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Developing a Whole-Life Value Model for the Irish National Road Network

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Abstract

Planning of road maintenance helps to spend available budgets efficiently and aims to keep the network in a safe and useable condition for road users. Road pavement maintenance models have traditionally excluded externalities as part of quantitative assessments of maintenance options. However, road maintenance affects wider society and therefore any maintenance decisions should integrate externalities into the decisions and tools that are used to generate maintenance programmes. This thesis investigates how externalities of carbon and noise emissions from maintenance can be included in a pavement maintenance model and the associated impacts on developing a maintenance programme.

Pavement maintenance models were studied and it showed that there is a general omission of externalities within the core of the models. A review of externalities (with an emphasis on environmental externalities) demonstrated that road authorities do have policies to take account of externalities but often in a qualitative assessment and often only at a project level, not at a strategic level.

This research developed a whole-life cost model into which novel methodologies for modelling carbon and noise were included, with the methodologies developed so that they can be used in other pavement management systems. The result was a model that took account of a wider range of value parameters as part of the economic analysis. Two in-depth case studies were completed to investigate the impact that the methodologies had on a road network. Using current government prices for carbon and noise, noise had a significantly greater impact on the resulting maintenance programme. Sensitivity analysis showed that the resulting maintenance programmes were a lot less sensitive to changes in the price of carbon, although both parameters did lead to changes in the resulting maintenance programme, especially when specific environmentally focused maintenance options were included as treatments.

Publications

Elements of this work have been published elsewhere as follows.

Buckland, T (2011). *NRA Pavement Cost Model: Manual*. TRL, PPR597.

Buckland, T (2011). *NRA Pavement Cost Model: User Guide*. TRL, CPR1253.

Buckland, T. & Wayman, M. (2012). Including carbon emissions in the economic appraisals of road schemes. In: *Proceedings of the 5th Eurasphalt & Eurobitume Congress, 2012, Istanbul, Turkey*. Available from the World Wide Web: <<http://www.eecongress2012.org/EEUSB/content/fulltext/A5EE-330.pdf>>

Buckland, T. (2012). Assessing road maintenance programmes on a 'value' basis: consideration of the road users' requirements. In: *Proceedings of the European Transport Conference 2012, Glasgow*. Available from the World Wide Web: <<http://abstracts.aetransport.org/paper/index/id/3969/confid/18>>

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Contents

Abstract	i
Publications	ii
Acknowledgements.....	iii
List of figures.....	vii
List of Tables	x
Acronyms.....	xiv
Chapter 1 Introduction	1
1.1 The importance of pavement networks.....	1
1.2 Asset management.....	2
1.3 Externalities	4
1.4 Pavement maintenance strategies	6
1.5 Research aim and objectives.....	8
1.6 Organisation of this thesis	10
Chapter 2 Pavement maintenance models	12
2.1 Pavement networks	13
2.2 Historical overview	14
2.3 Data	15
2.4 Deterioration relationships.....	21
2.5 Maintenance treatments.....	36
2.6 Whole-life costing.....	40
2.7 Modelling approaches.....	45
2.8 Reporting and outputs	48
2.9 Review of existing systems	49
2.10 Summary	55
Chapter 3 Externalities	57
3.1 Drivers of internalisation	57
3.2 Monetising externalities.....	59
3.3 Road transport externalities.....	63
3.4 Carbon emissions	74
3.5 Noise	84
3.6 Whole-life value	87
3.7 Summary	88
Chapter 4 Understanding stakeholder requirements	91
4.1 Consultations.....	92
4.2 Consultation planning	99
4.3 Individual consultations.....	107
4.4 Focus groups	127

4.5	Discussion	165
4.6	Summary	174
Chapter 5	Whole-life cost model.....	176
5.1	Data structure.....	177
5.2	Model structure	181
5.3	Modelling processes	187
5.4	Testing.....	229
5.5	Summary	230
Chapter 6	Developing carbon and noise methodologies	231
6.1	Treatments	231
6.2	Incorporating carbon.....	236
6.3	Incorporating noise.....	251
6.4	Linking all methodologies to stakeholder opinion	280
6.5	Summary	281
Chapter 7	Model application to the Irish national network.....	283
7.1	Data	283
7.2	Model capabilities	284
7.3	Comparison of modelling scenarios	286
7.4	Developing a maintenance strategy for a route.....	289
7.5	Developing a maintenance strategy for a region	335
7.6	Discussion	344
Chapter 8	Conclusions and future work	347
8.1	Research objectives	347
8.2	Conclusions.....	351
8.3	Future work	353
References	356
Appendix A	Summary of existing asset management systems.....	369
Appendix B	Equations proposed by Shiyab.....	380
Appendix C	Phase 1 SWOT analysis	381
Appendix D	Phase 2 SWOT analysis	382
Appendix E	Consultation background note	383
Appendix F	Intial focus group guide.....	385
Appendix G	Amended focus group guide.....	400

