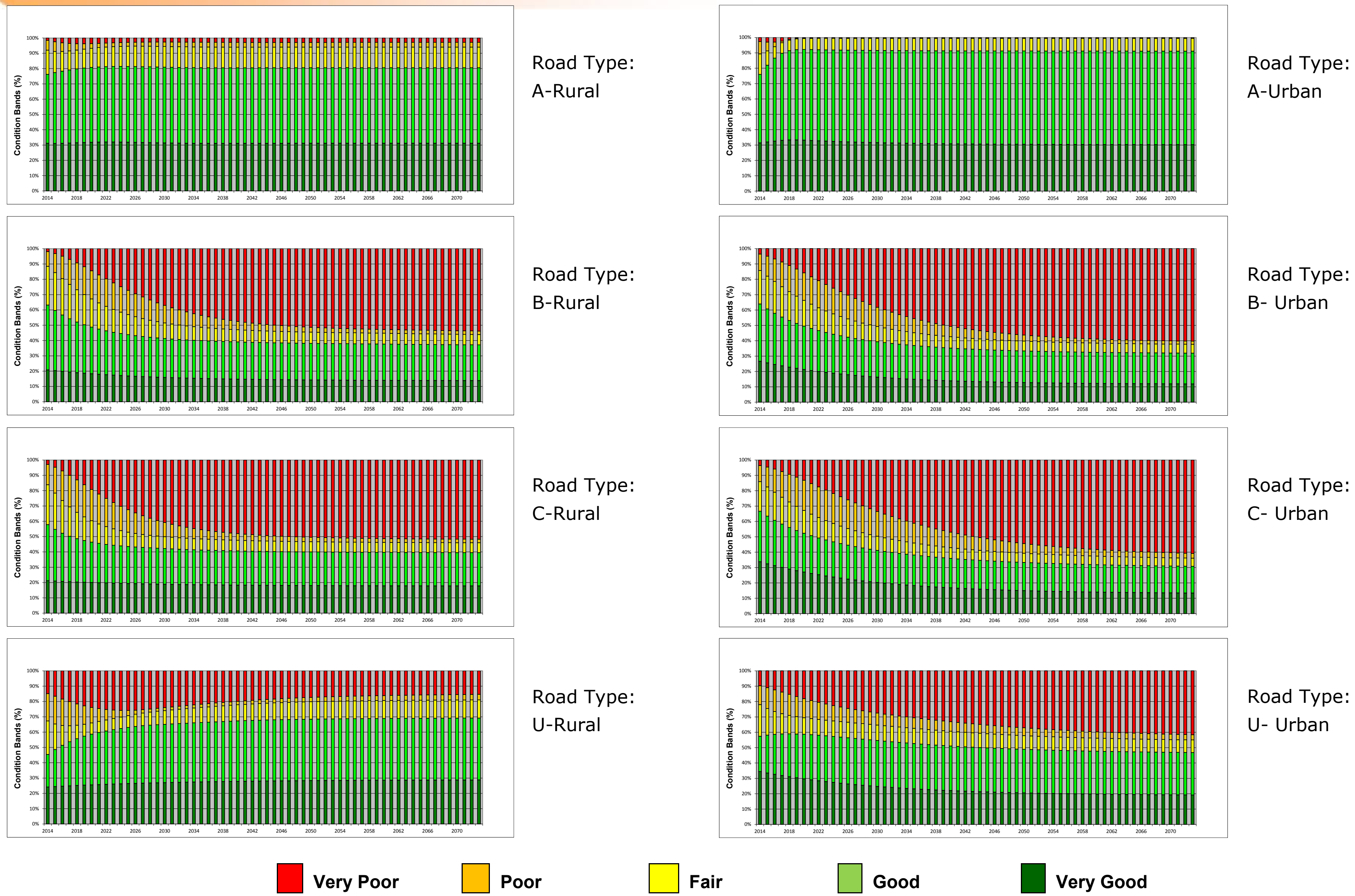


Figure 11: Test A - Carriageway condition: Analysis 1 (60 years analysis period)

National traffic flow data was provided from the national data held by DfT and the base annual growth rates were taken from the National Traffic Model data shown in WebTAG. That model holds growth rates for different regions of the country and the base data was taken as the average of the regional variation. For the sensitivity analyses, low and high traffic growth rates were taken from the range of regional values in the National Traffic Model. The annual growth rates used in the analyses are shown in Table 48. Table 49 shows the total traffic over the analysis period for the three sets of growth rates. The variation in total traffic carried by the network is not wide but reflects the current forecasts of growth in traffic flow over the next 30 years.

The assessment of changes in carriageway condition and maintenance need are not traffic dependent in HMAT so the direct costs of maintenance works do not change for the different traffic levels. The variation in traffic flow caused only small changes in the indirect costs associated with traffic flow. Those changes modified the reduction, compared to Analysis 1, in the discounted overall indirect costs to £4.20 for every extra £1 spent on direct maintenance works with low traffic growth but the high traffic growth did not change the reduction in indirect costs.

Figure 18 and Figure 19 in Appendix D show the summary results for Test B.

Table 48: Test B - Annual traffic growth rates (%)

Vehicle Type	Analysis Period Years						
	1	2-6	7-11	12-16	17-21	22-26	>27
	Low Growth						
Cars	0.70	1.55	1.52	0.89	0.81	0.64	0.00
Light Goods Vehicles	1.36	2.68	2.36	2.11	1.77	1.49	0.00
Goods Vehicles	-1.34	1.36	1.36	0.69	1.22	0.61	0.00
Buses and Coaches	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	High Growth						
Cars	0.87	1.78	1.88	1.01	0.82	0.64	0.00
Light Goods Vehicles	1.34	2.75	2.42	2.16	1.74	1.60	0.00
Goods Vehicles	-0.94	0.96	0.00	2.28	0.00	2.73	0.00
Buses and Coaches	2.38	0.00	-2.33	0.00	0.00	0.00	0.00

Table 49: Total traffic over the analysis period

Vehicle type	Total traffic (million veh. Km)		
	Low Growth Rates	Base Growth Rates	High Growth Rates
Cars	7,527,099	7,657,880	7,743,174
LGV	1,458,017	1,464,894	1,468,654
OGV1	145,639	141,472	142,904
OGV2	84,263	81,852	82,681
PSV	75,152	73,477	70,879
Total	9,290,170	9,419,574	9,508,292

C.3 Test C

Higher and lower maintenance works costs were applied to Analyses 1 and 4.

The maintenance works costs used in the Base Analyses were average values for the maintenance treatment costs derived from data provided by the wider Local Authority survey (see Table 41). Further analysis of the data was used to identify higher and lower values of the costs for use in Sensitivity Test C. There was a high variation in the costs provided by Local Authorities and higher and lower works cost values given by taking values one standard deviation above and below the mean cost value for each maintenance treatment on each road type resulted in unlikely levels of treatment costs. It was therefore agreed that the higher and lower costs for use in Test C should be 25 percent above and below the mean costs.

There was no change in the available budget in the analysis so the impact of the revised maintenance costs was to alter the amount of work that could be done each year from the available funding in Analysis 1. The amount of maintenance then affected the carriageway condition and the indirect costs associated with roadworks and carriageway condition. The modified treatment costs used in the sensitivity tests are shown in Table 50. No other maintenance works data (e.g. rate of working, average scheme length, lane closures) was changed as part of this test.

For performance target analyses (e.g. Analysis 4), treatment costs and budget constraints have no effect on the amount of maintenance as the work required to achieve the required conditions is assumed to be undertaken. The different treatment costs do, however, lead to a change in the total cost of the work but there is no change in the amount of maintenance work undertaken or the condition of the network in each year of the analysis period (for those condition bands defined in the performance target). With no change in carriageway condition or the amount of maintenance, the indirect costs are also not affected by the change in maintenance treatment costs.

The overall effect of the new treatment costs was to change the saving in discounted indirect costs from each £1 increase in direct works costs in Analysis 4 (compared with the current budget in Analysis 1) from £4.30 in the Base Analysis to £5.70 with lower maintenance treatment costs and £3.60 with the higher maintenance costs. Figure 20 and Figure 21 in Appendix D show the summary results for Test C.

In the base analysis the discounted works cost (excluding the costs of skidding works) for Analysis 4 was 159% of the Analysis 1 cost. Using the higher and lower maintenance costs, the discounted works cost for Analysis 4 was 193% of the Analysis 1 cost when using the higher treatment costs and 130% when using the lower treatment costs.

For Analysis 1, the lower maintenance costs enable more maintenance work to be undertaken and, therefore, the condition of the network at the end of the analysis period is better than in the Base Analysis. With higher maintenance treatment costs, the effect is reversed and the network condition at the end of the analysis period is worse than in the base analysis. Table 51 shows the carriageway conditions at the end of the analysis period for each set of maintenance treatment costs.

Use of the low works costs improved the condition of all road types at the end of the analysis period in Analysis 1. In particular there were significant reductions in the percentage of each road type in Very Poor condition but B-roads and C-roads and urban U-roads still had high percentages in Very Poor condition. In general, the improvements in condition (i.e. reductions in the percentage of the road type in Very Poor condition) were bigger for rural roads than urban roads.

With high works costs, the Very Poor condition at the end of the analysis period was significantly increased for all road types The biggest increase in Very Poor condition was for rural A-roads for which the percentage in that condition band increased from 2.9% to 16.94% in year 30. The changes to the percentages in Poor condition on all road types were much smaller (all less than 1% increases).

Table 51 shows the end condition for Analysis 4 only with the base treatment costs as the changes in treatment costs do not affect the network conditions for the performance target analysis.

C.4 Test D

Change to the order and percentage treated defined by the Treatment Strategies for Analyses 1 and 4.

The Base Analyses showed the importance of the Treatment Strategies in determining how much maintenance is undertaken, the types of treatment used and the overall future carriageway condition.

Specification of the Treatment Strategies includes the order in which maintenance treatments are selected and applied on each road type, and, therefore, the amount of available funding for each of the treatments and each road type. In general, the rules are set to apply carriageway surfacing treatments before strengthening treatments, on each road type.

The Analysis 4 Base Analysis used Treatment Strategies that achieved the required performance target (i.e. carriageway condition) so changing the rules in the strategy affected the future condition of the network.

For the first analysis in Test D, the treatment strategy rules were not changed but the order in which the rules were applied to each road type was reversed. Table 42 shows the treatment strategies used for the Base Analyses. This sensitivity test reversed the order of steps 1 to 7 for each road type shown in the table. The effect of these changes was to reduce the overall savings in overall discounted indirect costs from each £1 increase in direct works costs to £2.20 compared to £4.30 in the Base Analysis.

Figure 12 shows the effect on carriageway condition by the reversed treatment strategy in Analysis 4. These condition charts contrast with the conditions shown in Figure 40 for the Base Analysis and show a very different route to the performance target. Either approach is valid but the costs of the different strategies will always have a major impact on the network condition.

As part of the data supplied by the Local Authorities in response to the data survey, one County Council included an HMEP analysis to assess the funding required to improve the carriageway condition across the network for the Authority. Table 52 shows the treatment strategies adopted by the Local Authority and used as part of this sensitivity testing. The strategies use fewer treatments with more surface maintenance treatments (i.e. Surface Dressing) and less strengthening treatments applied at each intervention. With these changes, the effect on the condition of the network is very similar to that shown in Figure 40 for the Base Analysis. The saving in discounted overall indirect costs for every £1 increase in direct works costs (compared to Analysis 1) increased to £5.90. This shows the importance of adopting Treatment Strategies that deliver the aims of the network and the potential for increased benefits.

The County Council treatment strategies meant a change from the strategies used in the Base Analyses. As part of this sensitivity test on the Base Analysis, the changes made to that analysis by the County Council strategies, were applied in the opposite direction and a new set of treatment strategies created, as shown in Table 53.

The effect of this change was to greatly reduce the amount of surface maintenance and increase the amount of strengthening treatments. The reversed County Council changes resulted in a near doubling of the increase in direct works costs in Analysis 4 compared to Analysis 1 in the Base Analysis but the saving in the discounted overall indirect costs increased by less than 60% and this meant a saving in discounted overall indirect costs of £3.50 for every £1 increase in direct works costs for Analysis 4 compared to Analysis 1.

The condition (Poor and Very Poor condition bands) in year 30 for Analysis 4 with all the sets of Treatment Strategies are shown in Table 54. The effect of all the alternative strategies was to reduce the percentage of each road type in Very Poor condition (compared to the base treatment strategies) but the percentage in the Poor condition band clearly increased).

Using the sets of treatment strategies with Analysis 1 (current budget) resulted in a worsening in condition, with particular increases in the Very Poor condition band. The conditions at the end of the analysis period for Analysis 1 are shown in Table 55.

The overall summary results for Test D are shown in Figure 22, Figure 23 and Figure 24 in Appendix D.

Table 50: Test C - Maintenance treatment costs

Road Type	Treatment	Treatment Cost (£/m²) Low	Base	High
A-Rural	Surface Dressing	4.57	6.09	7.61
	Micro Asphalt	6.57	8.77	10.96
	Moderate Overlay	19.11	25.48	31.85
	Moderate Inlay	16.41	21.89	27.36
	Deep Inlay	26.77	35.70	44.62
	Reconstruction	40.57	54.09	67.61
A-Urban	Surface Dressing	4.55	6.07	7.58
	Micro Asphalt	6.38	8.51	10.64
	Moderate Overlay	17.34	23.12	28.90
	Moderate Inlay	16.77	22.36	27.95
	Deep Inlay	25.55	34.06	42.58
	Reconstruction	40.32	53.76	67.20
B-Rural	Surface Dressing	4.67	6.22	7.78
	Micro Asphalt	6.72	8.96	11.20
	Moderate Overlay	17.71	23.61	29.51
	Moderate Inlay	16.08	21.44	26.80
	Deep Inlay	25.46	33.95	42.44
	Reconstruction	40.75	54.33	67.91
B-Urban	Surface Dressing	4.53	6.04	7.54
	Micro Asphalt	6.48	8.64	10.80
	Moderate Overlay	16.87	22.49	28.11
	Moderate Inlay	16.02	21.36	26.70
	Deep Inlay	24.74	32.99	41.23
	Reconstruction	39.95	53.27	66.59
C-Rural	Surface Dressing	5.09	6.78	8.48
	Micro Asphalt	6.50	8.67	10.83
	Moderate Overlay	16.96	22.61	28.26
	Moderate Inlay	15.54	20.72	25.90
	Deep Inlay	24.88	33.17	41.46
	Reconstruction	40.29	53.73	67.16
C-Urban	Surface Dressing	4.94	6.59	8.24
	Micro Asphalt	6.30	8.40	10.51
	Moderate Overlay	16.59	22.13	27.66
	Moderate Inlay	15.63	20.84	26.05
	Deep Inlay	23.53	31.37	39.21
	Reconstruction	39.13	52.17	65.22
U-Rural	Surface Dressing	4.90	6.53	8.16
	Micro Asphalt	6.76	9.02	11.27
	Moderate Overlay	15.50	20.66	25.83
	Moderate Inlay	14.44	19.25	24.06
	Deep Inlay	23.54	31.38	39.23
	Reconstruction	36.34	48.45	60.56
U-Urban	Surface Dressing	4.39	5.85	7.32
	Micro Asphalt	6.51	8.68	10.86
	Moderate Overlay	15.93	21.24	26.55
	Moderate Inlay	14.99	19.99	24.98
	Deep Inlay	23.28	31.04	38.80
	Reconstruction	35.85	47.79	59.74

