DEVELOPMENT OF SOCIO-ECONOMIC MODELS FOR HIGHWAY MAINTENANCE

Analysis of DfT Road Network Using HDM-4

Final Report

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LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
CDB	Construction Defect indicator for the Roadbase
CDS	Construction Defect indicator for Surfacing
COBA	Costs Benefits Analysis (Manual)
COMP	Relative Compaction of the whole pavement
DfT	Department for Transport
DMRB	Design Manual for Roads and Bridges
DTT	Data Transfer Tool
HA	Highways Agency
HDM-4	Highway Development and Management Tool
HGV	Heavy Goods Vehicle
IRI	International Roughness Index
LGV	Light Goods Vehicle
MRSF	Machine Readable Survey Form
MT	Motorised Transport
NI	National Indicator
NMT	Non-Motorised Transport
NPV	Net Present Value
NRMCS	National Road Maintenance Condition Survey
OGV1	Other Goods Vehicle – Type 1
OGV2	Other Goods Vehicle – Type 2
PACA	Previous Areas of All Cracks
PACW	Previous Areas of Wide Cracks
PCSE	Passenger Car Space Equivalent
PCI	Pavement Condition Index

PSV	Passenger (Public) Service Vehicle
RAC	Road Agency Cost
RD	Road Deterioration
RUC	Road User Cost
RUE	Road User Effects
SA	Sensitivity Analysis
SCANNER	Surface Condition Assessment for the National Network of Roads
TRACS	Traffic-speed Condition Survey
TRL	Transport Research Laboratory (UK)
TTC	Travel Time Cost
TTS	TRACS Type Surveys
UK	United Kingdom
UKPMS	UK Pavement Management System
VOC	Vehicle Operating Cost

EXECUTIVE SUMMARY

Context

The UK Department for Transport (DfT) is concerned to know that long-term investments in maintenance of local roads are contributing optimally to the UK economy, and that road maintenance funds are distributed equitably, and provide value for money for the taxpayer. A key component of effective policy making is the ability to underpin strategic policy decisions with an effective evidence base. To that end, the DfT intends to use the Highway Development and Management tool (HDM-4) to assess the economic benefits of a marginal change in maintenance expenditure and the implications of maintenance expenditure in terms of traffic delays.

Broadly, the main issue considered using HDM-4 is one of effectiveness and efficiency in road asset management. Two questions are (a) what allocation of a certain sum of money (both capital and revenue) maximises the delivery of the Department's objectives; and (b) what is the effect of a marginal increase in maintenance funding? To address the first question, the DfT commissioned the University of Birmingham to develop HDM-4 for use in England at a strategic level to analyse the maintenance needs of the local roads. The work, completed in 2006, concentrated on review of existing systems used by DfT, existing data, development of a Data Transfer Tool (DTT), linking of HDM-4 to the National Road Maintenance Condition Survey (NRMCS) database, and basic level adaptation and calibration of HDM-4 to conditions in England.

The present project is a DfT commission through WSP that has aimed to address the second question. It extends the earlier work done by the University of Birmingham, in particular through the use of better data sources and a wider consideration of socio-economic effects, to investigate the effect of a marginal increase in maintenance funding. The main objective is to improve the understanding within the DfT of the costs and benefits of investing in the maintenance of local authority (LA) highway networks in England. This is the final project report on the expenditure/benefit trade-offs obtained from HDM-4 analysis of different scenarios of marginal changes to the current level of maintenance expenditure on Principal "A" Roads (as requested by the DfT) in England.

Structure

The report is structured into four major parts: Part 1 Background and Data Requirements, Part 2 Marginal Changes in Maintenance Funding, Part 3 Budget Cut Scenarios and Part 4 Work Zone Delays and Scanner Data.

Part 1: Background and Data Requirements

This part provides a chronology of the tasks that define the scope of the present commission, the overall study methodology including the use of HDM-4 for strategic analysis of the DfT principal road network, description of types and sources of data used, and the preparation of a homogeneous network of principal roads necessary for analysis of budget scenarios described in Parts 2 and 3.