Appendix H NRA Data trends415

Appendix I Default carriageway descriptions418

Appendix J Derived carbon quantities for excavation419

Appendix K Carbon costs.....421

Appendix L Derived noise dwelling data423

Appendix M Example noise input calculations424

Appendix N Noise costs427

Appendix O Example noise surface change429

Appendix P Example noise whole-life calculation430

List of figures

Figure 1-1: Example asset management system.....	3
Figure 1-2: Environmental externalities (source: Garrett Hardin, no date)	4
Figure 2-1: Common features of examined systems.....	52
Figure 3-1: Significance of transport sector in CO ₂ e emissions (source: DECC, 2011)...	68
Figure 3-2: The price of carbon as documented by NRA and DECC (in 2010 prices)	78
Figure 3-3: Arnstein's ladder of participation.....	93
Figure 3-4: Public impact levels (adapted from IAP, 2007).....	93
Figure 4-1: Consultation aims	101
Figure 4-2: Key stakeholders consulted and their relevance	103
Figure 4-3: Information shared through different stages of the consultation.....	105
Figure 4-4: Process for setting up the consultations	109
Figure 4-5: Example images displayed when welcoming participants.....	133
Figure 4-6: Trade-off images for lighting energy.....	137
Figure 4-7: Trade-off images for hard-shoulder running	137
Figure 4-8: Pairwise comparison spreadsheet and example data entry	140
Figure 4-9: Trade-off graphic for night working	146
Figure 4-10: Trade-off graphic for material choice	146
Figure 4-11: Trade-off images for noise choices	147
Figure 4-12: Graphic illustrating scenarios for ordering exercise.....	149
Figure 4-13: Statistical analysis of focus group input (number of words spoken)	150
Figure 4-14: Participants' top 100 words from their general comments about the environment in focus group 1 (software used: tagxedo.com).....	152
Figure 4-15: Participants' top 100 words from their general comments about the environment in focus group 2 (software used: tagxedo.com).....	153
Figure 5-1: Model databases and their relationship in the model.....	180
Figure 5-2: Modelling processes	184
Figure 5-3: Analysis configuration screen: Data tab	188
Figure 5-4: Network selection screen	190
Figure 5-5: Example analysis networks	191
Figure 5-6: Missing Data Example	193
Figure 5-7: Run-time data setup flowchart.....	196
Figure 5-8: Data projection example.....	197
Figure 5-9: Data ageing flowchart	198
Figure 5-10: Homogenisation process	201
Figure 5-11: Example of homogenisation output compared to raw data.....	203

Figure 5-12: Treatment identification process	204
Figure 5-13: Treatment year's assessment loop	205
Figure 5-14: Complete scheme creation and option evaluation.....	210
Figure 5-15: Example QUADRO input file.....	214
Figure 5-16: Residual value example	219
Figure 5-17: Prioritisation by budget process	222
Figure 5-18: Prioritisation by condition process - Part 1	226
Figure 5-19: Prioritisation by condition process - Part 2	227
Figure 6-1: Carbon emissions (kg CO ₂ e/t)	239
Figure 6-2: Carbon emissions (kg CO ₂ e/m ²) assuming asphalt density of 2.3 t/m ³	239
Figure 6-3: Energy use in asphalt plants (source: Carbon Trust, 2010)	245
Figure 6-4: Phase 2 noise mapping for county Kilkenny, Ireland (source: NRA).....	254
Figure 6-5: Example of noise level increase over 5 years of measurement for porous asphalt (PAC) and double layer porous asphalt (DPAC) surfaces. (The example above is from FEHRL (2006) and the data was for light vehicles at a reference speed of 50 km/h).	264
Figure 6-6: Example of how noise data has been shown to demonstrate an initial noise change, followed by a plateauing some years later, for hot rolled asphalt (HRA), porous asphalt (PAC), brushed cement concrete (BCC), stone mastic asphalt (SMA), emulsified asphalt cement concrete (EACC) and thin surfacings (TSF). (The example above is from FEHRL (2006) and the data was for medium heavy vehicles at a reference speed of 85 km/h).	264
Figure 6-7: Example of noise thresholds incorporated alongside pavement condition thresholds	276
Figure 7-1: N4 location in Ireland (source: Google Maps, 2015a)	293
Figure 7-2: N4 (source: Google Maps, 2015b)	294
Figure 7-3: Counties along the route of the N4 (aligned with Figure 7-4 to Figure 7-9).....	296
Figure 7-4: N4 traffic (all charts start with Sligo at 0 km chainage)	296
Figure 7-5: N4 rut depth (for the condition parameters, the blue line represents the individual data records, whilst the red line represents the homogenised data)	297
Figure 7-6: N4 longitudinal profile variance	297
Figure 7-7: N4 texture	298
Figure 7-8: N4 SCRIM.....	298
Figure 7-9: N4 noise.....	299
Figure 7-10: Scheme 5 treatment profile in initial analysis with only works and delay costs cost profile (Euros per year)	330
Figure 7-11: Scheme 5 treatment profile, standard Do Something including carbon and noise costs cost profile (Euros per year)	331
Figure 7-12: Scheme 5 treatment profile, Do Something standard carbon, low-noise cost profile (Euros per year)	331
Figure 7-13: Scheme 5 treatment profile, Do Something low-carbon, low-noise cost profile (Euros per year)	332

Figure 7-14: Location of County Kilkenny in dark green (source: Wikipedia, 2010) 336

Figure 7-15: Map of Kilkenny County (source: Google Maps, 2015c) 337

Figure H-1: Rut depth trending data (all trends from 3 or more data points) 415

Figure H-2: Rut depth trending data (positive trends only from 3 or more data points) 416