NB. The A-roads treatment types and costs were also used for Motorways

Table 51: Test C - Carriageway conditions in year 30

Analysis 1

Road Type	Low Costs		Base Costs		High Costs	
	P	VP	P	VP	P	VP
A-Rural	1.28%	0.16%	3.11%	2.90%	3.68%	16.94%
A-Urban	0.47%	0.03%	0.53%	0.04%	0.83%	0.06%
B-Rural	3.99%	36.07%	4.53%	49.07%	4.84%	56.89%
B-Urban	5.16%	41.94%	5.67%	52.79%	5.98%	59.31%
C-Rural	3.45%	35.73%	3.76%	49.02%	3.89%	57.11%
C-Urban	7.93%	39.88%	8.72%	49.69%	9.19%	55.57%
U-Rural	2.36%	2.51%	2.43%	18.91%	2.79%	32.08%
U-Urban	4.55%	20.06%	5.88%	34.45%	6.68%	43.09%

P – Poor condition VP – Very Poor condition

Analysis 4

Road Type	Base Costs	
	P	VP
A-Rural	1.06%	0.92%
A-Urban	0.47%	1.81%
B-Rural	2.12%	0.64%
B-Urban	2.12%	0.61%
C-Rural	2.59%	0.43%
C-Urban	2.27%	0.72%
U-Rural	2.30%	3.29%
U-Urban	2.31%	3.27%

P – Poor condition VP – Very Poor condition

Table 52: Test D - Local Authority treatment strategies, Analysis 4

Strategy Name and Road Type	Step	Treatment	Condition Band	% Treated	VG	G	F	P	VP
Strat&Main A-roads and Motorways	1	Surface Dressing	F	50%			50%		
	2	Micro Asphalt	F	0%			0%		
	3	Moderate Overlay	F	0%			0%		
	4	Moderate Inlay	P	35%				35%	
	5	Deep Inlay	P	30%				30%	
	6	Deep Inlay	VP	20%					20%
	7	Reconstruction	VP	35%					35%
Secondary B-roads	1	Surface Dressing	F	50%			50%		
	2	Micro Asphalt	F	0%			0%		
	3	Moderate Overlay	F	20%			20%		
	4	Moderate Inlay	P	20%				20%	
	5	Deep Inlay	P	10%				10%	
	6	Deep Inlay	VP	0%					0%
	7	Reconstruction	VP	20%					20%
Link C-roads	1	Surface Dressing	F	50%			50%		
	2	Micro Asphalt	F	0%			0%		
	3	Moderate Overlay	F	15%			15%		
	4	Moderate Inlay	P	0%				0%	
	5	Deep Inlay	P	20%				20%	
	6	Deep Inlay	VP	0%					0%
	7	Reconstruction	VP	30%					30%
Local U-roads	1	Surface Dressing	F	50%			50%		
	2	Micro Asphalt	F	0%			0%		
	3	Moderate Overlay	F	0%			0%		
	4	Moderate Inlay	P	20%				20%	
	5	Deep Inlay	P	20%				20%	
	6	Deep Inlay	VP	0%					0%
	7	Reconstruction	VP	20%					20%

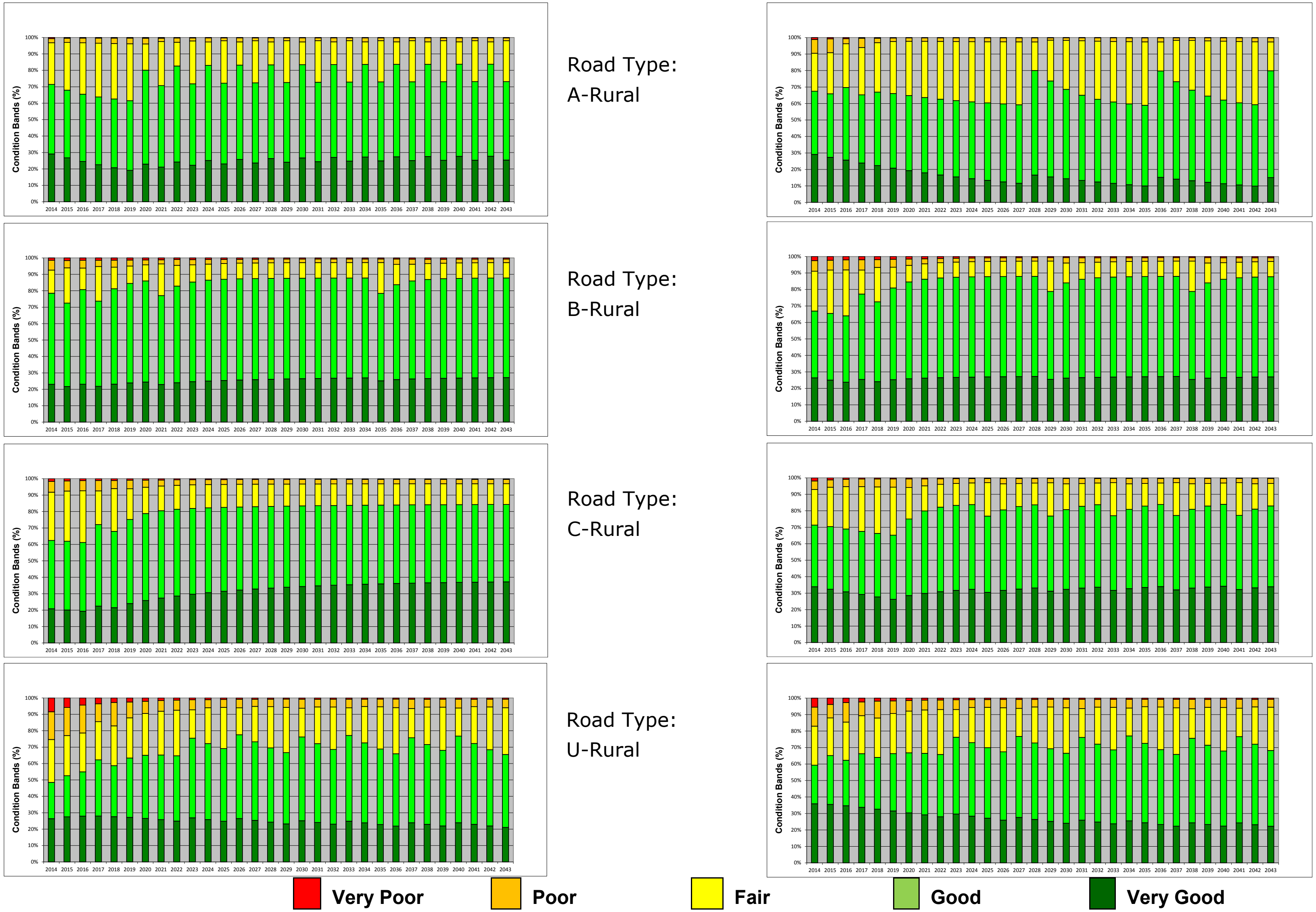


Figure 12: Test D - Carriageway condition: Analysis 4 (Reversed treatment strategies)

Table 53: Test D - Reversed change of LA treatment strategies: Analysis 4

Strategy Name and Road Type	Step	Treatment	Condition Band	% Treated	VG	G	F	P	VP
Strat&Main A-roads and Motorways	1	Surface Dressing	F	5%			5%		
	2	Micro Asphalt	F	0%			0%		
	3	Moderate Overlay	F	0%			0%		
	4	Moderate Inlay	P	55%				55%	
	5	Deep Inlay	P	30%				30%	
	6	Deep Inlay	VP	70%					70%
	7	Reconstruction	VP	5%					5%
Secondary B-roads	1	Surface Dressing	F	5%			5%		
	2	Micro Asphalt	F	0%			0%		
	3	Moderate Overlay	F	0%			0%		
	4	Moderate Inlay	P	20%				20%	
	5	Deep Inlay	P	40%				40%	
	6	Deep Inlay	VP	0%					0%
	7	Reconstruction	VP	10%					10%
Link C-roads	1	Surface Dressing	F	5%			5%		
	2	Micro Asphalt	F	0%			0%		
	3	Moderate Overlay	F	9%			9%		
	4	Moderate Inlay	P	0%				0%	
	5	Deep Inlay	P	20%				20%	
	6	Deep Inlay	VP	0%					0%
	7	Reconstruction	VP	20%					20%
Local U-roads	1	Surface Dressing	F	5%			5%		
	2	Micro Asphalt	F	0%			0%		
	3	Moderate Overlay	F	0%			0%		
	4	Moderate Inlay	P	40%				40%	
	5	Deep Inlay	P	10%				10%	
	6	Deep Inlay	VP	0%					0%
	7	Reconstruction	VP	30%					30%

Table 54: Test D - Condition in year 30: Analysis 4

Road Type	Base Analysis		Reversed Rules		County Council Rules		Opposite County Council Change	
	P	VP	P	VP	P	VP	P	VP
A-Rural	1.06%	0.92%	1.64%	0.28%	2.66%	0.51%	2.26%	0.24%
A-Urban	0.47%	1.81%	2.45%	0.16%	1.20%	1.24%	1.32%	0.95%
B-Rural	2.12%	0.64%	2.15%	0.69%	1.50%	1.30%	4.36%	6.06%
B-Urban	2.12%	0.61%	2.27%	0.74%	1.50%	1.10%	4.32%	5.74%
C-Rural	2.59%	0.43%	2.61%	0.43%	3.67%	1.41%	9.32%	6.22%
C-Urban	2.27%	0.72%	3.02%	0.36%	3.48%	0.97%	9.69%	4.69%
U-Rural	2.30%	3.29%	5.24%	0.74%	2.61%	3.14%	5.39%	1.55%
U-Urban	2.31%	3.27%	4.76%	0.76%	2.65%	2.78%	5.43%	1.59%

Table 55: Test D - Condition in year 30: Analysis 1

Road Type	Base Analysis		Reversed Rules		County Council Rules		Opposite County Council Change	
	P	VP	P	VP	P	VP	P	VP
A-Rural	3.12%	2.90%	7.86%	0.97%	5.78%	33.83%	5.64%	46.61%
A-Urban	0.53%	0.04%	0.53%	0.04%	7.81%	1.96%	8.90%	18.69%
B-Rural	4.53%	49.07%	7.50%	46.10%	4.78%	53.59%	7.33%	65.53%
B-Urban	5.67%	52.80%	8.25%	50.22%	5.92%	56.62%	8.23%	66.31%
C-Rural	3.76%	49.02%	7.23%	45.55%	3.82%	60.36%	5.68%	66.20%
C-Urban	8.72%	49.69%	12.02%	46.38%	9.42%	58.10%	10.39%	60.07%
U-Rural	2.43%	18.91%	7.39%	13.44%	6.88%	41.49%	7.78%	46.78%
U-Urban	5.88%	34.45%	9.84%	30.49%	9.28%	49.16%	10.07%	52.27%

C.5 Test E

Changes to the condition impacts resulting from changes to the unit costs of the impacts for Analyses 1 and 4.

The impacts caused by the carriageway condition are derived in HMAT from the unit costs of fuel consumption, vehicle operating costs excluding fuel and the time costs arising from changes in vehicle speed for each road type, vehicle type, fuel type, carriageway condition and base vehicle speed. To assess the scale of the sensitivity to the base data the unit costs for the three condition impacts were increased by 10% and decreased by 10% from the values used in the base analyses. In the Base Analysis with Analysis 4, the increased direct maintenance works costs led to an overall decrease in the discounted indirect costs of £4.30 for every £1 increase in direct works cost. The 10% reduction in the unit costs of condition impacts reduced the saving to £3.80 for every £1 increase in direct works cost and the 10% increase in the unit costs of the condition impacts increased the savings in overall indirect costs to £4.70 for every £1 increase in direct works costs.

The summary results for Test E are shown in Figure 25 and Figure 26 in Appendix D.

C.6 Test F

Roadworks impacts resulting from longer and shorter durations of roadworks for each road type for Analyses 1 and 4.

Road works impacts vary with the amount of maintenance carried out and the number of schemes that are used to undertake the maintenance. HMAT contains an average maintenance scheme length for each road type and all treatments are assumed to use the same scheme length for all maintenance on that road type.

Table 45 shows the average scheme lengths used in the Base Analyses. The HMAT calculation of roadworks impacts uses the total length of maintenance with the average impact per km of maintenance. The average scheme length therefore has no effect on the roadworks impacts.

To assess the effect on the return from the increased spend on maintenance on the overall indirect costs, the roadworks impacts in the Base Analyses were changed by increasing and decreasing the treatment output rates by 25 percent on all road types for both Analyses 1 and 4. The roadworks impacts are a small component of the overall indirect costs associated with the level of maintenance funding and the effects of increasing and decreasing those impacts in the Base Analyses have a very small effect. In the Base Analyses for Analysis 1 and 4, each extra £1 of direct works costs for Analysis 4 (compared to Analysis 1) leads to a reduction in the discounted overall indirect costs of £4.30. Increasing the roadworks impacts by reducing the treatment output rates by 25 percent changed the reduction in the overall indirect costs to £4.25 and decreasing the impacts by increasing the treatment output rates by 25 percent changed the reduction in the overall indirect costs to £4.26.

The overall summary results for Test F are shown in Figure 27 and Figure 28 in Appendix D.

C.7 Test G

Budget allocations to road types changed in Analyses 1 and 4 and new allocation applied to Analysis 1.

The Activity Allocations and road type and treatment type allocations are based on percentages of the available budget so for the same Activity Allocation a higher total budget will mean more money is available for carriageway maintenance (unless the budget level moves to a higher band and the distributions may then be different) and, therefore, more maintenance would be undertaken.

The survey of Local Authorities for data to use in HMAT did not provide new information on the breakdown of carriageway budgets for road types and maintenance treatment types. The Base Analyses therefore continued to use the allocations derived from Local

Authority published reports and described in Section 3.2. The allocations used are shown in Table 56 (road type allocations) and Table 57 (treatment type allocations). The budget constraints imposed by these allocations have been included in the Base Analyses, representing the best data available for use in analyses of the national network (see Section B.4), and have been one of the main causes of the conditions and associated costs predicted in the analyses.