Part 2: Marginal Changes in Maintenance Funding

Part 2 discusses the results of analysis of the following six scenarios of marginal changes in maintenance funding:

- Scenario 2-1 – Unconstrained budget: assumes that there are no constraints in the budget necessary for maintenance of principal road network in England.
- Scenario 2-2: assumes a 20% increase in the base expenditure on maintenance of principal roads in England
- Scenario 2-3: assumes a 10% increase in the base expenditure on maintenance of principal roads in England
- Scenario 2-4 – Base Case: represents the current expenditure out turned by Local Authorities on principal roads, that is, an annual average capital expenditure of about £360 million.
- Scenario 2-5: assumes a 10% decrease in the base expenditure on maintenance of principal roads in England
- Scenario 2-6: assumes a 20% decrease in the base expenditure on maintenance of principal roads in England

Part 3: Budget Cuts

Part 3 considers additional scenarios of budget cuts; these were introduced as part of the expanded scope of this study. The scenarios are analysed for an optimistic and pessimistic initial road network condition distribution and are designed to investigate the effect of reducing the current level of annual capital maintenance expenditure on principal roads by 20% and 40% over the first three and six years of analysis and thereafter maintain a 'business-as-usual' annual expenditure of £360 million. For the optimistic initial road network condition, the analysis also considered the additional expenditure necessary to return the average road condition to the business as usual level in the long-term during the years after budget cuts are stopped.

Analysis Scenarios for Optimistic Condition Distribution

- Scenario 3-O-1: This is the Business-as-Usual scenario, it represents the current expenditure out turned by Local Authorities on principal roads, that is, an annual average capital expenditure of about £360 million.

- Scenario 3-O-2: represents a 20% reduction in the first 3 analysis years in the Business-as-Usual capital expenditure levels, followed by the Business-as-Usual expenditure levels in the years after budget cuts are cancelled.

- Scenario 3-O-3: represents a 20% reduction in the first 6 analysis years in the Business-as-Usual capital expenditure levels, followed by the Business-as-Usual expenditure levels in the years after budget cuts are cancelled.

- Scenario 3-O-4: represents a 40% reduction in the first 3 analysis years in the Business-as-Usual capital expenditure levels, followed by the Business-as-Usual expenditure levels in the years after budget cuts are cancelled.

- Scenario 3-O-5: represents a 40% reduction in the first 6 analysis years in the Business-as-Usual capital expenditure levels, followed by the Business-as-Usual expenditure levels in the years after budget cuts are cancelled.

- Scenario 3-O-6: this scenario assumes 20% reduction in the first 3 analysis years in the Business as Usual capital expenditure levels on principal roads in England. Heavy Investments are applied after the first 3 years to return the average road network conditions in the long-term to that modelled under Scenario 3-O-1 (Business-as-Usual)

- Scenario 3-O-7: this scenario assumes 20% reduction in the first 6 analysis years in the Business-as-Usual capital expenditure levels on principal roads in England. Heavy Investments are applied after the first 6 years to return the average road network conditions in the long-term to that modelled under Scenario 3-O-1 (Business-as-Usual)

- Scenario 3-O-8: this scenario assumes 40% reduction in the first 3 analysis years in the Business as Usual capital expenditure levels on principal roads in England. Heavy Investments are applied after the first 3 years to return the average road network conditions in the long-term to that modelled under Scenario 3-O-1 (Business-as-Usual)

- Scenario 3-O-9: this scenario assumes 40% reduction in the first 6 analysis years in the Business as Usual capital expenditure levels on principal roads in England. Heavy Investments are applied after the first 6 years to return the average road network conditions in the long-term to that modelled under Scenario 3-O-1 (Business-as-Usual)

Analysis Scenarios for Pessimistic Condition Distribution

- Scenario 3-P-1: represents the Business as Usual scenario. The current capital expenditure level on principal roads in England of £360million per year was assumed.

- Scenario 3-P-2: represents a 20% reduction in the first 3 analysis years in the Business as Usual capital expenditure levels, followed by the Business as Usual expenditure levels in the years after budget cuts are cancelled.

- Scenario 3-P-3: represents a 20% reduction in the first 6 analysis years in the Business as Usual capital expenditure levels, followed by the Business as Usual expenditure levels in the years after budget cuts are cancelled.

- Scenario 3-P-4: represents a 40% reduction in the first 3 analysis years in the Business as Usual capital expenditure levels, followed by the Business as Usual expenditure levels in the years after budget cuts are cancelled.

- Scenario 3-P-5: represents a 40% reduction in the first 3 analysis years in the Business as Usual capital expenditure levels, followed by the Business as Usual expenditure levels in the years after budget cuts are cancelled.