Figure H-3: 3m Longitudinal Profile trending data (all trends from 3 or more data points) 416

Figure H-4: 3m Longitudinal Profile trending data (positive trends only from 3 or more data points) 417

List of Tables

Table 2-1: PARIS rutting rates	30
Table 2-2: Maintenance treatments	39
Table 3-1: Comparison between Irish, Scottish and New Zealand trunk networks	64
Table 3-2: Environmental sub-criteria	67
Table 3-3: Green Book discount rates	80
Table 3-4: Property price reductions due to noise	85
Table 4-1: Key principles and their associated value in stakeholder consultation	95
Table 4-2: Phase 1 consultations	110
Table 4-3: Phase 1 consultation outcomes	112
Table 4-4: Phase 2 consultations	115
Table 4-5: Phase 2 consultation outcomes	119
Table 4-6: List of items for focus group 1	138
Table 4-7: Lookup weights for pairwise comparison	141
Table 4-8: Trial group participants	142
Table 4-9: Revised list of items for ordering exercise in focus group 1	143
Table 4-10: Focus group 1 participants	144
Table 4-11: Revised list of items for ordering exercise in focus group 2	148
Table 4-12: Focus group 2 participants	149
Table 4-13: Responses to ordering exercise for Town A scenario	157
Table 4-14: Responses to ordering exercise for Town B scenario	158
Table 4-15: Pairwise comparison results from focus group 1	161
Table 4-16: Pairwise comparison results from focus group 2	161
Table 4-17: Results of comparison of pairs	162
Table 4-18: Pairwise comparison weightings	163
Table 4-19: Works costs obtained through the stakeholder consultation	167
Table 4-20: Example weighting sets	173
Table 5-1: Default deterioration mechanism and rates	199
Table 5-2: Default road type relationship coefficients	200
Table 5-3: Default thresholds	207
Table 5-4: Recommended unit cost rates for use in the base model	212
Table 5-5: QUADRO data setup for modelled road types	213
Table 5-6: QUADRO results mapped to Irish road types and closures	216
Table 5-7: Closure types	217
Table 5-8: Closure working patterns	217
Table 5-9: Default treatment reset values	228

Table 6-1: Maintenance drivers and reporting function status for 'carbon' and 'noise' impacts	233
Table 6-2: Model treatment options	236
Table 6-3: Transport utilisation carbon emissions per km calculated using asPECT	240
Table 6-4: Sensitivity of binder content amounts using asPECT	241
Table 6-5: Sensitivity of the inclusion of polymer modified binder using asPECT	242
Table 6-6: Sensitivity to the impact of recycled content (of thin surfacing material) on embodied carbon	243
Table 6-7: Sensitivity to the impact of recycled content (of base material) on embodied carbon.....	243
Table 6-8: Materials assumptions made for treatment options.....	246
Table 6-9: Resulting embodied carbon quantities from asPECT	247
Table 6-10: Problems and mitigation of available noise mapping data	256
Table 6-11: Noise costs	261
Table 6-12: Noise data for different pavement types and conditions	266
Table 6-13: Representation of noise change between surface types	267
Table 6-14: Ranges of average lifetime noise reductions	267
Table 6-15: Lifetime noise reduction estimated from non-zero conservative ranges in Table 6-14	268
Table 6-16: Derived initial noise reduction	269
Table 6-17: Number of years after maintenance that constant noise value is achieved	270
Table 6-18: Constant noise change values	271
Table 6-19: Noise data used in the model database	273
Table 6-20: Expected life data.....	279
Table 6-21: Deterioration uplift factors to reflect changes in performance between standard- and low-noise surfaces.....	280
Table 7-1: Cost parameters and links to example policies	288
Table 7-2: N4 road types.....	294
Table 7-3: N4 analysis setup.....	300
Table 7-4: Scheme lengths identified and selected.....	301
Table 7-5: Cost outputs using only works costs	303
Table 7-6: Condition outputs from works costs only analysis.....	304
Table 7-7: Prioritised order of selected schemes.....	305
Table 7-8: Cost outputs using works and delay costs	307
Table 7-9: Condition outputs from works and delay costs analysis	308
Table 7-10: Cost outputs from analysis including carbon costs	309
Table 7-11: Condition outputs from works, delay and carbon costs analysis.....	310
Table 7-12: Cost outputs from analysis including noise costs	312
Table 7-13: Condition outputs from works, delay and noise costs analysis	313
Table 7-14: Cost outputs from analysis including carbon and noise costs.....	315