The allocations used did not appear to provide sufficient funding for B-roads, while providing a higher than expected allocation to U-roads. Revised allocations were investigated by DfT and new allocations were proposed for use in the budget analyses. The revised allocations are shown in Table 58 and Table 59 for road types and treatment types respectively. There was no change to the total available budget. The main changes to the allocations were:

- Increased allocations to B-roads
- Reduced allocation to urban A-roads
- Reduced allocation to rural U-roads
- Reduced budget available for Motorways
- Severe reductions in the allocations to Reconstruction works
- Increased allocations to surfacing treatments
- Increased allocations to overlay (carriageway strengthening) treatments

Table 56: Budget allocations for road types

Road Type	Analysis 1	Analysis 2		Analysis 3	
	Budget (£k)	Budget (£k)	% Change from Analysis 1	Budget (£k)	% Change from Analysis 1
A-roads (R)	437,929	494,785	13%	388,406	-11%
A-roads (U)	218,964	238,358	9%	191,038	-13%
B-roads (R)	79,623	91,604	15%	70,044	-12%
B-roads (U)	19,906	22,901	15%	15,929	-20%
C-roads (R)	278,682	334,165	20%	216,670	-22%
C-roads (U)	39,812	45,802	15%	31,857	-20%
Motorways (R)	19,906	22,901	15%	15,929	-20%
Motorways (U)	19,906	22,901	15%	15,929	-20%
U-roads (R)	437,929	508,337	16%	321,944	-26%
U-roads (U)	437,929	508,337	16%	325,109	-26%
Totals	**1,990,585**	**2,290,090**	**15%**	**1,592,854**	**-20%**

(R) – Rural (U) – Urban
Notes: The Budgets for Analyses 2 and 3 are for years 1 to 5 only. Analysis 1 budgets are used for other years
The same budgets are used for urban and rural Motorways

Table 57: Budget allocations for maintenance treatments

Road Type	Treatment	Analysis 1 Budget (£k)	Analysis 2 Budget (£k)	Analysis 2 % Change from Analysis 1	Analysis 3 Budget (£k)	Analysis 3 % Change from Analysis 1
A-roads (R)	Surface Dressing	43,793	54,358	24%	54,275	24%
	Micro Asphalt	43,793	49,479	13%	46,558	6%
	Moderate Overlay	87,586	103,837	19%	77,681	-11%
	Moderate Inlay	87,586	98,957	13%	73,823	-16%
	Deep Inlay	87,586	94,077	7%	69,964	-20%
	Reconstruction	87,586	94,077	7%	66,105	-25%
A-roads (U)	Surface Dressing	21,896	26,187	20%	26,695	22%
	Micro Asphalt	21,896	23,836	9%	22,899	5%
	Moderate Overlay	43,793	50,022	14%	38,208	-13%
	Moderate Inlay	43,793	47,672	9%	36,310	-17%
	Deep Inlay	43,793	45,321	3%	34,412	-21%
	Reconstruction	43,793	45,321	3%	32,514	-26%
B-roads (R)	Surface Dressing	7,962	10,064	26%	9,788	23%
	Micro Asphalt	7,962	9,160	15%	8,396	5%
	Moderate Overlay	15,925	19,224	21%	14,009	-12%
	Moderate Inlay	15,925	18,321	15%	13,313	-16%
	Deep Inlay	15,925	17,417	9%	12,617	-21%
	Reconstruction	15,925	17,417	9%	11,921	-25%
B-roads (U)	Surface Dressing	1,991	2,516	26%	2,226	12%
	Micro Asphalt	1,991	2,290	15%	1,909	-4%
	Moderate Overlay	3,981	4,806	21%	3,186	-20%
	Moderate Inlay	3,981	4,580	15%	3,027	-24%
	Deep Inlay	3,981	4,354	9%	2,869	-28%
	Reconstruction	3,981	4,354	9%	2,711	-32%
C-roads (R)	Surface Dressing	27,868	36,712	32%	30,277	9%
	Micro Asphalt	27,868	33,416	20%	25,972	-7%
	Moderate Overlay	55,736	70,129	26%	43,334	-22%
	Moderate Inlay	55,736	66,833	20%	41,181	-26%
	Deep Inlay	55,736	63,537	14%	39,029	-30%
	Reconstruction	55,736	63,537	14%	36,877	-34%
C-roads (U)	Surface Dressing	3,981	5,032	26%	4,452	12%
	Micro Asphalt	3,981	4,580	15%	3,819	-4%
	Moderate Overlay	7,962	9,612	21%	6,371	-20%
	Moderate Inlay	7,962	9,160	15%	6,055	-24%
	Deep Inlay	7,962	8,709	9%	5,738	-28%
	Reconstruction	7,962	8,709	9%	5,422	-32%
Motorways (R) and (U)	Surface Dressing	1,991	2,516	26%	2,226	12%
	Micro Asphalt	1,991	2,290	15%	1,909	-4%
	Moderate Overlay	3,981	4,806	21%	3,186	-20%
	Moderate Inlay	3,981	4,580	15%	3,027	-24%
	Deep Inlay	3,981	4,354	9%	2,869	-28%
	Reconstruction	3,981	4,354	9%	2,711	-32%
U-roads (R)	Surface Dressing	43,793	55,847	28%	44,988	3%
	Micro Asphalt	43,793	50,834	16%	38,591	-12%
	Moderate Overlay	87,586	106,681	22%	64,389	-26%
	Moderate Inlay	87,586	101,667	16%	61,191	-30%
	Deep Inlay	87,586	96,654	10%	57,992	-34%
	Reconstruction	87,586	96,654	10%	54,794	-37%
U-roads (U)	Surface Dressing	43,793	55,847	28%	45,430	4%
	Micro Asphalt	43,793	50,834	16%	38,970	-11%
	Moderate Overlay	87,586	106,681	22%	65,022	-26%
	Moderate Inlay	87,586	101,667	16%	61,792	-29%
	Deep Inlay	87,586	96,654	10%	58,562	-33%
	Reconstruction	87,586	96,654	10%	55,333	-37%
Totals		**1,990,585**	**2,290,090**	**15%**	**1,592,854**	**-20%**

(R) – Rural (U) – Urban

Notes: Budgets for Analyses 2 and 3 are for years 1 to 5 only. Analysis 1 budgets are used in other years

The same budgets are used for urban and rural Motorways

The revised budgets do not affect the maintenance applied in performance target analyses (e.g. Analysis 4).

Figure 13 shows the change in conditions of the road types (excluding Motorways) in Analysis 1, using the revised allocations. The effects of the new allocations can be seen by comparing Figure 5 with Figure 13. The changes in conditions were concerned mainly with the Very Poor, Poor and Fair condition bands. There was little effect on the Very Good and Good bands.

Table 58: Budget allocations for road types – Test G, Analysis 1

Road Type	Base Budget (£k)	Revised Budget (£k)	% of Base
A-roads (R)	437,929	393,089	**90%**
A-roads (U)	218,964	108,255	**49%**
B-roads (R)	79,623	162,508	**204%**
B-roads (U)	19,906	44,191	**222%**
C-roads (R)	278,682	512,307	**184%**
C-roads (U)	39,812	88,610	**223%**
Motorways (R)	19,906	941	**5%**
Motorways (U)	19,906	941	**5%**
U-roads (R)	437,929	272,591	**62%**
U-roads (U)	437,929	407,152	**93%**
Totals	**1,990,585**	**1,990,585**	**100%**

(R) – Rural (U) – Urban

With the new allocations, there was a small worsening in the condition of both rural and urban A-roads but the change levelled off for the last 15 years of the analysis period. The increased allocations to B-roads resulted in improved conditions, so the conditions of B-roads were similar to the achieved conditions of A-roads. The conditions of B-roads were stable after 10 to 15 years into the analysis period. The conditions of C-roads also improved with the new allocations but the conditions of both rural and urban roads were still deteriorating at the end of the analysis period. With the reduced funding for U-roads, there was a worsening in the rural U-roads condition and it was still deteriorating at the end of the analysis period. The change in condition of urban U-roads was similar using either the original or new allocations. The predicted conditions of Motorways are not shown in Figure 13 as these roads make up a very small part of the network. Although the budget allocations to rural and urban Motorways were the same, the reduced allocations resulted in a worsening in condition in the second half of the analysis period for rural Motorways and in the first half of the analysis period for urban Motorways.

Figure 29 in Appendix D shows the summary results for the comparison of Base Analysis, Analysis 1 with the original budget allocations with Analysis 1 using the new allocations. By changing the emphasis on the types of maintenance works undertaken, the new allocations reduced the vehicle operating costs and time components of the condition impacts and increased the carbon (from fuel) costs. There was also a small reduction in the roadworks impacts. This analysis has shown that the adoption of different budget allocations can improve the effectiveness of the maintenance spend. In this Test, using the new allocations, there was a reduction in the discounted direct works costs (approximately £1.58 billion) while also reducing the discounted indirect costs by more than £11 billion.

A further assessment of the effect of the new allocations compared the Analysis 4 analysis with Analysis 1 with the new budget allocations. The results are summarised in Appendix D, Figure 30. Figure 14 shows the comparison of Analysis 1 and Analysis 4 using the original allocations. The discounted works costs in Analysis 1 with the new allocations were approximately 5% lower than with the original allocations. With the new allocations in Analysis 1, the discounted indirect costs associated with Analysis 4 were £3.45 for every £1 increase in the cost of Analysis 4 (compared to Analysis 1with the new budget allocations). This compared to £4.30 when using the original allocations (i.e. use of the new budget allocations in Analysis 1 was closer to achieving the performance targets in Analysis 4 than the use of the original allocations).

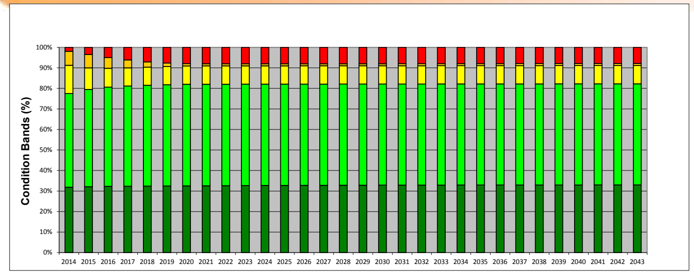
As noted earlier, the new allocations did not affect the Analysis 4 analysis so those costs were unchanged and showed the discounted direct works costs were 166% of the Analysis 1 works costs with the new allocations.

Test G has demonstrated that further investigations will help to better understand the most effective budget allocations for a road network. Although the allocations used reflect existing practices (derived from different sources) they do not show that they are the best allocations that could be adopted.

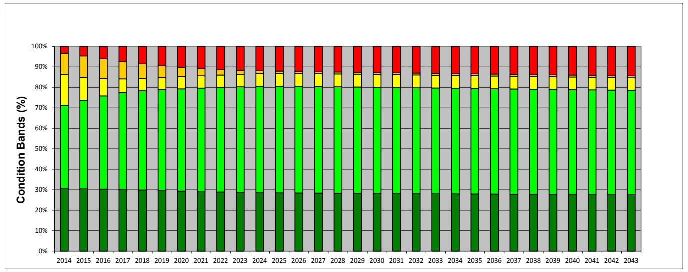
Table 59: Test G - Budget allocations for maintenance works: Analysis 1

Road Type	Treatment	Base Budget (£k)	Revised Budget (£k)	% of Base Budget
A-roads (R)	Surface Dressing	43,793	42,102	96%
	Micro Asphalt	43,793	60,630	138%
	Moderate Overlay	87,586	132,115	151%
	Moderate Inlay	87,586	74,429	85%
	Deep Inlay	87,586	83,812	96%
	Reconstruction	87,586	0	0%
A-roads (U)	Surface Dressing	21,896	14,509	66%
	Micro Asphalt	21,896	20,341	93%
	Moderate Overlay	43,793	41,446	95%
	Moderate Inlay	43,793	26,263	60%
	Deep Inlay	43,793	5,697	13%
	Reconstruction	43,793	0	0%
B-roads (R)	Surface Dressing	7,962	22,808	286%
	Micro Asphalt	7,962	32,855	413%
	Moderate Overlay	15,925	43,288	272%
	Moderate Inlay	15,925	18,106	114%
	Deep Inlay	15,925	44,865	282%
	Reconstruction	15,925	587	4%
B-roads (U)	Surface Dressing	1,991	6,293	316%
	Micro Asphalt	1,991	9,002	452%
	Moderate Overlay	3,981	11,717	294%
	Moderate Inlay	3,981	5,755	145%
	Deep Inlay	3,981	11,423	287%
	Reconstruction	3,981	0	0%
C-roads (R)	Surface Dressing	27,868	61,789	222%
	Micro Asphalt	27,868	79,013	284%
	Moderate Overlay	55,736	206,053	370%
	Moderate Inlay	55,736	56,840	102%
	Deep Inlay	55,736	104,382	187%
	Reconstruction	55,736	4,230	8%
C-roads (U)	Surface Dressing	3,981	10,768	270%
	Micro Asphalt	3,981	13,725	345%
	Moderate Overlay	7,962	36,159	454%
	Moderate Inlay	7,962	11,396	143%
	Deep Inlay	7,962	16,561	208%
	Reconstruction	7,962	0	0%
Motorways (R) and (U)	Surface Dressing	1,991	101	5%
	Micro Asphalt	1,991	146	7%
	Moderate Overlay	3,981	318	8%
	Moderate Inlay	3,981	176	4%
	Deep Inlay	3,981	201	5%
	Reconstruction	3,981	0	0%
U-roads (R)	Surface Dressing	43,793	54,518	124%
	Micro Asphalt	43,793	54,518	124%
	Moderate Overlay	87,586	54,518	62%
	Moderate Inlay	87,586	40,889	47%
	Deep Inlay	87,586	40,889	47%
	Reconstruction	87,586	27,259	31%
U-roads (U)	Surface Dressing	43,793	81,430	186%
	Micro Asphalt	43,793	81,430	186%
	Moderate Overlay	87,586	81,430	93%
	Moderate Inlay	87,586	61,073	70%
	Deep Inlay	87,586	61,073	70%
	Reconstruction	87,586	40,715	46%
Totals		**1,990,585**	**1,990,585**	**100%**