Part 4: Work Zone Delays and SCANNER Data

This part covers exploratory tasks related to the long-term phase of the study including: delays at work zones and use of Surface Condition Assessment for the National Network of Roads (SCANNER) data. The analysis discussed in Parts 2 and 3 did not consider the costs of delays that would be caused by carrying out maintenance works. In Part 4 of the report, the concepts for modelling delays at work zone were introduced, a delay costs matrix was formulated, and the effect of including costs of delays at work zones on the results of Part 2 scenarios was investigated. In addition, the possibility of adapting SCANNER data for use in future analysis using HDM-4 was explored.

Methodology

Parts 1, 2 and 3

The methods used were based on a desk study of data obtained from work on the previous DfT commission and available new data from published sources. The initial procedures of the study involved establishing a baseline case of the present situation of the Principal A roads in England. This included a representation of the road network infrastructure into a matrix of homogeneous sections, a representation of the vehicles that use the road network, and definition of traffic characteristics in terms of volumes, loading and growth rates.

The next step was to update the HDM-4 system developed in 2006. The main data sets required as inputs for HDM-4 analyses were categorised under the headings: road network, vehicle fleet, traffic, and road works. Logical assumptions were made to fill in the gaps in cases where data were either lacking or missing. In summary, 348 representative road sections of total length 27,975 km and 5 representative vehicle types were included in the study. The annual traffic growth rate varied by vehicle type, ranging from 0.69 to 2.44 percent, in accordance with the National road traffic forecast.

The road network inventory and condition data that was available to the study team was the NRMCS data collected in 2006. To account for the uncertainty in the current (2010) road network condition, two road network matrices were produced. The first is an optimistic assumption that the distribution of the current condition of principal roads gives an average roughness of about 2 IRI (International Roughness Index). The second is a pessimistic one which assumes that the network is in a more deteriorated state and the condition distribution results in an average initial roughness of about 3 IRI.

The following road works (or treatment) types and their unit costs were combined logically to form work standards and alternatives analysed in HDM-4:

- Routine (or Minimum) maintenance – includes patching, edge repair, crack sealing, drainage and miscellaneous works; as recurrent (or revenue) works.
- Surface improvement – includes single bituminous surface dressing; as capital works
- Resurfacing – includes thin overlay, shallow mill and replace, and medium mill and replace; as capital works
- Strengthening – includes deep mill and replace, thick overlay and reconstruction; as capital works.

The outputs from the HDM-4 were analysed and summarised into more appropriate report formats.

Part 4

The methodology was based on desk study of available models for work zone effects. This included the development of concepts of modelling delays at work zones, the development of a delay costs matrix for road maintenance activities, the determination of the effects of the delays associated with maintenance expenditure and related assumptions.

The second part of the methodology deals with the assessment of what further work is needed to adapt the DTT to HDM-4 to accept SCANNER data and the assessment of the work needed to rewrite the equations within the model to be fully consistent with the new SCANNER data.

Summary Results

Part 2 of the report discussed the effect of a marginal change in maintenance expenditure on Principal A roads in England. Six different scenarios of maintenance expenditure were analysed over a 30-year period and the following are the main conclusions from the study:

- Base scenario (denoted as Scenario 2-4) involves an annual average capital expenditure of £360 million and recurrent expenditure of £114.5 million, giving a total of £474.5 million. This level of expenditure was estimated to maintain the road network condition at an average IRI below 3.5 m/km from Year 1 to Year 16. After Year 16 the roads will deteriorate to IRI of 4.8, leading to a potentially big accumulation of maintenance backlog in the road network.

- Unconstrained budget scenario (denoted as Scenario 2-1) will require a minimum total annual average expenditure (for both capital and recurrent works) of £521 million. This level of expenditure would maintain the road network condition at an average IRI of 2.5 m/km throughout the analysis period. Compared to the Base Scenario the net economic benefit (∆NPV) associated with this expenditure scenario is an increase of about £84.0 billion over 30 years. The (∆NPV / undiscounted total financial cost) ratio for this scenario is 4.43. Total financial cost comprises capital and recurrent (or revenue) expenditure. The benefit cost ratio (BCR) of this scenario relative to the base scenario is 8.0. This ratio is defined as one plus the ratio of net benefit to the discounted total financial cost of this scenario.

- Scenario 2-2: 120 percent of base expenditure, involves an annual average capital expenditure of £432 million and recurrent expenditure of £112 million, giving a total of £544 million. This level of expenditure would maintain the road network condition at an average IRI of 2.6 m/km throughout the analysis period. Compared to the Base Scenario the net economic benefit associated with this expenditure scenario (∆NPV) is an increase of about £83.2 billion over 30 years. The (∆NPV / undiscounted total financial cost) ratio for this scenario is 5.1. The BCR of this scenario relative to the base scenario is 9.1.