Table 7-15: Condition outputs from works, delay, carbon and noise costs analysis	315
Table 7-16: Costs when choosing between a Do Minimum and four Do Something options	319
Table 7-17: Condition outputs from works, delay, carbon and noise costs using 4 Do Something options.....	321
Table 7-18: Costs when choosing only between a Do Minimum and low-carbon, low-noise Do Something	322
Table 7-19: Condition outputs from works, delay, carbon and noise costs using only the low-noise, low-carbon Do Something	323
Table 7-20: Noise costs scheme sensitivity	324
Table 7-21: Carbon costs scheme sensitivity	325
Table 7-22: Noise and carbon cost weighting sensitivity	326
Table 7-23: Overall costs when carbon and noise costs are attributed to society	328
Table 7-24: Condition outputs from works, delay attributed to the agency and carbon and noise costs attributed to society	329
Table 7-25: County Kilkenny analysis setup.....	338
Table 7-26: Data coverage for County Kilkenny	338
Table 7-27: Cost outputs for Kilkenny (Do Minimum and standard Do Something)	339
Table 7-28: Cost outputs for Kilkenny (Do Minimum and four Do Something options) .	342
Table 7-29: Calculated noise savings	344
Table A-1: Asset Management Tool Comparison	377
Table B-1: Proposed age and ESAL formulae	380
Table C-1: SWOT analysis following completion of phase 1 individual consultations	381
Table D-1: SWOT analysis following completion of phase 2 individual consultations	382
Table I-1: Default carriageway descriptions and types	418
Table J-1: Carbon quantities for material excavation	419
Table K-1: Carbon costs used in the model lookup tables (expressed in 2010 prices, in Euros , €/kg CO _{2e}).	421
Table L-1: Noise dwelling data in 5 dB bands for Ireland (obtained from NRA noise mapping exercise).....	423
Table M-1: Route lengths for Kilkenny	424
Table M-2: Assessments of noise mapping extents in Kilkenny	425
Table M-3: Noise dwelling calculation data	425
Table M-4: Example model input data for Kilkenny	426
Table N-1: Noise change costs for transport related noise (WebTAG Unit 3.3.2), and calculated lower and upper half-band values.....	427
Table P-1: Noise pavement emission change due to surfaces	431
Table P-2: Noise dwelling change due to interventions	432

Table P-3: Calculated noise costs as a result of the interventions.....434

Acronyms

AADT	Annual Average Daily Traffic
AC	Asphalt Concrete
ADEPT	The Association of Directors of Environment, Economy, Planning & Transport
asPECT	asphalt Pavement Embodied Carbon Tool
BSI	British Standards Institution
CBI	Confederation of British Industry
CHANGER	Calculator for Harmonised Assessment and Normalisation of Greenhouse-gas Emissions for Roads
CHF	Swiss Franc
CO ₂	Carbon Dioxide
CO ₂ e	Carbon Dioxide equivalents
CPX	Close-Proximity Method
dB	Decibel
DECC	Department of Energy & Climate Change
DfT	Department for Transport, UK
DoT	Department of Transport, Republic of Ireland
DPAC	Double-layer Porous Asphalt Concrete
EACC	Emulsified Asphalt Cement Concrete
EIA	Environmental Impact Assessment
END	European Noise Directive
EPD	Environmental Product Declaration
ESA	Equivalent Standard Axles
ESAL	Equivalent Standard Axle Load
ETS	Emissions Trading System
EU	European Union
FEHRL	Forum of European National Highway Research Laboratories

FWD	Falling Weight Deflectometer
GHG	Greenhouse Gases
GIS	Geographical Information System
GPR	Ground Penetrating Radar
HA	Highways Agency
HAPMS	Highways Agency Pavement Management System
HDM	Highway Development and Management Software
HRA	Hot Rolled Asphalt
IRI	International Roughness Index
ISO	International Organization for Standardization
LA	Local Authority
LCA	Life Cycle Assessment
L_{den}	Day Evening Night Sound Level
MSSC	Mean Summer SCRIM Coefficient
MPA	Mineral Products Association
NIMBY	Not In My Back Yard
NO_x	Nitrogen Oxides
NPV	Net Present Value
NRA	National Roads Authority, Ireland
NZTA	New Zealand Transport Agency
OGC	Office of Government Commerce
PA	Porous Asphalt
PAS	Publicly Available Specification
PCR	Product Category Rules
PM_{10}	Particulate Matter, less than or equal to 10micron
PMB	Polymer Modified Binder
PMS	Pavement Management System
PPP	Public Private Partnership
PSV	Polished Stone Value

QUADRO	QUeues And Delays at ROadworks
RBA	Refined Bitumen Association
RPI	Retail Prices Index
RSTA	Road Surface Treatments Association
SCRIM	Sideways Force Coefficient Routine Investigation Machine
SD	Surface Dressing
SMA	Stone Mastic Asphalt
SNP or SNC	Structural Number
SPB	Statistical Pass-By
SQL	Structured Query Language
STAG	Scottish Transport Appraisal Guidance
SWOT	Strength, Weaknesses, Opportunities, Threats
TRL	Transport Research Laboratory, UK
TS	Thin Surfacing
TSD	Traffic Speed Deflectometer
UKPMS	United Kingdom Pavement Management System
VOC	Vehicle Operating Cost
WHO	World Health Organisation
WLC	Whole-Life Cost
WLV	Whole-Life Value
WTA	Willingness to accept
WTP	Willingness to pay

Chapter 1 Introduction

1.1 The importance of pavement networks

Pavement networks have developed significantly over the last century (in terms of their design or size for example) and their growth and improvement, coupled with advances in road transport, has led to dramatic increases in the movement of people and goods. The importance of these networks within the wider economy is significant. Investment not only benefits the economy but it also promotes better access and integration for society, leading more generally to improvements in standards of living (European Union Road Federation, 2006). Conversely, without suitable investment and management the networks can deteriorate to levels which can result in adverse impacts.