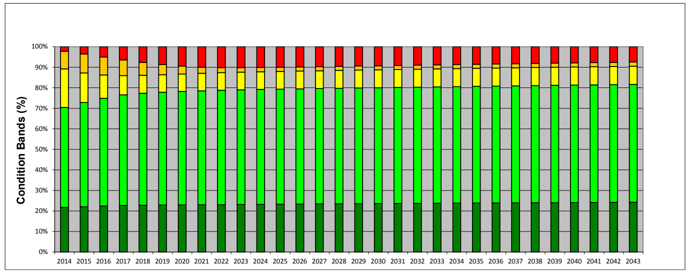
(R) – Rural (U) – Urban



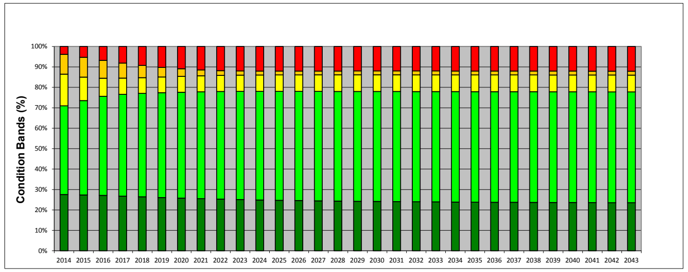
Road Type:
A-Rural



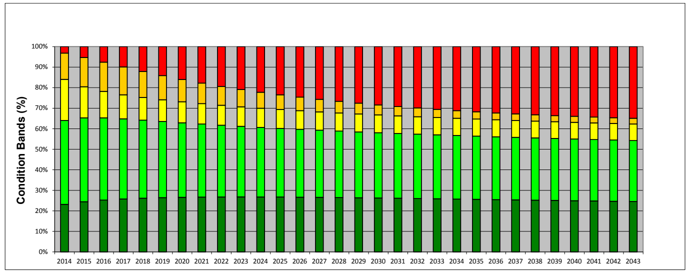
Road Type:
A-Urban



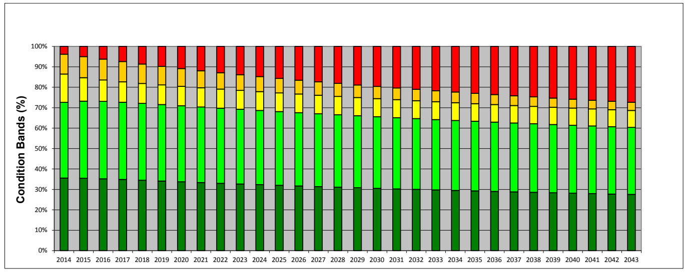
Road Type:
B-Rural



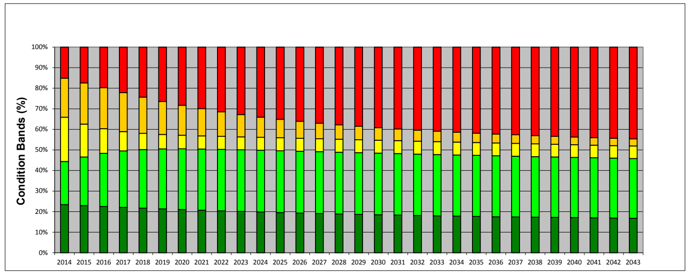
Road Type:
B- Urban



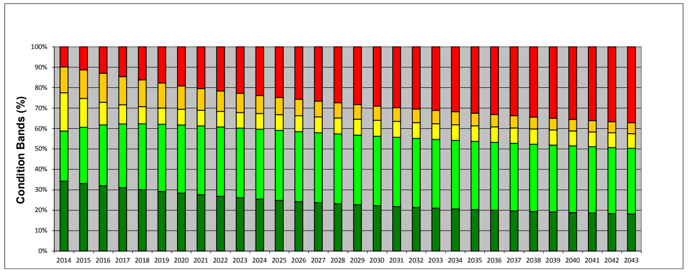
Road Type:
C-Rural



Road Type:
C- Urban



Road Type:
U-Rural



Road Type:
U- Urban

Very Poor **Poor** **Fair** **Good** **Very Good**

Figure 13: Test G - Carriageway condition: Analysis 1

Appendix D. Summary results from the analyses of the national network

	Scenario (Base)	Scenario	Scenario	Scenario
	1. Analysis 1	2. Analysis 3	3. Analysis 4	4. Analysis 2
Direct Costs (Outturn)				
Carriageway Output (£k)	**35,128,560**	-1,678,872	+20,739,600	+1,067,482
Skid (£k)	**881,216**	+17,051	0	+21,633
Lighting (£k)	**10,574,598**	+49,876	0	+118,777
Other (£k)	**39,654,742**	-354,541	0	+644,906
Total (Outturn) Direct Costs (£k)	**86,239,115**	**-1,966,486**	**+20,739,600**	**+1,852,798**
Direct Costs (Allocated) categorised by maintenance drivers				
Safety (£k)	**22,867,568**	-251,904	0	+598,927
Accessibility (£k)	**1,498,068**	-75,460	0	+60,246
Condition (£k)	**23,308,176**	-897,136	0	+670,764
Reliability (£k)	**6,697,245**	-303,672	0	+211,350
Customer Service (£k)	**20,003,614**	-398,227	0	+415,965
Environment (£k)	**13,746,977**	-236,896	0	+206,043
Total Direct (Allocated) Costs (£k)	**88,121,648**	**-2,163,295**	**0**	**+2,163,295**
Indirect Costs				
Road Condition Impacts				
VOC (£k)	**2,606,181,586**	+4,125,173	-61,406,475	-3,580,410
Value of Time (£k)	**1,628,947,645**	+1,626,595	-27,297,515	-1,484,725
Carbon (from fuel) (£k)	**84,029,850**	-12,679	+250,458	+17,249
Road Works Impacts				
Accidents (£k)	**769,005**	-9,004	+147,228	+8,135
Carbon (from fuel) (£k)	**9,967**	-77	+1,028	+68
Time (£k)	**965,600**	-7,791	+106,986	+6,925
Accident Impacts				
Total Number of Accidents	**4,367,130**	0	0	0
Total Accident Cost (£k)	**194,702,858**	0	0	0
Carbon Impacts (embodied)				
Carbon Quantity (tonnes CO2e)	**22,846,487**	-853,853	+9,733,917	+408,516
Carbon Cost (£k)	**1,173,886**	-47,691	+507,808	+22,956
Indirect Benefits				
Job Impacts				
Jobs	**918,452**	-14,759	+202,807	+13,454
GVA (£k)	**32,641,698**	-758,524	+7,931,027	+700,256
Total Indirect Costs[1]				
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)				
Total (£k)	4,515,606,511	**+5,722,218**	**-88,198,291**	**-5,032,758**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)				
Total (£k)	4,484,138,698	**+6,433,052**	**-95,621,509**	**-5,710,058**
Economic analysis (excl. Carbon Impacts and Job Impacts)				
Works costs change	**Base**	**-1,966,486**	**+20,739,600**	**+1,852,798**
Non-works costs change	**Base**	**+5,722,218**	**-88,198,291**	**-5,032,758**
Net Present Value[2]	**Base**	**-3,755,732**	**+67,458,691**	**+3,179,960**
Economic analysis (incl. Carbon Impacts and Job Impacts)				
Works costs change	**Base**	**-1,966,486**	**+20,739,600**	**+1,852,798**
Non-works costs change	**Base**	**+6,433,052**	**-95,621,509**	**-5,710,058**
Net Present Value[2]	**Base**	**-4,466,566**	**+74,881,909**	**+3,857,260**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 14: Summary results for the Base Analyses (discounted costs)

	Scenario (Base)	Scenario	Scenario	Scenario
	1. Analysis 1	2. Analysis 3	3. Analysis 4	4. Analysis 2
Direct Costs (Outturn)				
Carriageway Output (£k)	**27,242,072**	-1,635,611	+17,514,282	+1,043,340
Skid (£k)	**680,958**	+17,051	0	+21,633
Lighting (£k)	**8,171,492**	+49,876	0	+118,777
Other (£k)	**30,643,094**	-354,541	0	+644,906
Total (Outturn) Direct Costs (£k)	**66,737,615**	**-1,923,225**	**+17,514,282**	**+1,828,656**
Direct Costs (Allocated) categorised by maintenance drivers				
Safety (£k)	**17,670,851**	-251,904	0	+598,927
Accessibility (£k)	**1,157,628**	-75,460	0	+60,246
Condition (£k)	**18,011,330**	-897,136	0	+670,764
Reliability (£k)	**5,175,278**	-303,672	0	+211,350
Customer Service (£k)	**15,457,739**	-398,227	0	+415,965
Environment (£k)	**10,622,939**	-236,896	0	+206,043
Total Direct (Allocated) Costs (£k)	**68,095,765**	**-2,163,295**	**0**	**+2,163,295**
Indirect Costs				
Road Condition Impacts				
VOC (£k)	**1,875,370,906**	+3,598,931	-40,875,293	-3,197,956
Value of Time (£k)	**1,111,103,814**	+1,375,891	-16,930,072	-1,298,570
Carbon (from fuel) (£k)	**53,745,630**	-12,588	+161,786	+16,952
Road Works Impacts				
Accidents (£k)	**577,323**	-8,505	+114,762	+7,658
Carbon (from fuel) (£k)	**6,822**	-71	+791	+63
Time (£k)	**671,785**	-7,267	+82,435	+6,402
Accident Impacts				
Total Number of Accidents	**2,911,420**	0	0	0
Total Accident Cost (£k)	**150,456,106**	0	0	0
Carbon Impacts (embodied)				
Carbon Quantity (tonnes CO2e)	**15,299,473**	-804,804	+7,685,646	+382,908
Carbon Cost (£k)	**752,081**	-44,981	+393,541	+21,585
Indirect Benefits				
Job Impacts				
Jobs	**613,297**	-14,090	+151,903	+13,099
GVA (£k)	**25,260,714**	-741,981	+6,697,633	+691,023
Total Indirect Costs[1]				
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)				
Total (£k)	**3,191,932,386**	**+4,946,391**	**-57,445,592**	**-4,465,451**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)				
Total (£k)	**3,167,423,754**	**+5,643,391**	**-63,749,684**	**-5,134,889**
Economic analysis (excl. Carbon Impacts and Job Impacts)				
Works costs change	**Base**	**-1,923,225**	**+17,514,282**	**+1,828,656**
Non-works costs change	**Base**	**+4,946,391**	**-57,445,592**	**-4,465,451**
Net Present Value[2]	**Base**	**-3,023,166**	**+39,931,310**	**+2,636,795**
Economic analysis (incl. Carbon Impacts and Job Impacts)				
Works costs change	**Base**	**-1,923,225**	**+17,514,282**	**+1,828,656**
Non-works costs change	**Base**	**+5,643,391**	**-63,749,684**	**-5,134,889**
Net Present Value[2]	**Base**	**-3,720,166**	**+46,235,402**	**+3,306,233**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 15: Test A - Summary results (20 years, discounted costs)

	Scenario (Base)	Scenario	Scenario	Scenario
	1. Analysis 1	2. Analysis 3	3. Analysis 4	4. Analysis 2
Direct Costs (Outturn)				
Carriageway Output (£k)	**40,875,447**	-1,680,954	+23,034,726	+1,067,132
Skid (£k)	**1,026,830**	+17,051	0	+21,633
Lighting (£k)	**12,321,959**	+49,876	0	+118,777
Other (£k)	**46,207,346**	-354,541	0	+644,906
Total (Outturn) Direct Costs (£k)	**100,431,582**	**-1,968,568**	**+23,034,726**	**+1,852,448**
Direct Costs (Allocated) categorised by maintenance drivers				
Safety (£k)	**26,646,236**	-251,904	0	+598,927
Accessibility (£k)	**1,745,611**	-75,460	0	+60,246
Condition (£k)	**27,159,651**	-897,136	0	+670,764
Reliability (£k)	**7,803,907**	-303,672	0	+211,350
Customer Service (£k)	**23,309,039**	-398,227	0	+415,965
Environment (£k)	**16,018,547**	-236,896	0	+206,043
Total Direct (Allocated) Costs (£k)	**102,682,991**	**-2,163,295**	**0**	**+2,163,295**
Indirect Costs				
Road Condition Impacts				
VOC (£k)	**3,147,122,323**	+4,358,765	-77,483,572	-3,731,110
Value of Time (£k)	**2,101,110,194**	+1,776,571	-36,997,079	-1,578,608
Carbon (from fuel) (£k)	**118,312,958**	-13,528	+343,393	+17,781
Road Works Impacts				
Accidents (£k)	**911,286**	-8,972	+170,055	+8,087
Carbon (from fuel) (£k)	**12,374**	-76	+1,185	+67
Time (£k)	**1,190,139**	-7,728	+123,402	+6,851
Accident Impacts				
Total Number of Accidents	**5,822,840**	0	0	0
Total Accident Cost (£k)	**226,875,828**	0	0	0
Carbon Impacts (embodied)				
Carbon Quantity (tonnes CO2e)	**30,414,538**	-855,843	+11,719,162	+406,931
Carbon Cost (£k)	**1,644,639**	-47,809	+631,342	+22,857
Indirect Benefits				
Job Impacts				
Jobs	**1,223,853**	-14,799	+252,773	+13,446
GVA (£k)	**38,013,352**	-759,320	+8,808,705	+700,122
Total Indirect Costs[1]				
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)				
Total (£k)	5,595,535,103	**+6,105,031**	**-113,842,616**	**-5,276,932**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)				
Total (£k)	5,559,166,389	**+6,816,542**	**-122,019,980**	**-5,954,197**
Economic analysis (excl. Carbon Impacts and Job Impacts)				
Works costs change	**Base**	**-1,968,568**	**+23,034,726**	**+1,852,448**
Non-works costs change	**Base**	**+6,105,031**	**-113,842,616**	**-5,276,932**
Net Present Value[2]	**Base**	**-4,136,462**	**+90,807,890**	**+3,424,483**
Economic analysis (incl. Carbon Impacts and Job Impacts)				
Works costs change	**Base**	**-1,968,568**	**+23,034,726**	**+1,852,448**
Non-works costs change	**Base**	**+6,816,542**	**-122,019,980**	**-5,954,197**
Net Present Value[2]	**Base**	**-4,847,974**	**+98,985,253**	**+4,101,748**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 16: Test A - Summary results (40 years, discounted costs)