- Scenario 2-3: 110 percent of base expenditure, involves an annual average capital expenditure of £396 million and recurrent expenditure of £112.7 million, giving a total of £508.7 million. This level of expenditure would maintain the road network condition at an average IRI below 3.0 m/km over the 30 years analysis period. Compared to the Base Scenario the net economic benefit associated with this expenditure scenario (∆NPV) is an increase of about £54.8 billion over 30 years. The (∆NPV / undiscounted total financial cost) ratio for this scenario is 3.59. The BCR of this scenario relative to the base scenario is 6.8.

- Scenario 2-5: 90 percent of base expenditure, involves an annual average capital expenditure of £324 million and recurrent expenditure of £116 million, giving a total of £440 million. This level of expenditure would maintain the road network condition at an average IRI below 3.5 m/km from Year 1 to Year 14. After Year 14 the roads will deteriorate fast to fair and then poor condition, leading to a large amount of maintenance backlog. Compared to the Base Scenario the net economic benefit associated with this expenditure scenario (∆NPV) is a reduction of about £55.3 billion over 30 years. The (∆NPV / undiscounted total financial cost) ratio for this scenario is -4.19. The BCR of this scenario relative to the base scenario is -5.7.

- Scenario 2-6: 80 percent of base expenditure, involves an annual average capital expenditure of £288 million and recurrent expenditure of £118 million, giving a total of £406 million. This level of expenditure would maintain the road network condition at an average IRI below 3.5 m/km from Year 1 to Year 13. After Year 13 the roads will deteriorate fast to fair and then poor condition, leading to a potentially huge amount of maintenance backlog. Compared to the Base Scenario the net economic benefit associated with this expenditure scenario (∆NPV) is a reduction of about £112.2 billion over 30 years. The (∆NPV / undiscounted total financial cost) ratio for this scenario is -9.21. The BCR of this scenario relative to the base scenario is -13.7.

- The results from the analyses suggest that an average minimum annualised capital expenditure of £440 million would be necessary to keep the average road network roughness below 3 IRI in the long-term.

- From the relationship between the (NPV / financial cost) ratio and the level of annual financial expenditure for both capital and recurrent works, the study indicates that the optimal level of expenditure that maximises the economic benefits is around £500 million per year, which equates to an average figure of around £18,000 per km per year. This expenditure profile is close to that defined by Scenario 3.

- The results of sensitivity analysis have indicated that the initial AADT is a very sensitive parameter therefore it is important to get the correct traffic data on the roads. An increase or decrease in traffic growth rate would result in a reduction in NPV. This is probably an indication that the traffic growth rate used in this study is an optimal value for this road network. The effect of an increase in unit costs of works over the base rate will result in a significant reduction in net economic benefits. The analysis period is the most sensitive parameter as a shorter analysis period does not give as long a time for the road user benefits to accrue over the lifetime of the maintenance work that is performed. The 30-year analysis period is the most appropriate one since the useful life of capital works related to bituminous pavements is very well covered over this period.

Part 3 of the report discussed the results of analysis of optimistic and pessimistic initial road network condition distributions. The optimistic assumption of initial principal road network condition distribution gave a length weighted roughness of 2 IRI. The Pessimistic assumption of initial road network distribution gave a length weighted roughness of 3 IRI.

Summary of Results for Optimistic Initial Road Network Condition

The optimistic condition analysis was done for a total of nine scenarios comprising: a business as usual scenario; four scenarios of budget cuts over fixed periods followed by business as usual investment in the years after budget cuts were cancelled; and another four scenarios of budget cuts over fixed periods followed by heavy investment in the years after cuts were cancelled to return the average road network condition to the business as usual level in the long-term. A summary of results for each of these scenarios is provided in subsequent sections.

- *Scenario 3-O-1 (Business as Usual)*. The estimated annual capital expenditure for this scenario was £360 million and the average annual recurrent expenditure was £105.4 million, giving a total of £464.8 million. This level of expenditure was estimated to maintain the road network condition to a good condition to an average IRI over the 30 year analysis period of 2.7 m/km. The Business as Usual scenario (Scenario 3-O-1) was used as a base case for the purpose of economic comparison with the other scenarios within the optimistic road network condition analysis. To that end, the Net Present Value (NPV) associated with this scenario was zero with a Benefit Cost Ratio (BCR) of 1.