Road pavements are one asset type within the transport sector and a Pavement Management System (PMS) is an asset management system specifically for road pavements. A PMS is one of the key tools for road asset management used by many highway authorities, whose responsibility it is to manage the pavement networks in a safe and serviceable condition (Haas & Hudson, 1978).

The variation in both the characteristics of a pavement network and the surveyed data means there is not one overall assessment approach or set of algorithms that can be universally applied to a pavement network. However, it is widely accepted that significant resources need to be spent managing the pavement networks throughout their lives because they are a key asset for any highway authority.

Whilst it is generally agreed that safety based maintenance cannot usually be deferred, other periodic maintenance needs to be justified and cost efficient. Budget constraints usually mean that road agencies have to prioritise their portfolio of work due to inadequate funds to maintain all of the lengths of the network identified for maintenance (Robinson, 1993). This has even greater importance when there is a decline in funding

for new construction and best use needs to be made of the existing infrastructure (Green, 2010).

Other factors can also contribute to the appraisal process. Decreasing the level of delays or increasing safety levels are measures that have been included in appraisals. Whilst transport and roads are key for economic prosperity, they can however generate negative impacts. For example, transport is a major contributor to greenhouse gas (GHG) emissions (European Climate Foundation, no date) and lowering GHG emissions is one objective road agencies have to address. Traffic noise can have a detrimental effect on neighbouring populations and road agencies have to consider the noise implications that might arise from any new construction or maintenance (Muller-Wenk and Hofstetter, 2003).

Within the appraisal of maintenance options there are therefore a number of other aspects to consider and it is important that the process considers the trade-offs between those aspects, some of which might be conflicting.

In this thesis a framework is developed for including both GHG emissions from maintenance and traffic noise within the development and prioritisation of road maintenance programmes. Those two aspects are at the forefront of any additional aspects and therefore have been chosen for this research. The purpose of the research is to provide the highway authorities with the ability to address wider stakeholder issues in the management of road networks. A maintenance programme strategy model was developed specifically for use on the Irish national network into which the assessment of these environmental emissions was incorporated.

1.2 Asset management

Asset management aims to help get the best use from an asset, and as described by The Institute of Asset Management (2009) it is about “making the right decisions and optimising these processes.” It is commonly concerned with optimising the costs of an

asset base, often in the context of managing an organisation's physical assets (e.g. a road network) in order to support decisions they need to make.

An asset management system (see Figure 1-1) incorporates processes, tools and data required to manage the asset and generally includes:

- Data acquisition;
- Data repository system(s), which includes information such as the asset type, locational data, condition data, management strategies etc.;
- Analysis, prediction and decision support tools; and
- Reporting tools.

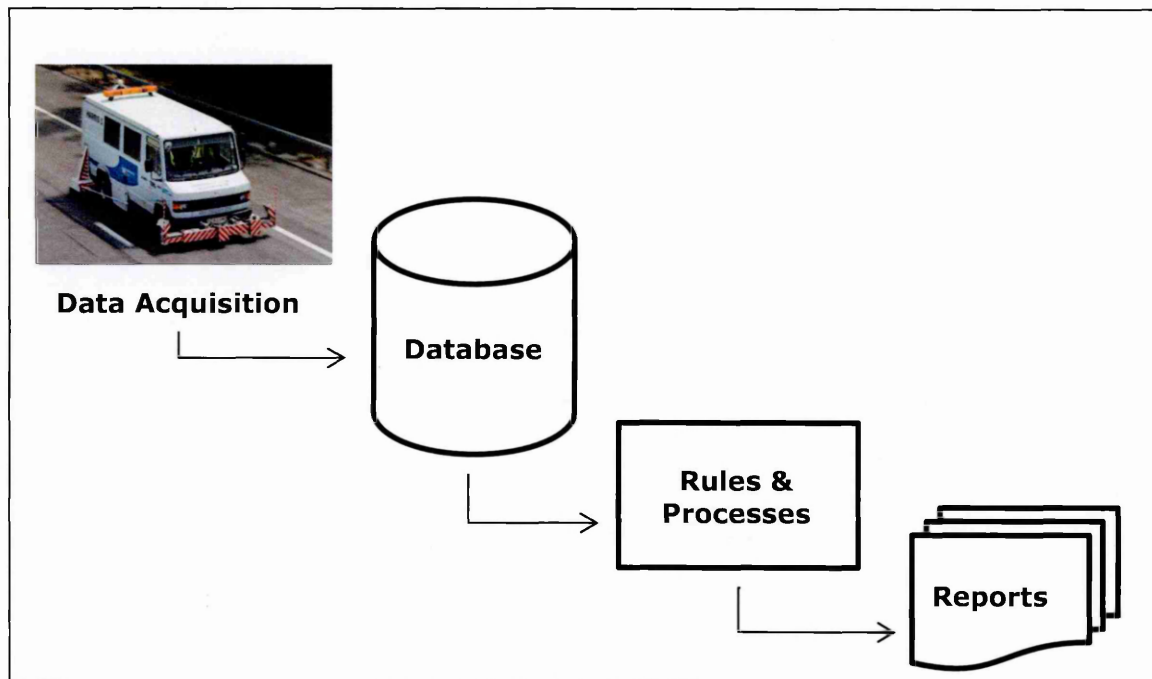


Figure 1-1: Example asset management system

A well-managed and well-maintained asset management system can help make best use of the available resources to meet the needs of both the managing organisation and the users. The same is also true of a PMS.