	Scenario (Base)	Scenario	Scenario	Scenario
	1. Analysis 1	2. Analysis 3	3. Analysis 4	4. Analysis 2
Direct Costs (Outturn)				
Carriageway Output (£k)	**48,328,695**	-1,681,649	+25,996,471	+1,067,972
Skid (£k)	**1,215,803**	+17,051	0	+21,633
Lighting (£k)	**14,589,631**	+49,876	0	+118,777
Other (£k)	**54,711,118**	-354,541	0	+644,906
Total (Outturn) Direct Costs (£k)	**118,845,247**	**-1,969,263**	**+25,996,471**	**+1,853,288**
Direct Costs (Allocated) categorised by maintenance drivers				
Safety (£k)	**31,550,078**	-251,904	0	+598,927
Accessibility (£k)	**2,066,864**	-75,460	0	+60,246
Condition (£k)	**32,157,979**	-897,136	0	+670,764
Reliability (£k)	**9,240,100**	-303,672	0	+211,350
Customer Service (£k)	**27,598,719**	-398,227	0	+415,965
Environment (£k)	**18,966,521**	-236,896	0	+206,043
Total Direct (Allocated) Costs (£k)	**121,580,261**	**-2,163,295**	**0**	**+2,163,295**
Indirect Costs				
Road Condition Impacts				
VOC (£k)	**3,851,015,304**	+4,482,391	-99,156,363	-3,808,941
Value of Time (£k)	**2,927,311,349**	+1,875,328	-54,282,940	-1,639,947
Carbon (from fuel) (£k)	**182,410,209**	-13,902	+506,667	+18,025
Road Works Impacts				
Accidents (£k)	**1,095,998**	-8,966	+199,706	+8,088
Carbon (from fuel) (£k)	**15,501**	-76	+1,385	+67
Time (£k)	**1,481,830**	-7,710	+144,344	+6,846
Accident Impacts				
Total Number of Accidents	**8,734,260**	0	0	0
Total Accident Cost (£k)	**268,628,934**	0	0	0
Carbon Impacts (embodied)				
Carbon Quantity (tonnes CO2e)	**45,541,476**	-856,732	+15,647,866	+408,219
Carbon Cost (£k)	**2,524,123**	-47,859	+859,500	+22,931
Indirect Benefits				
Job Impacts				
Jobs	**1,834,477**	-14,823	+352,168	+13,475
GVA (£k)	**44,982,654**	-759,586	+9,941,306	+700,443
Total Indirect Costs[1]				
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)				
Total (£k)	7,231,959,125	**+6,327,065**	**-152,587,202**	**-5,415,861**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)				
Total (£k)	7,189,500,595	**+7,038,792**	**-161,669,007**	**-6,093,374**
Economic analysis (excl. Carbon Impacts and Job Impacts)				
Works costs change	**Base**	**-1,969,263**	**+25,996,471**	**+1,853,288**
Non-works costs change	**Base**	**+6,327,065**	**-152,587,202**	**-5,415,861**
Net Present Value[2]	**Base**	**-4,357,802**	**+126,590,730**	**+3,562,573**
Economic analysis (incl. Carbon Impacts and Job Impacts)				
Works costs change	**Base**	**-1,969,263**	**+25,996,471**	**+1,853,288**
Non-works costs change	**Base**	**+7,038,792**	**-161,669,007**	**-6,093,374**
Net Present Value[2]	**Base**	**-5,069,529**	**+135,672,536**	**+4,240,085**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 17: Test A - Summary results (60 years, discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**35,128,560**	+20,739,600
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**86,239,115**	**+20,739,600**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,579,226,812**	-60,712,186
Value of Time (£k)	**1,611,749,458**	-26,934,825
Carbon (from fuel) (£k)	**83,567,334**	+243,191
Road Works Impacts		
Accidents (£k)	**761,424**	+145,629
Carbon (from fuel) (£k)	**9,610**	+1,010
Time (£k)	**934,402**	+105,439
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**22,846,487**	+9,733,917
Carbon Cost (£k)	**1,173,886**	+507,808
Indirect Benefits		
Job Impacts		
Jobs	**918,452**	+202,807
GVA (£k)	**32,641,698**	+7,931,027
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,470,951,899**	**-87,151,742**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,439,484,086**	**-94,574,961**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-87,151,742**
Net Present Value[2]	**Base**	**+66,412,142**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-94,574,961**
Net Present Value[2]	**Base**	**+73,835,361**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 18: Test B - Summary results: Low traffic (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**35,128,560**	+20,739,600
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**86,239,115**	**+20,739,600**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,627,630,861**	-61,924,094
Value of Time (£k)	**1,639,554,707**	-27,518,025
Carbon (from fuel) (£k)	**84,739,001**	+252,597
Road Works Impacts		
Accidents (£k)	**774,481**	+148,274
Carbon (from fuel) (£k)	**10,241**	+1,046
Time (£k)	**987,508**	+108,403
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**22,846,487**	+9,733,917
Carbon Cost (£k)	**1,173,886**	+507,808
Indirect Benefits		
Job Impacts		
Jobs	**918,452**	+202,807
GVA (£k)	**32,641,698**	+7,931,027
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,548,399,657**	**-88,931,799**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,516,931,844**	**-96,355,018**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-88,931,799**
Net Present Value[2]	**Base**	**+68,192,199**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-96,355,018**
Net Present Value[2]	**Base**	**+75,615,418**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 19: Test B - Summary results: High traffic (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**32,189,497**	+9,711,461
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**83,300,053**	**+9,711,461**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,583,870,098**	-39,094,987
Value of Time (£k)	**1,618,595,544**	-16,945,414
Carbon (from fuel) (£k)	**84,150,512**	+129,796
Road Works Impacts		
Accidents (£k)	**838,545**	+77,687
Carbon (from fuel) (£k)	**10,567**	+428
Time (£k)	**1,025,710**	+46,876
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**27,704,228**	+4,876,177
Carbon Cost (£k)	**1,424,762**	+256,932
Indirect Benefits		
Job Impacts		
Jobs	**886,117**	+90,167
GVA (£k)	**31,517,772**	+3,713,758
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,483,193,834**	**-55,785,614**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,453,100,824**	**-59,242,440**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+9,711,461**
Non-works costs change	**Base**	**-55,785,614**
Net Present Value[2]	**Base**	**+46,074,153**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+9,711,461**
Non-works costs change	**Base**	**-59,242,440**
Net Present Value[2]	**Base**	**+49,530,979**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 20: Test C - Summary results: Low costs (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**36,251,912**	+33,583,018
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**87,362,468**	**+33,583,018**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,627,625,812**	-82,850,701
Value of Time (£k)	**1,641,150,099**	-39,499,970
Carbon (from fuel) (£k)	**83,805,003**	+475,305
Road Works Impacts		
Accidents (£k)	**670,081**	+246,152
Carbon (from fuel) (£k)	**8,961**	+2,034
Time (£k)	**867,299**	+205,286
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**18,970,078**	+13,610,327
Carbon Cost (£k)	**974,344**	+707,349
Indirect Benefits		
Job Impacts		
Jobs	**931,188**	+335,043
GVA (£k)	**33,071,279**	+12,842,476
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,548,830,113**	**-121,421,893**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,516,733,178**	**-133,557,020**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+33,583,018**
Non-works costs change	**Base**	**-121,421,893**
Net Present Value[2]	**Base**	**+87,838,875**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+33,583,018**
Non-works costs change	**Base**	**-133,557,020**
Net Present Value[2]	**Base**	**+99,974,001**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 21: Test C - Summary results: High costs (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**34,810,645**	+29,273,688
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**85,921,201**	**+29,273,688**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,606,481,134**	-39,894,971
Value of Time (£k)	**1,629,464,959**	-23,700,321
Carbon (from fuel) (£k)	**83,999,066**	+269,523
Road Works Impacts		
Accidents (£k)	**755,268**	+134,937
Carbon (from fuel) (£k)	**9,825**	+1,083
Time (£k)	**951,763**	+106,988
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**22,589,920**	+21,072,734
Carbon Cost (£k)	**1,160,380**	+1,093,670
Indirect Benefits		
Job Impacts		
Jobs	**915,438**	+293,751
GVA (£k)	**32,520,124**	+11,194,546
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	4,516,364,873	**-63,082,761**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	4,485,005,129	**-73,183,636**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+29,273,688**
Non-works costs change	**Base**	**-63,082,761**
Net Present Value[2]	**Base**	**+33,809,073**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+29,273,688**
Non-works costs change	**Base**	**-73,183,636**
Net Present Value[2]	**Base**	**+43,909,948**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 22: Test D - Summary results: Reverse strategy (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**26,160,300**	+25,220,687
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**77,270,855**	**+25,220,687**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,652,091,268**	-100,569,912
Value of Time (£k)	**1,651,853,438**	-49,165,743
Carbon (from fuel) (£k)	**83,630,858**	+670,815
Road Works Impacts		
Accidents (£k)	**558,014**	+346,588
Carbon (from fuel) (£k)	**7,685**	+3,289
Time (£k)	**742,203**	+325,033
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**18,424,832**	+9,518,789
Carbon Cost (£k)	**946,488**	+500,942
Indirect Benefits		
Job Impacts		
Jobs	**823,518**	+249,457
GVA (£k)	**29,212,148**	+9,644,638
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,583,586,323**	**-148,389,932**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,555,320,664**	**-157,533,628**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+25,220,687**
Non-works costs change	**Base**	**-148,389,932**
Net Present Value[2]	**Base**	**+123,169,244**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+25,220,687**
Non-works costs change	**Base**	**-157,533,628**
Net Present Value[2]	**Base**	**+132,312,941**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 23: Test D - Summary results: County Council strategy (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**23,121,897**	+39,151,255
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**74,232,453**	**+39,151,255**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,675,477,330**	-90,185,620
Value of Time (£k)	**1,663,728,393**	-49,230,642
Carbon (from fuel) (£k)	**83,419,538**	+687,397
Road Works Impacts		
Accidents (£k)	**422,489**	+400,801
Carbon (from fuel) (£k)	**5,859**	+4,198
Time (£k)	**564,537**	+411,123
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**17,431,282**	+29,398,878
Carbon Cost (£k)	**894,128**	+1,513,820
Indirect Benefits		
Job Impacts		
Jobs	**790,726**	+418,010
GVA (£k)	**28,050,233**	+14,971,824
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,618,321,003**	**-137,912,742**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,591,164,899**	**-151,370,746**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+39,151,255**
Non-works costs change	**Base**	**-137,912,742**
Net Present Value[2]	**Base**	**+98,761,487**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+39,151,255**
Non-works costs change	**Base**	**-151,370,746**
Net Present Value[2]	**Base**	**+112,219,491**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 24: Test D - Summary results: County Council opposite change strategy (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**35,128,560**	+20,739,600
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**86,239,115**	**+20,739,600**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,833,968,620**	-67,547,123
Value of Time (£k)	**1,791,842,409**	-30,027,267
Carbon (from fuel) (£k)	**92,326,032**	+275,504
Road Works Impacts		
Accidents (£k)	**769,005**	+147,228
Carbon (from fuel) (£k)	**9,967**	+1,028
Time (£k)	**965,600**	+106,986
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**22,846,487**	+9,733,917
Carbon Cost (£k)	**1,173,886**	+507,808
Indirect Benefits		
Job Impacts		
Jobs	**918,452**	+202,807
GVA (£k)	**32,641,698**	+7,931,027
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,914,584,491**	**-97,043,644**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,883,116,679**	**-104,466,863**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-97,043,644**
Net Present Value[2]	**Base**	**+76,304,044**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-104,466,863**
Net Present Value[2]	**Base**	**+83,727,263**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 25: Test E - Summary results: Increased condition impacts (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**35,128,560**	+20,739,600
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**86,239,115**	**+20,739,600**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,378,394,552**	-55,265,828
Value of Time (£k)	**1,466,052,880**	-24,567,764
Carbon (from fuel) (£k)	**75,733,667**	+225,413
Road Works Impacts		
Accidents (£k)	**769,005**	+147,228
Carbon (from fuel) (£k)	**9,967**	+1,028
Time (£k)	**965,600**	+106,986
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**22,846,487**	+9,733,917
Carbon Cost (£k)	**1,173,886**	+507,808
Indirect Benefits		
Job Impacts		
Jobs	**918,452**	+202,807
GVA (£k)	**32,641,698**	+7,931,027
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,116,628,530**	**-79,352,937**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,085,160,717**	**-86,776,156**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-79,352,937**
Net Present Value[2]	**Base**	**+58,613,337**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-86,776,156**
Net Present Value[2]	**Base**	**+66,036,556**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 26: Test E - Summary results: Decreased condition impacts (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**35,128,560**	+20,739,600
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**86,239,115**	**+20,739,600**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,606,181,586**	-61,406,475
Value of Time (£k)	**1,628,947,645**	-27,297,515
Carbon (from fuel) (£k)	**84,029,850**	+250,458
Road Works Impacts		
Accidents (£k)	**615,204**	+117,782
Carbon (from fuel) (£k)	**7,974**	+823
Time (£k)	**772,480**	+85,588
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**22,846,487**	+9,733,917
Carbon Cost (£k)	**1,173,886**	+507,808
Indirect Benefits		
Job Impacts		
Jobs	**918,452**	+202,807
GVA (£k)	**32,641,698**	+7,931,027
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,515,257,596**	**-88,249,339**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,483,789,784**	**-95,672,558**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-88,249,339**
Net Present Value[2]	**Base**	**+67,509,739**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-95,672,558**
Net Present Value[2]	**Base**	**+74,932,958**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 27: Test F - Summary results: Increased rate of working (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**35,128,560**	+20,739,600
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**86,239,115**	**+20,739,600**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,606,181,586**	-61,406,475
Value of Time (£k)	**1,628,947,645**	-27,297,515
Carbon (from fuel) (£k)	**84,029,850**	+250,458
Road Works Impacts		
Accidents (£k)	**1,025,340**	+196,303
Carbon (from fuel) (£k)	**13,289**	+1,371
Time (£k)	**1,287,467**	+142,647
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**22,846,487**	+9,733,917
Carbon Cost (£k)	**1,173,886**	+507,808
Indirect Benefits		
Job Impacts		
Jobs	**918,452**	+202,807
GVA (£k)	**32,641,698**	+7,931,027
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,516,188,035**	**-88,113,210**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,484,720,222**	**-95,536,429**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-88,113,210**
Net Present Value[2]	**Base**	**+67,373,610**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+20,739,600**
Non-works costs change	**Base**	**-95,536,429**
Net Present Value[2]	**Base**	**+74,796,829**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 28: Test F - Summary results: Decreased rate of working (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 1a
Direct Costs (Outturn)		
Carriageway Output (£k)	**35,128,560**	-1,586,079
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**86,239,115**	**-1,586,079**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,606,181,586**	-6,017,822
Value of Time (£k)	**1,628,947,645**	-5,154,947
Carbon (from fuel) (£k)	**84,029,850**	+142,642
Road Works Impacts		
Accidents (£k)	**769,005**	-29,451
Carbon (from fuel) (£k)	**9,967**	-823
Time (£k)	**965,600**	-76,499
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**22,846,487**	-3,505,566
Carbon Cost (£k)	**1,173,886**	-180,208
Indirect Benefits		
Job Impacts		
Jobs	**918,452**	-19,501
GVA (£k)	**32,641,698**	-606,532
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	4,515,606,511	**-11,136,900**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	4,484,138,698	**-10,710,576**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**-1,586,079**
Non-works costs change	**Base**	**-11,136,900**
Net Present Value[2]	**Base**	**+12,722,978**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**-1,586,079**
Non-works costs change	**Base**	**-10,710,576**
Net Present Value[2]	**Base**	**+12,296,654**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 29: Test G - Summary results: Current and revised budget allocations Analysis 1 (discounted costs)

	Scenario (Base)	Scenario
	1. Analysis 1	2. Analysis 4
Direct Costs (Outturn)		
Carriageway Output (£k)	**33,542,481**	+22,325,679
Skid (£k)	**881,216**	0
Lighting (£k)	**10,574,598**	0
Other (£k)	**39,654,742**	0
Total (Outturn) Direct Costs (£k)	**84,653,037**	**+22,325,679**
Direct Costs (Allocated) categorised by maintenance drivers		
Safety (£k)	**22,867,568**	0
Accessibility (£k)	**1,498,068**	0
Condition (£k)	**23,308,176**	0
Reliability (£k)	**6,697,245**	0
Customer Service (£k)	**20,003,614**	0
Environment (£k)	**13,746,977**	0
Total Direct (Allocated) Costs (£k)	**88,121,648**	**0**
Indirect Costs		
Road Condition Impacts		
VOC (£k)	**2,600,163,764**	-55,388,653
Value of Time (£k)	**1,623,792,698**	-22,142,568
Carbon (from fuel) (£k)	**84,172,492**	+107,816
Road Works Impacts		
Accidents (£k)	**739,554**	+176,679
Carbon (from fuel) (£k)	**9,144**	+1,851
Time (£k)	**889,101**	+183,485
Accident Impacts		
Total Number of Accidents	**4,367,130**	0
Total Accident Cost (£k)	**194,702,858**	0
Carbon Impacts (embodied)		
Carbon Quantity (tonnes CO2e)	**19,340,922**	+13,239,483
Carbon Cost (£k)	**993,678**	+688,016
Indirect Benefits		
Job Impacts		
Jobs	**898,951**	+222,308
GVA (£k)	**32,035,166**	+8,537,559
Total Indirect Costs[1]		
Excluding Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,504,469,611**	**-77,061,391**
Including Carbon Impacts (Carbon Cost) and Job Impacts (GVA)		
Total (£k)	**4,473,428,122**	**-84,910,934**
Economic analysis (excl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+22,325,679**
Non-works costs change	**Base**	**-77,061,391**
Net Present Value[2]	**Base**	**+54,735,712**
Economic analysis (incl. Carbon Impacts and Job Impacts)		
Works costs change	**Base**	**+22,325,679**
Non-works costs change	**Base**	**-84,910,934**
Net Present Value[2]	**Base**	**+62,585,255**

Notes:
1. Benefits are shown as negative costs
2. Negative NPV show an overall increase in cost (i.e. non-works costs increase more than the change in maintenance expenditure)

Figure 30: Test G - Summary results: Revised budget allocations Analyses 1 and 4 (discounted costs)

Appendix E. Further results from the Base Analyses of the national network

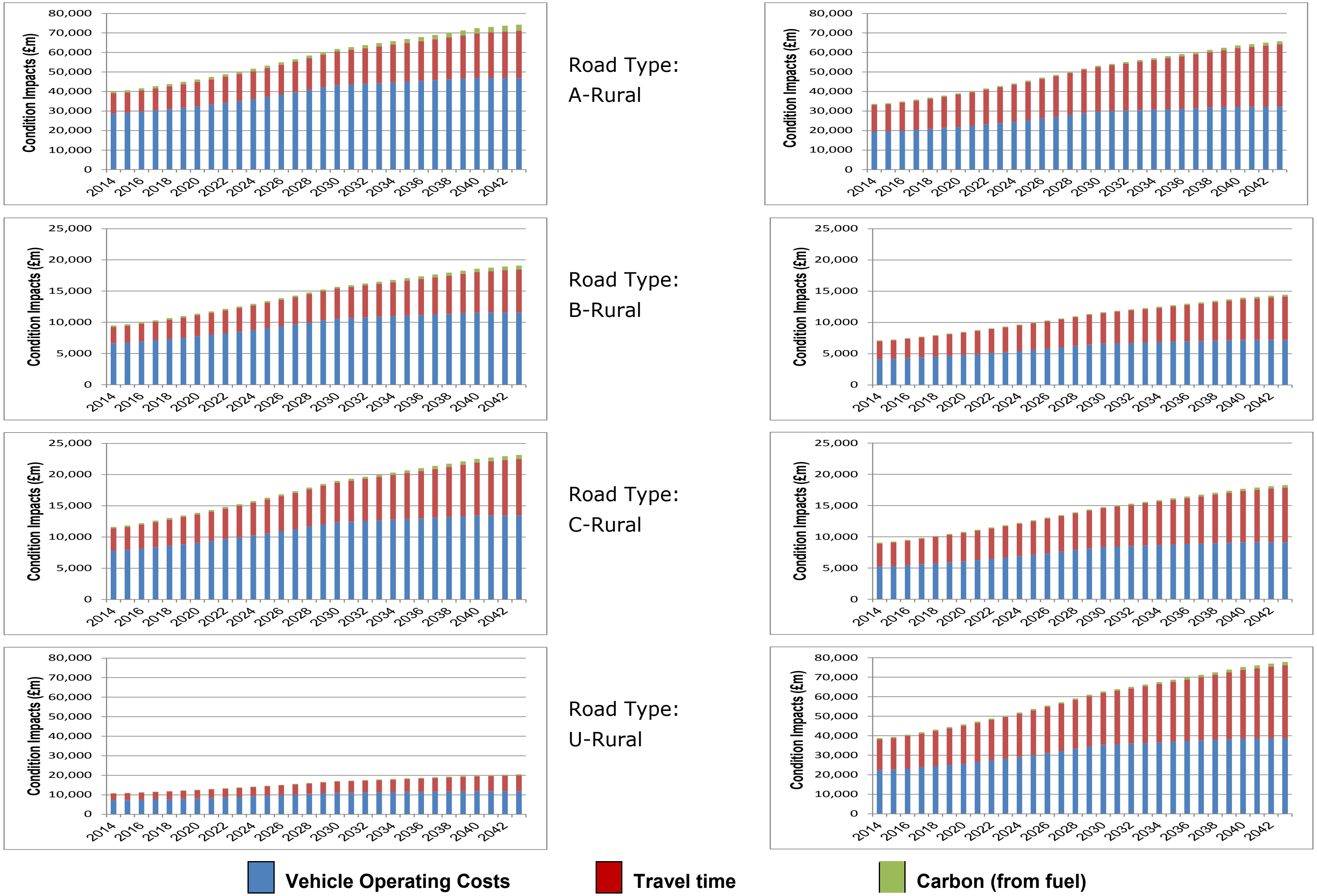
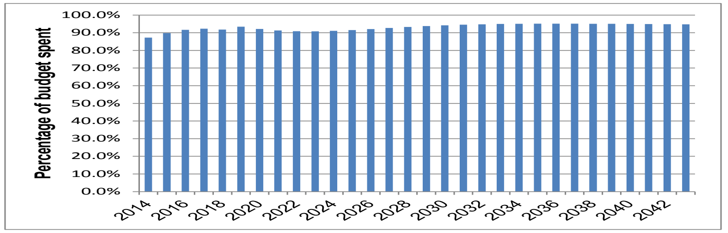
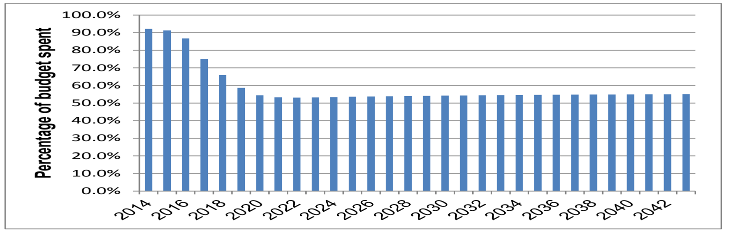