- *Scenario 3-O-2 (20% Cut Year 1-3 then Business as Usual)*. The estimated annual capital expenditure for this scenario was £355.2 million and the average annual recurrent expenditure was £106.2 million, giving a total of £461.4 million. This level of expenditure was deemed necessary to maintain the road network condition to a good condition to an average IRI over the 30 year analysis period of 2.9 m/km. The net economic benefits associated with this expenditure scenario when compared with the Business as Usual scenario (Scenario 3-O-1), in terms of NPV, is about £-14.8 billion over 30 years. The BCR cost ratio for this scenario is -0.7.

- *Scenario 3-O-3 (20% Cut Year 1-6 then Business as Usual).*The estimated annual capital expenditure for this scenario was £344.7 million and the average annual recurrent expenditure was £105.5 million, giving a total of £450.2 million. This level of expenditure is considered necessary to maintain the road network condition to a good condition to an average IRI over the 30 year analysis period of 3.1 m/km. The net economic benefits associated with this expenditure scenario when compared with the Business as Usual scenario (Scenario 3-O-1), in terms of NPV, is about £-27.6 billion over 30 years. The BCR cost ratio for this scenario is -2.3.

- *Scenario 3-O-4 (40% Cut Year 1-3 then Business as Usual)*. The estimated annual capital expenditure for this scenario was £348.7 million and the average annual recurrent expenditure was £105.5 million, giving a total of £454.2 million. This level of expenditure is considered necessary to maintain the road network condition to a good condition to an average IRI over the 30 year analysis period of 3.2 m/km. The net economic benefits associated with this expenditure scenario when compared with the Business as Usual scenario (Scenario 3-O-1), in terms of NPV, is about £-32.9 billion over 30 years. The BCR cost ratio for this scenario is -2.9.

- *Scenario 3-O-5 (40% Cut Year 1-6 then Business as Usual)*. The estimated annual capital expenditure for this scenario was £331.3 million and the average annual recurrent expenditure was £107.8 million, giving a total of £454.10 million. This level of expenditure is considered necessary to maintain the road network condition to a good condition to an average IRI over the 30 year analysis period of 3.5 m/km. The net economic benefits associated with this expenditure scenario when compared with the Business as Usual scenario (Scenario 3-O-1), in terms of NPV, is about £-61.4 billion over 30 years. The BCR cost ratio for this scenario is -6.5.

Summary of Results for Pessimistic Initial Network Condition

The pessimistic initial road network condition analysis was done for a total of five scenarios. The first of which was the business as usual scenario, followed by four scenarios of budget cuts over the first three or six years of the analysis with business as usual investment applied in subsequent years.

- *Scenario 3-P-1 (Business as Usual)*. The estimated annual capital expenditure for this scenario was £357 million (close to the expected business as usual annual expenditure of £360 million) and the average annual recurrent expenditure was £115.7 million, giving a total of £472.7 million. This level of expenditure was estimated to maintain the road network condition to an average IRI over the 30 year analysis period of 5.37 m/km. The Business as Usual scenario (Scenario 3-P-1) was used as a base case for the purpose of economic comparison with the other scenarios within the pessimistic road network condition analysis. To that end, the Net Present Value (NPV) associated with this scenario was zero with a Benefit Cost Ratio (BCR) of 1.

- *Scenario 3-P-2 (20% Cut Year 1-3 then Business as Usual)*. The estimated annual capital expenditure for this scenario was £350 million and the average annual recurrent expenditure was £115million, giving a total of £465 million. This level of expenditure was deemed necessary to maintain the road network condition to an average IRI over the 30 year analysis period of 5.39 m/km. The net economic benefits associated with this expenditure scenario when compared with the Business as Usual scenario (Scenario 3-P-1), in terms of NPV, is about £-2.6 billion over 30 years. The BCR cost ratio for this scenario is 0.7.

- *Scenario 3-P-3 (20% Cut Year 1-6 then Business as Usual)*. The estimated annual capital expenditure for this scenario was £339.2 million and the average annual recurrent expenditure was £112.3 million, giving a total of £451.5 million. This level of expenditure is considered necessary to maintain the road network condition to an average IRI over the 30 year analysis period of 5.51 m/km. The net economic benefits associated with this expenditure scenario when compared with the Business as Usual scenario (Scenario 3-P-1), in terms of NPV, is about £-19.1 billion over 30 years. The BCR cost ratio for this scenario is -1.3.