An increase in the disparity of the demands on highway assets (increasing) and the availability of resources (decreasing) is becoming a world-wide issue. This has the potential to lead to a greater deterioration of the asset (Flintsh and Kuttesch, 2002). Good quality asset management and appropriately designed systems can help to manage this disparity and enable highway authorities to make more robust decisions.

However, the use of road pavements and the resulting deterioration to maintenance affects the wider society (e.g. delays, gaseous emissions) and any maintenance decisions need to recognise that externalities may be affected.

1.3 Externalities

An externality is a cost or benefit encountered by a person or party who is not the originator of the economic action (Bishop, 2004). It is normally considered with respect to effects on the wider society, who are affected by the outcome of a change of decisions in which they may not have direct involvement (see Figure 1-2). A positive externality provides benefits to society, for example keeping bees can lead to added benefits due to the role they play in pollination in the wider area. Conversely, a negative externality imposes costs on society, for example pollutants released into the atmosphere can impact upon health and well-being.

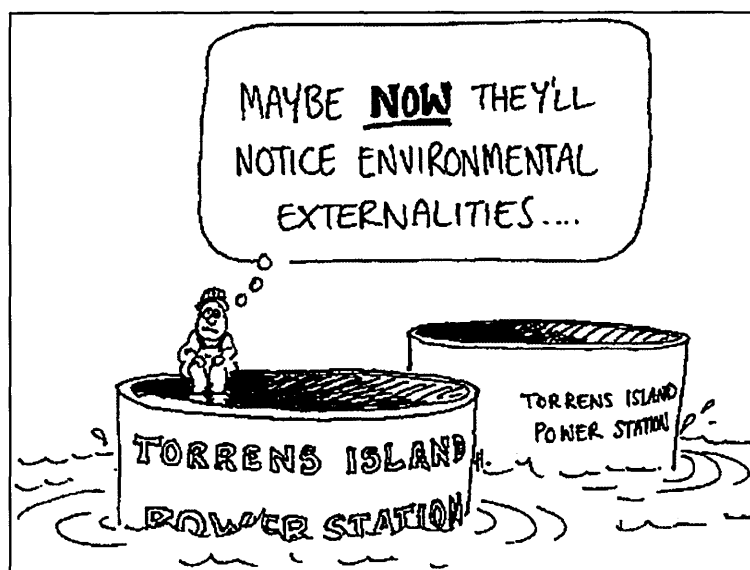


Figure 1-2: Environmental externalities (source: Garrett Hardin, no date)

The rapid growth of economies over recent decades, as well as an increased awareness of the wider impact of human activities has meant that pressure to reduce impacts on the environment has increased. There is greater appreciation of the need for decisions taken today to give consideration to minimising impacts on the environment, and transport has been identified as a key area in which the effects of externalities need to be considered (e.g. Hormandinger and Lucas, 1996; Bickel et al., 2006).

For more than a decade, a stated objective of the European Commission (European Commission, 2000; European Commission, no date) has been to include the costs of externalities within any assessment of the costs of transport. This is to ensure that the full economic costs of actions and consequences for the whole society are considered in any appraisal of transport investments. Delays to road users are one example where there has been a common acceptance of their inclusion within the appraisal process.

1.3.1 Externalities in road transport

The European Environment Agency (2010) states that including the external costs of environmental impacts, congestion and accidents are important steps for a comprehensive appraisal of road projects. Omission of externalities (including monetised and non-monetised factors) can lead to significant impacts being ignored during investment appraisal. An example of their potential impact is provided by the proposed widening of the A303 through the Blackdown Hills in England; this was rejected due to the large negative environmental impact of the project (The Campaign for Better Transport, no date).

Historically, externalities of transport have not been fully considered within economic appraisals of road projects. One reason for this is the lack of agreement on the methodology for assessing and monetising their impacts, primarily due to uncertainties or difficulties in actually measuring the impacts. For some externalities the impracticality of including them (e.g. lack of data, poor quality data, or uncertainties over their effects) is often used as justification for their omission (Land Transport New Zealand, 2006).

When including externalities within assessments, thought has to be given to whether it is even possible to quantify the measure to be used to assess the externality. Due to the difficulty in adding such values, externalities often remain outside the economic appraisal framework.

Exceptions to the above are the consideration of the costs to society of congestion (delays during road journeys) and accidents (delays due to injuries or fatalities). One or both have been routinely included as costs within analyses by road authorities (e.g. Robinson, 1993; PIARC Technical Committee on Flexible Roads, 2000; Ozdemiroglu and Bullock, 2002; Santos et al., 2012). One of the primary reasons for this is the development of traffic flow relationships and data on the valuation of time, along with a common acceptance of their consequences. In the case of congestion for example, there is significant research into the value of time of road users at a great level of granularity, as well as algorithms to predict delays to road users due to congestion, roadworks and accidents (Mackie et al., 2003; DfT, 2012a). Over time, these costs have been integrated within appraisals alongside direct costs.

1.4 Pavement maintenance strategies

A PMS forms one of the key elements of road asset management, and extensive data measurement and capture means that the quantity of data stored is often very large. To make best use of the stored data, a PMS attempts to replicate the real-world engineering knowledge through a set of rules and algorithms to help understand what is happening on the network.