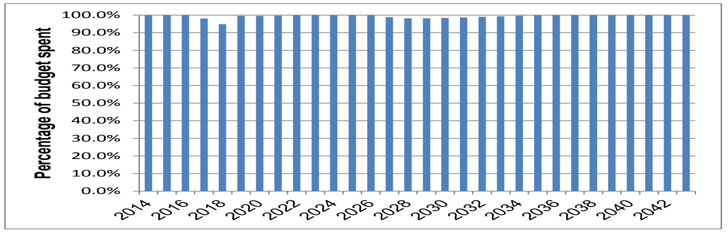
Figure 31: Condition impacts for each road type: Analysis 1 (undiscounted costs)



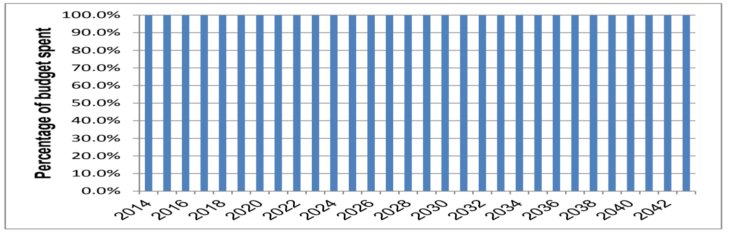
Road Type:
A-Rural



Road Type:
A-Urban



Road Type:
U-Rural



Road Type:
U- Urban

Figure 32: Share of available (undiscounted) budget that is spent: Analysis 2

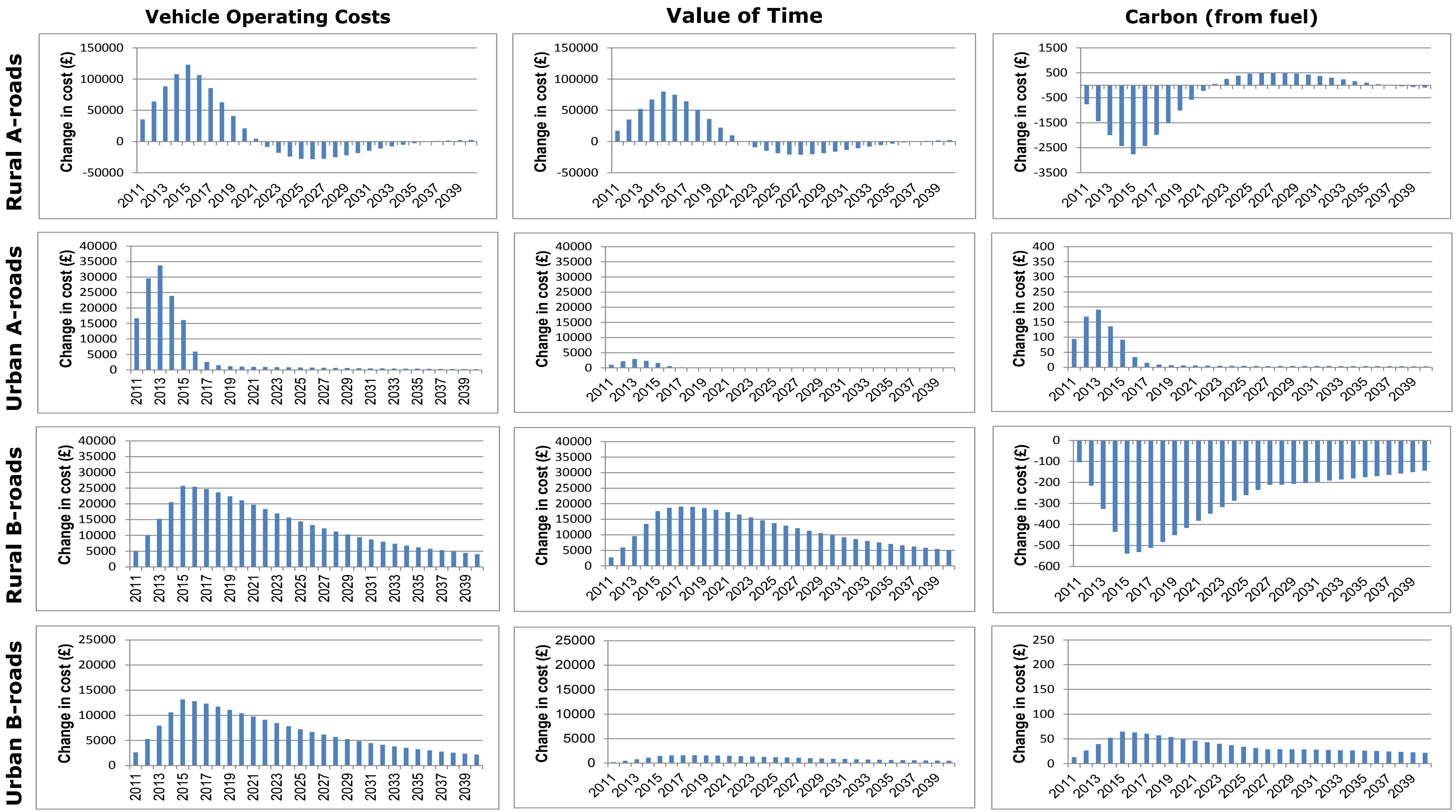


Figure 33: Change in undiscounted condition impacts (Analysis 1-Analysis 2) (A-roads and B-roads)

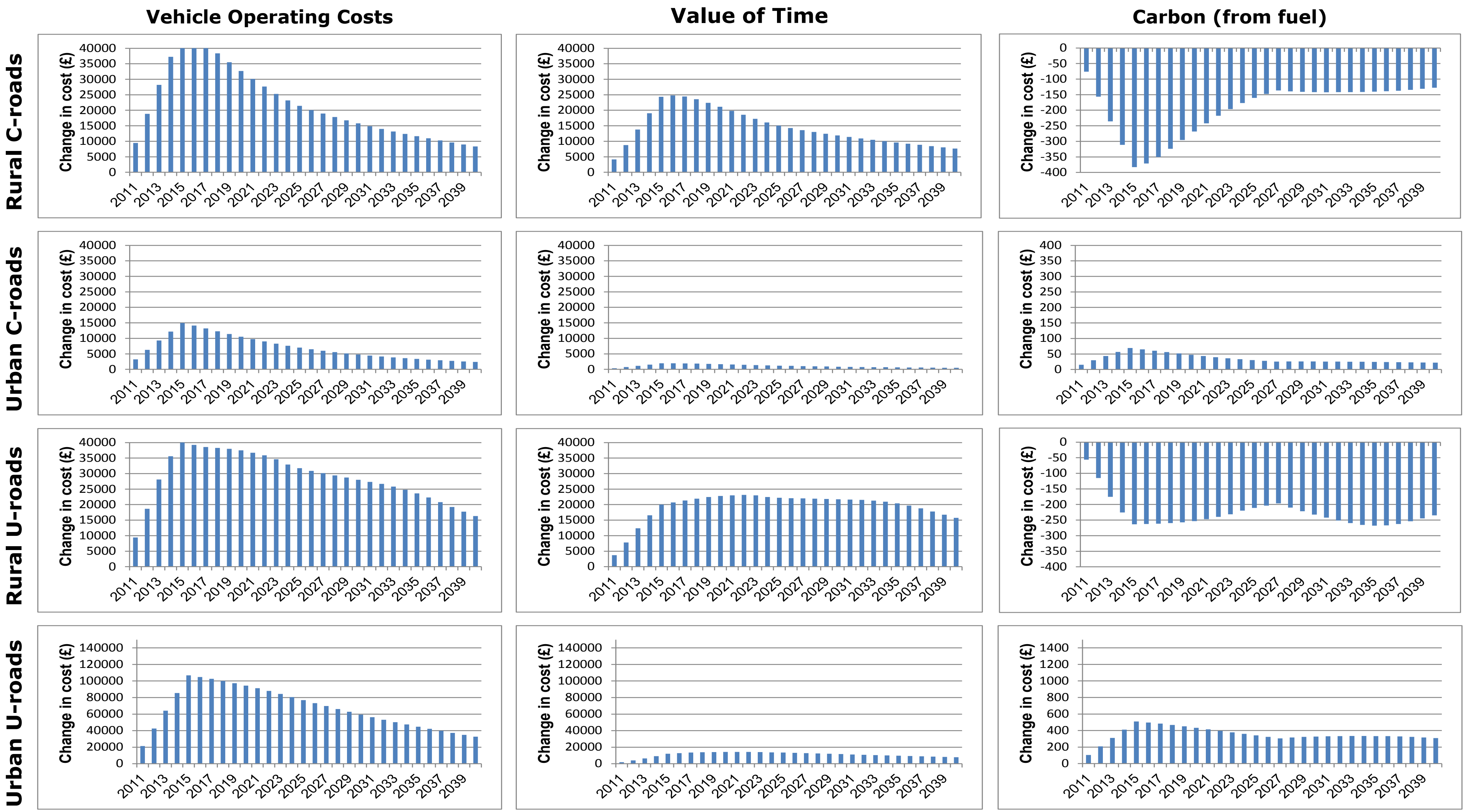
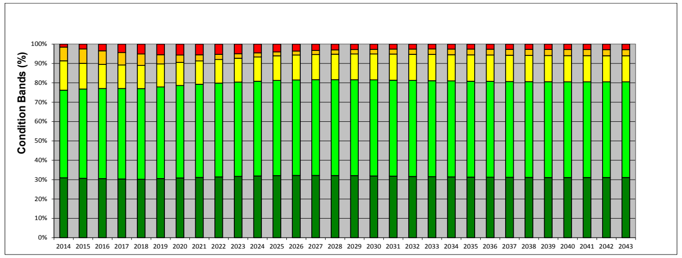
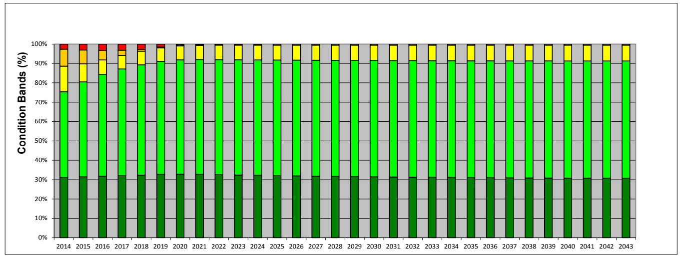


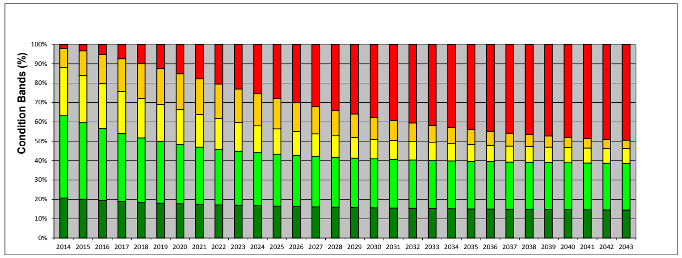
Figure 34: Change in undiscounted condition impacts (Analysis 1-Analysis 2) (C-roads and U-roads)