- Scenario 3-P-4 (40% Cut Year 1-3 then Business as Usual). The estimated annual capital expenditure for this scenario was £343.1 million and the average annual recurrent expenditure was £114 million, giving a total of £457.1 million. This level of expenditure is considered necessary to maintain the road network condition to an average IRI over the 30 year analysis period of 5.43 m/km. The net economic benefits associated with this expenditure scenario when compared with the Business as Usual scenario (Scenario 3-P-1), in terms of NPV, is about £-6.5 billion over 30 years. The BCR cost ratio for this scenario is 0.2.

- *Scenario 3-P-5 (40% Cut Year 1-6 then Business as Usual)*. The estimated annual capital expenditure for this scenario was £323.5 million and the average annual recurrent expenditure was £107.0 million, giving a total of £430.5 million. This level of expenditure is considered necessary to maintain the road network condition to an average IRI over the 30 year analysis period of 6.3 m/km. The net economic benefits associated with this expenditure scenario when compared with the Business as Usual scenario (Scenario 3-P-1), in terms of NPV, is about £-61.4 billion over 30 years. The BCR cost ratio for this scenario is -107.9.

Part 4 investigated the effect of including costs of work zone delays on the economic indicators, comprising Net Present Value (NPV) and the Benefit Cost Ratio (BCR), and also the effect on the results of the scenarios of marginal changes in maintenance expenditure scenarios given in Part 2. The results are summarised in the table 0-1. The inclusion of work zone delay costs did not have a significant effect on NPV and BCR, as shown in the Table. This is because the average vehicle operating speed on the road network is predicted to be low for most of the second half of the 30 year analysis period. Delays due to work zones would not therefore cause much difference to the effect of the low operating speed.

As can be seen from Table 0-1, the effect of delays will cause the NPV to reduce for scenarios of increased road maintenance expenditure. However, when the maintenance budget is reduced the consequence will be reduced or less frequent road works and therefore the cost of delays will be reduced, leading to a slight increase in NPV.

Table 0-1 Summary of Economic Indicators

Scenario	Without Delay Costs			With Delay Costs		
	Total Transport Costs	NPV	Benefit Cost Ratio	Total Transport Costs	NPV	Benefit Cost Ratio
	£ Billion	£ Billion	BCR	£ Billion	£ Billion	BCR
Scenario 2-1	4,479	83.876	8.0	4,481	83.781	7.98
Scenario 2-2	4,480	83.168	9.1	4,482	82.864	9.06
Scenario 2-3	4,508	54.805	6.8	4,511	54.566	6.74
Scenario 2-4	4,563	0.000	1.0	4,565	0.000	1.00
Scenario 2-5	4,619	-55.332	-5.7	4,620	-55.099	-5.67
Scenario 2-6	4,675	-112.215	-13.7	4,677	-111.752	-13.64

Finally, this study has demonstrated the capability of HDM-4 in determining the effects of marginal changes and budget cuts in maintenance expenditure levels. The analysis tool optimises investment options, subject to available budget, to minimise total transport costs by considering the costs to the road authority and road users. To that end, HDM-4 provides a good framework for investigating the expenditure/benefits trade-offs. This can improve the understanding within the DfT of investing in the maintenance of local authority highway networks in England.

The Way Forward

It is important to note that the reliability of the results of any study using prediction models such as HDM-4 is dependent upon two primary considerations:

- How well the data provided to the model represent the reality of the current conditions and influencing factors, in the terms understood by the model; and,

- How well the predictions of the model fit the real behaviour and the interactions between various factors for the conditions prevailing in the countries and regions to which it is applied.

Although the study team made great effort to obtain reliable input data and calibrate the models, available project resources limited these tasks. Nevertheless, the rigorous sensitivity analysis conducted has confirmed the robustness of the results obtained. Default HDM-4 model parameters and data obtained from desk studies were used mainly. Confidence in using the results obtained from this study could be increased through additional studies to calibrate HDM-4 models to conditions in England to Level 2 Calibration.

It is envisaged that under the long-term phase, major work will include development of a better method of dealing with road delays, adapting the DTT to use the Surface Condition Assessment for the National Network of Roads (SCANNER) system and updating the calibration of HDM-4. Further work will also include differentiation of the proven methodology to reflect UK regional domains, taking into consideration several factors such as climate, soil type and geology, traffic and other parameters deemed by DfT to be significant.