The scope of available PMSs vary, ranging from something that holds basic pavement inventory and condition data to more comprehensive systems, including complete analysis packages for examining the effects of different management scenarios. Regardless of the exact setup of each individual PMS it is widely acknowledged (e.g. Phillips, 1994; Sinhal, et al., 2001;) that the benefits include:

- Improved knowledge of the network, through collection and storage of asset inventory and condition data;
- Enhanced representation of management objectives;
- Improved programme planning activities; and
- Budget savings.

One reason why these tools help realise benefits is that they allow plans and strategies to be investigated to understand how the network will perform under different future strategies (e.g. a decrease in future maintenance budgets).

Being able to analyse different maintenance strategies (and their resultant impacts across a network) provides invaluable information to decision makers and helps identify where investments can provide the greatest benefits. If networks can be managed to deliver an optimal maintenance strategy which takes account of trade-offs in the level of deterioration then it helps manage budgets more efficiently, providing greater returns on investments. Research in three states looked at pavement-preservation programmes that had been implemented, which all aimed to preserve investments in highways by the application of selected surface treatments that maintained or improved the life of the pavement. Through the resulting analysis, Davies and Sorenson (2000) showed that preventative maintenance projects are up to fourteen times cheaper (per lane km) than rehabilitation or reconstruction treatments.

1.4.1 Whole-life cost of road pavements

To properly assess any appraisal option, consideration should be given to all associated future costs. Whole-life analyses consider costs that would be incurred over the life of an asset and can support the identification of the most cost-effective option (Flanagan and Norman, 1983). For road pavements, the total costs associated with alternative maintenance profiles over an analysis period (typically 30 to 60 years) can be estimated and compared.

The costs considered in a whole-life approach can be categorised as either direct or indirect costs. Direct costs are those that have to be met by the highway authority (e.g. the costs of the maintenance) whereas indirect costs are those which are caused by the actions of the highway authority but which are not necessarily met directly by the highway authority (although some highway authorities might have to pay penalties for road closures; unlike the NRA). They may fall upon society in general (e.g. the costs to the national economy due to delays on the road network in the UK have been estimated to be up to £8 billion per year (CBI, 2012)). By considering both direct and indirect costs in this way, the approach attempts to address the needs of both highway authorities and road users.

1.4.2 Whole-life value

In recent years there has been a shift in the importance placed on other value criteria such that assessments consider additional measures that aim to take greater account of sustainability in the optimisation. GHG emissions from maintenance and traffic noise are examples of the types of measures that have grown in importance, often being driven by legislation (for example, Directive 2002/49/EC (2002) on traffic noise mapping).

This change has led to a growing recognition of the need to prioritise maintenance schemes not just on a cost basis but using a more complete consideration of whole-life value and sustainability in the appraisal (Chang and Kendall, 2011). Whole-life value assessments can be thought of as an extension of whole-life cost that includes monetised costs of other impacts. However, issues can arise when it is not possible to monetise all impacts.

1.5 Research aim and objectives

Transport externalities have been identified as key parameters for inclusion within transport appraisals (CE, 2007). Incorporating externalities into appraisals is a means to limit the otherwise negative effect that externalities can generate. In terms of the externalities identified in the paper by CE (2007) congestion and accidents are listed as

the dominant cost components. Accidents can and are routinely included in road appraisal assessments and so there has already been considerable research into this. The costs of congestion from maintenance (i.e. the impacts on road users of additional delays at roadworks) are also routinely included in road investment appraisals and models.

The next largest impacts are noise and climate change and therefore one of the aims of this research is to incorporate the externalities of GHG emissions from maintenance and traffic noise into a pavement whole-life value model in order to include their impact in the development of network maintenance programmes. Rather than considering these important environmental effects through disjointed assessments, this research aims to develop a framework for integrating carbon and noise alongside the more traditionally modelled aspects of works costs and user delay costs (as a proxy for additional congestion at roadworks).

1.5.1 Research objectives

To fulfil this aim, the following specific objectives were proposed:

1. To review current knowledge on externalities and look for options to incorporate them in pavement maintenance assessment, to take account of their impact in assessing maintenance schemes;
2. To develop a network level pavement model specific for use on the Irish national network;
3. To develop methodologies that allow carbon emissions and traffic noise from maintenance to be integrated within a network level pavement whole-life value model. The methodologies need to make sure that the costs of carbon and noise impacts of maintenance are modelled in a way that is comparable to other direct (e.g. works) and indirect (e.g. delay) costs, and suitable to be used to prioritise maintenance options;

4. To develop a strategy to address the impacts on the resulting maintenance programme of carbon emissions and traffic noise from maintenance. The impacts will be demonstrated through case studies based on data from the Irish national network; and
5. Make recommendations for future consideration of carbon and noise in road maintenance assessment, based on outputs from the modelled case studies and any general implications for modelling externalities.

In summary, this thesis describes the research undertaken to develop a model specific for the Irish national network that includes carbon and noise impacts within the selection and prioritisation of road pavement maintenance options.

1.6 Organisation of this thesis

This thesis is divided into 8 chapters, and the chapters that follow this introduction are briefly described in this section.