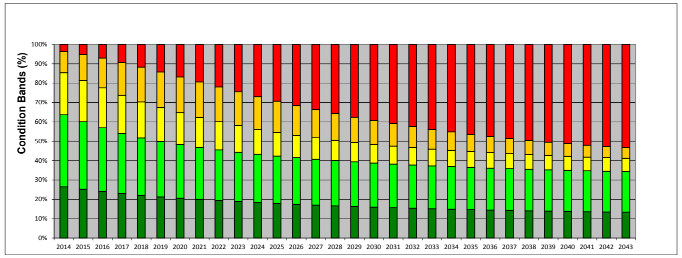
Road Type:
A-Rural



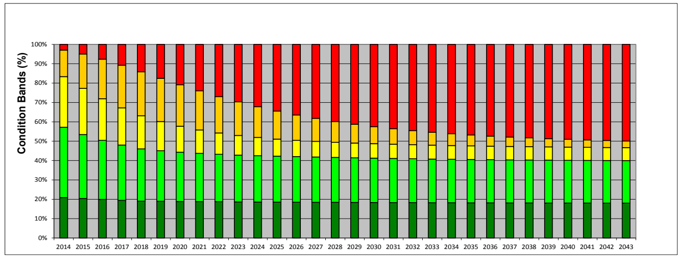
Road Type:
A-Urban



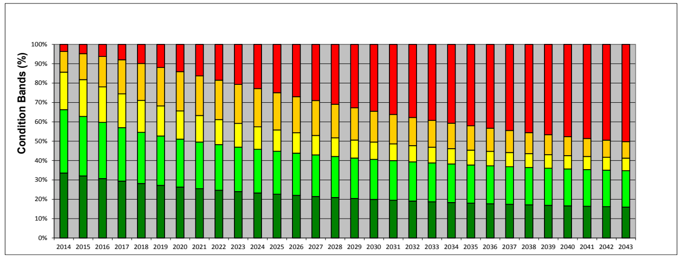
Road Type:
B-Rural



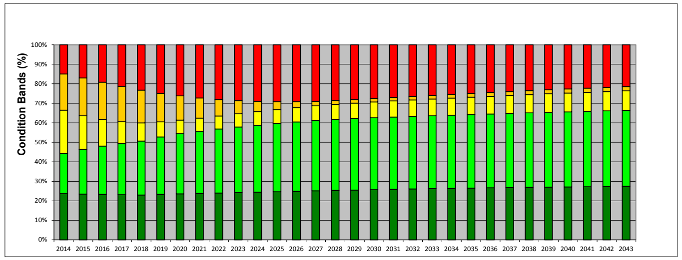
Road Type:
B- Urban



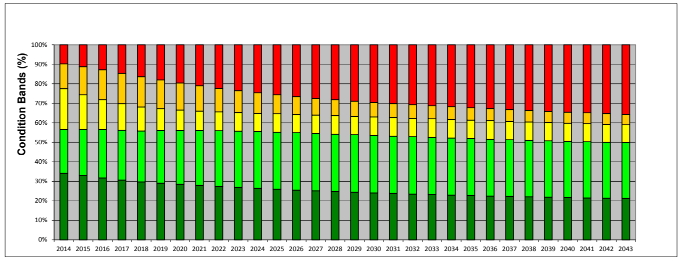
Road Type:
C-Rural



Road Type:
C- Urban



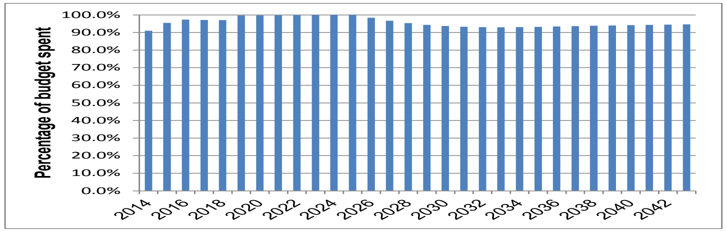
Road Type:
U-Rural



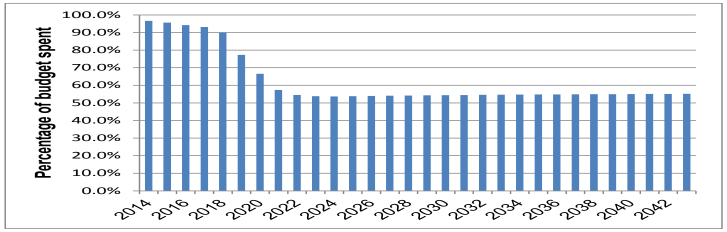
Road Type:
U- Urban

Very Poor   Poor   Fair   Good   Very Good

Figure 35: Carriageway condition for each road type: Analysis 3



Road Type:
A-Rural



Road Type:
A- Urban

Figure 36: Share of available (undiscounted) budget that is spent: Analysis 3

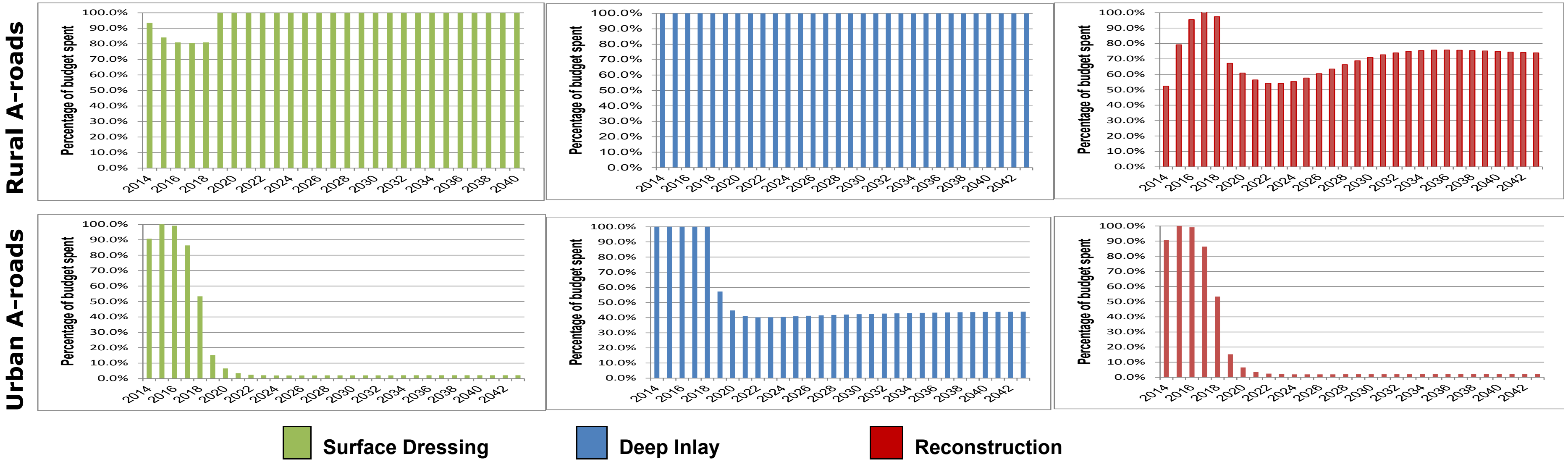


Figure 37: Percentage of budget spent: Analysis 3

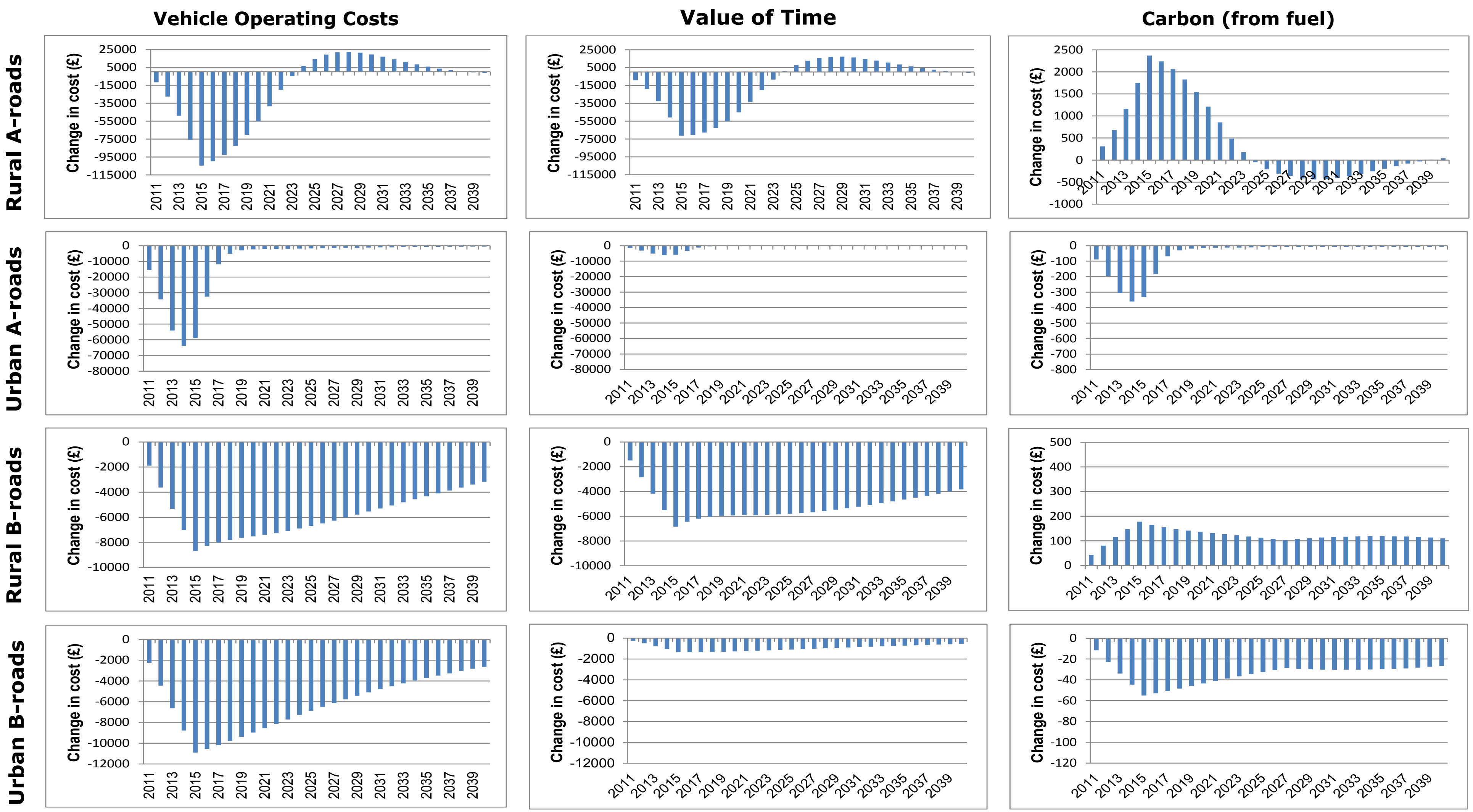


Figure 38: Change in undiscounted condition impacts (Analysis 1-Analysis 3) (A-roads and B-roads)

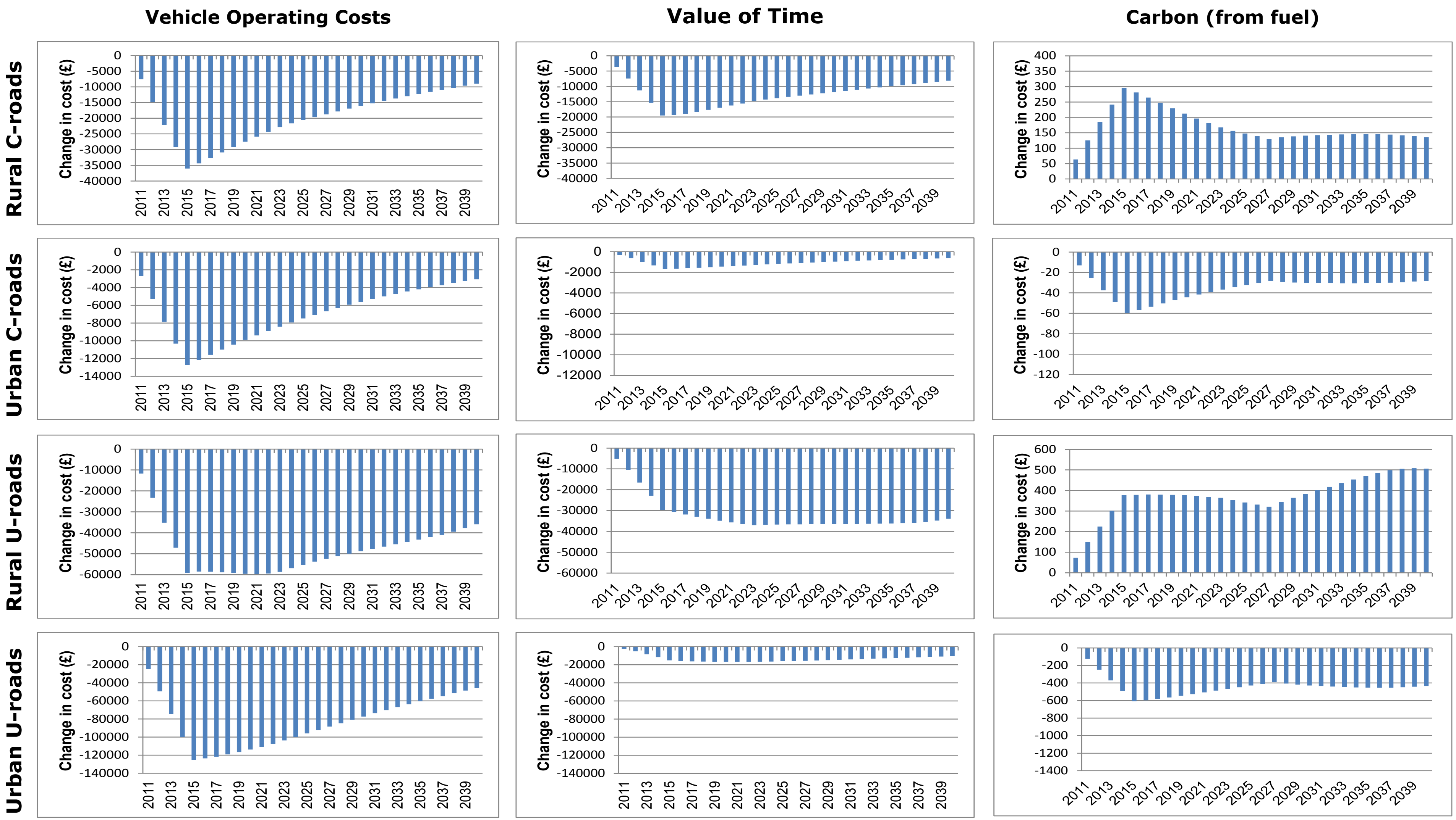
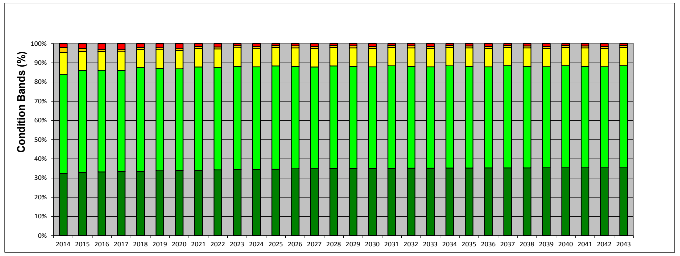
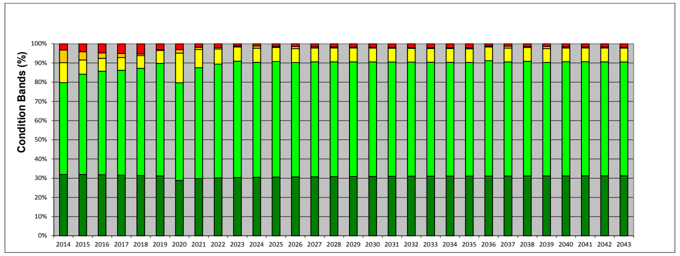


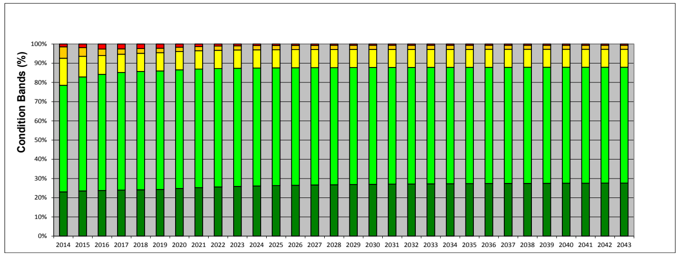
Figure 39: Change in undiscounted condition impacts (Analysis 1*-Analysis 3) (C-roads and U-roads)



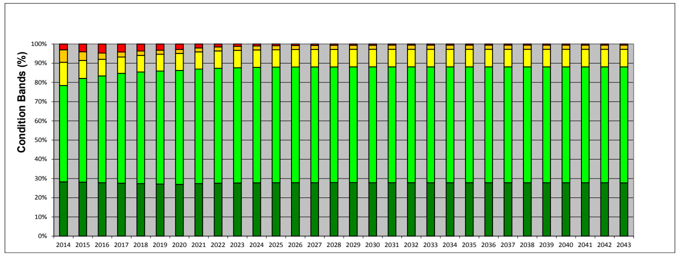
Road Type:
A-Rural



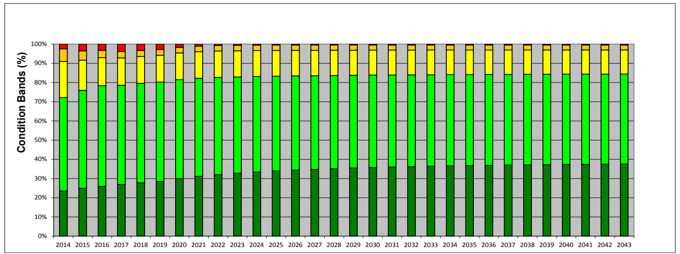
Road Type:
A-Urban



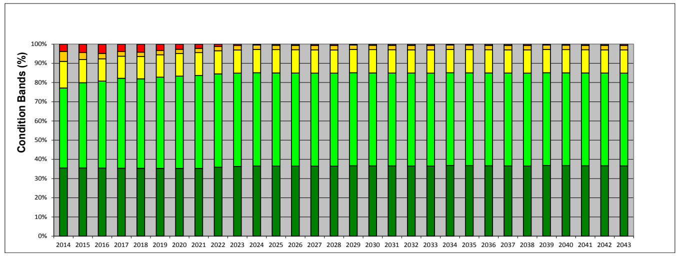
Road Type:
B-Rural



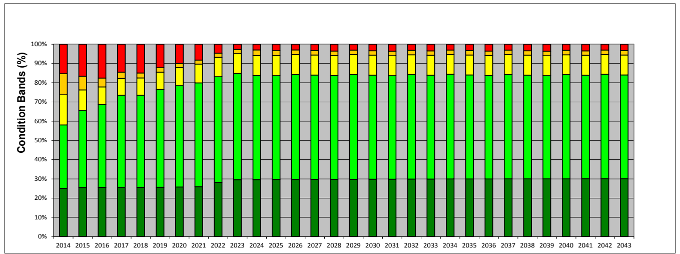
Road Type:
B- Urban



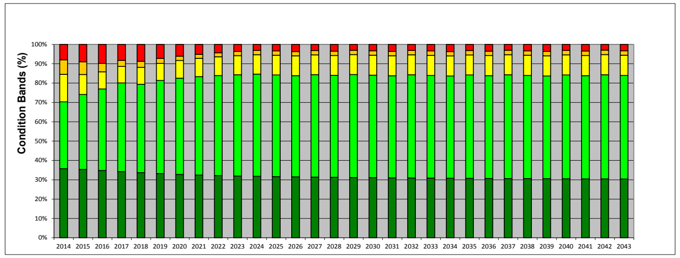
Road Type:
C-Rural



Road Type:
C- Urban



Road Type:
U-Rural



Road Type:
U- Urban

Very Poor Poor Fair Good Very Good

Figure 40: Carriageway condition for each road type: Analysis 4

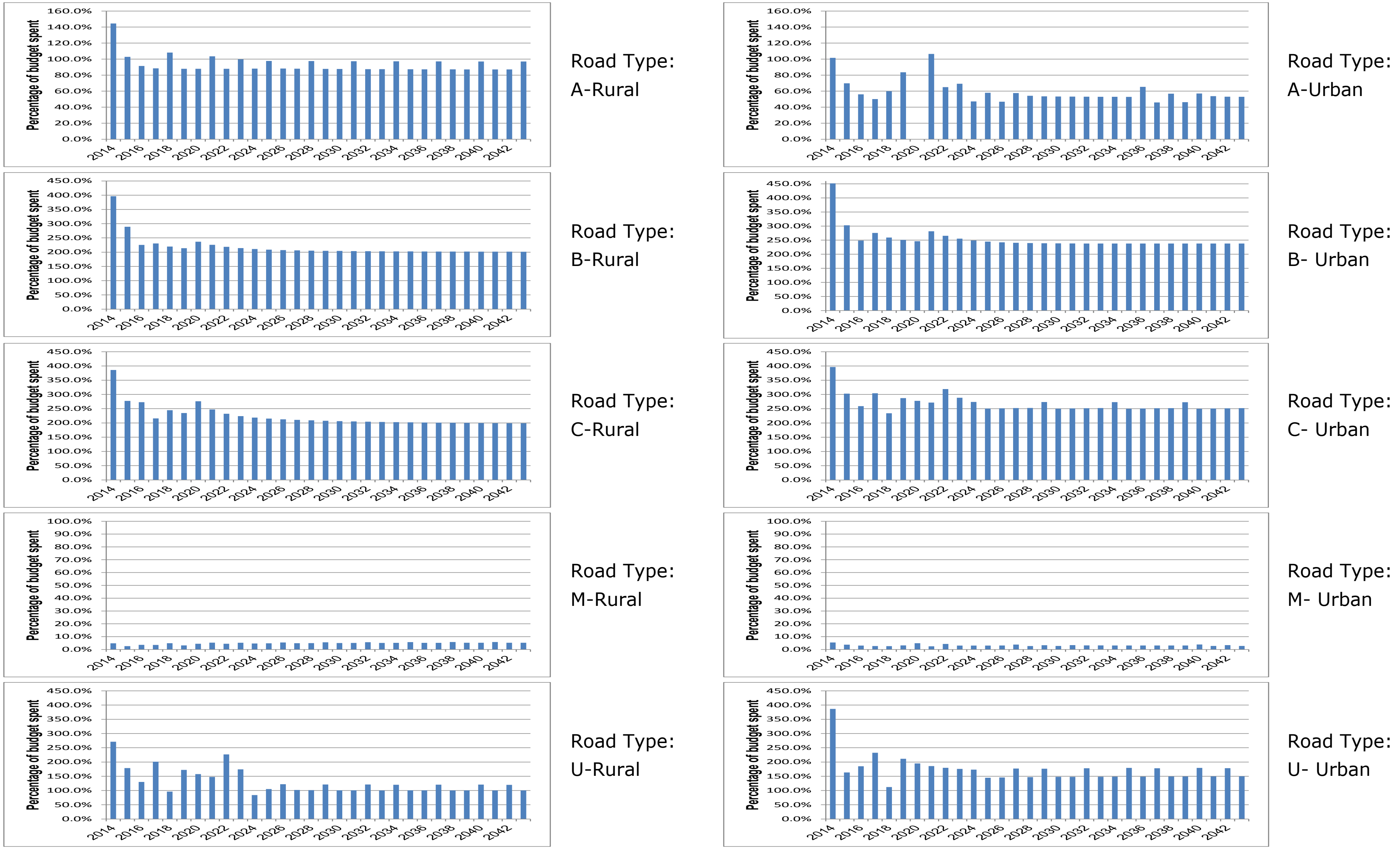


Figure 41: Percentage of the current (undiscounted) budget that is spent: Analysis 4

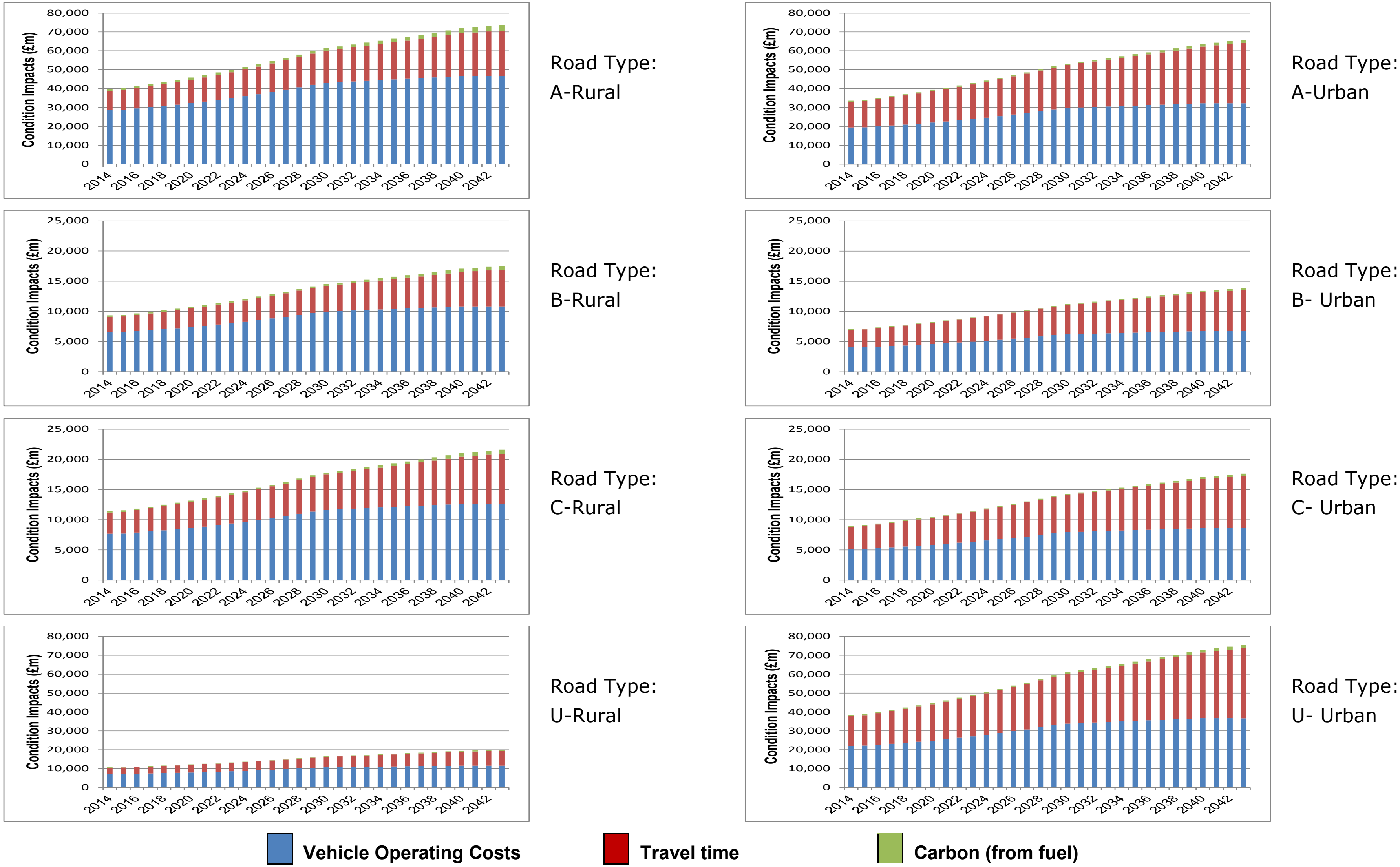


Figure 42: Condition impacts for each road type: Analysis 4 (undiscounted costs)

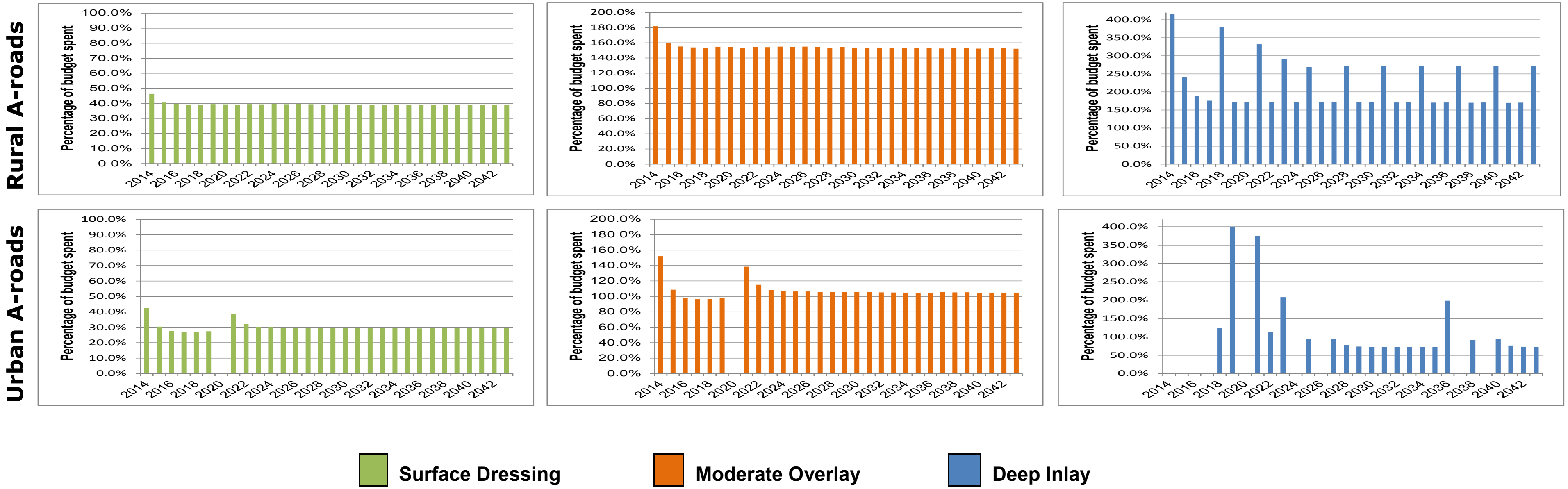


Figure 43: Percentage of budget spent: Analysis 4

Figure 44: Change in undiscounted condition impacts (Analysis 1-Analysis 4) (A-roads and B-roads)

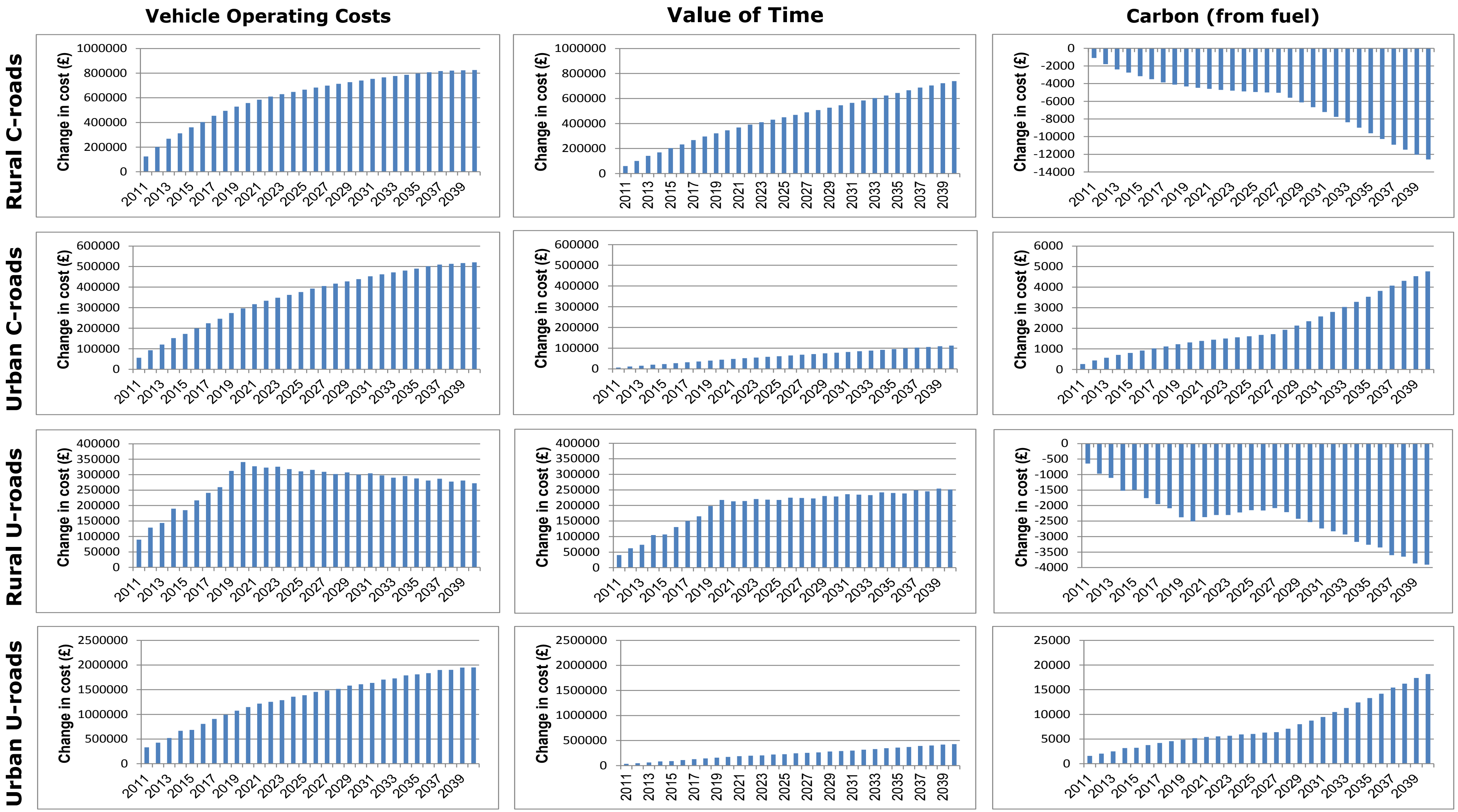


Figure 45: Change in undiscounted condition impacts (Analysis 1-Analysis 4) (C-roads and U-roads)