Chapter 2 presents a background to the principles underlying the management and modelling of road pavement network maintenance strategies. This will provide the reader with a greater understanding of the terminology used in this thesis. It provides a review of models that are currently used or documented in literature and presents the justification for some of the modules in the model.

Chapter 3 discusses externalities and how they are currently dealt with in road transport asset management. It introduces the benefits that can be delivered by widening appraisals to include 'value' and discusses how environmental externalities are currently being considered by different highway authorities.

Chapter 4 describes the consultations undertaken to determine the importance that different stakeholders place on 'value' criteria, specifically carbon and noise. The results from these consultations are discussed in relation to how they were used in the development of modelling methodologies.

Chapter 5 presents the base model that was developed as part of this research. This includes the 'base' functionality that is associated with current pavement cost models and is the tool into which the new methodologies are incorporated.

Chapter 6 discusses the modelling methodologies that form the main novelty of this research. These methodologies are informed from both the literature reviews and the consultation exercises and have been developed to allow carbon and noise to be included as parameters within the modelling of pavement maintenance schemes. Particular attention has been given to expressing the scheme costs and benefits in a way that is compatible with other costs and benefits modelled at a network level.

Chapter 7 discusses the results from the case studies and the influence that carbon and noise have had on the development of a pavement maintenance programme.

Chapter 8 presents overall conclusions from this study. Recommendations are made on how the knowledge resulting from this research can be further developed.

Chapter 2 Pavement maintenance models

The first research objective involves incorporating externalities in pavement maintenance assessments to take account of their impact in predicting maintenance schemes. In order to understand the options for that, it is first necessary to understand how road pavement maintenance models have been developed and the core components they contain. Therefore, this chapter reviews the available literature on pavement maintenance models and concludes with a review of current systems.

The approach to the literature review in chapters 2 and 3 was based on developing an in-depth understanding, using information in the public domain, related to pavement maintenance systems and externalities, in order to provide the reader with a comprehensive background to the topics. In addition, it also set out to identify relevant new research and the importance of that research in relation to the research objectives. As well as providing a robust background to the topics, the critical review of literature was key to identifying and describing gaps that existed and using these to help refine the research.

The literature review started out by searching for sources on the key topics by using online library catalogues and keyword searches accessed through TRL and the Open University. This was an iterative searching process as new topics and keywords became apparent. This primarily returned journal papers, reviews and books and the gathering of this information allowed me to identify key texts and authors in the respective fields. Manual searching through relevant journals and conferences presented additional information. General reading around the subject areas throughout the research, coupled with my experience on other related research projects, enabled more recent texts to be included as relevant.

2.1 Pavement networks

Road pavement networks are a vital part of a country's infrastructure and although they can vary considerably (e.g. sealed/unsealed, single-lane/multi-lane, light-traffic/heavy-traffic) they always command a high level of importance. As pavement networks have expanded and become more heavily trafficked, road users' expectations on service levels have also grown; meaning they expect, for example, reliability and consistency in journey times and safer travel conditions.

Key to being able to deliver acceptable levels of service to road users is effective management of the network, which in turn is dependent on the quality and robustness of the underlying data.

Among other things, data is required to:

- Identify when and where maintenance is needed;
- Make decisions on the type of maintenance intervention that will provide the best return on investment;
- Plan the maintenance at times that cause the least inconvenience to road users, allowing networks to be kept operational more of the time; and
- Better understand the impacts (positive and negative) of the road pavement networks.

Other factors such as the increased reliability associated with modern day materials and maintenance practices also play a vital role in keeping roads in a serviceable condition while reducing negative impacts upon road users. However, good data is the most valuable resource in planning modern day pavement maintenance.

The vast size of the pavement networks around the world means that huge amounts of data are collected, whether this is from automated machine surveys to manual visual surveys. In 2013 the total length of the top ten largest road networks in the world was estimated at over 20 million kilometres (Central Intelligence Agency, 2013). This

quantity of data presents significant demands on data management systems to provide an ordered structure over the data and undertake otherwise time-consuming analyses.

The focus for the remainder of this chapter provides a commentary on what is state-of-the-art, reviewing the literature for processes, data and analysis aspects of how pavement maintenance is planned and some of the pavement management systems that are currently in use.

2.2 Historical overview

When making decisions it is common for the decision maker to consider the potential positive and negative implications. Although we may not realise it, these considerations form relatively simple analyses that have been undertaken for centuries. For example, early settlers would have considered the availability of food and water when choosing where to live, in addition to factors such as the ability to defend the location and the availability of materials. A more modern example is purchasing a car, where the buyer is likely to consider aspects such as servicing, car tax and fuel economy and the impact they will have during the lifetime of the car, in addition to the initial purchase price.

It all translates into weighing up the future costs and benefits in order to come to a decision. The advent of monetary systems and markets for goods and services provides a basis for formalising the data into cost-benefit analyses.

Formal cost-benefit analyses were officially first authorised for use in the USA in the 1930s when dam construction engineers were tasked with making sure that costs and benefits for anyone affected were considered during the planning (Hanley and Barbier, 2009). In the UK, Robinson (1993) reports that life cycle costing was used in the late nineteenth century when engineers in London assessed the initial construction and maintenance costs of stone sett pavements compared to water-bound macadam. This example from before 1870 used 40 years' worth of records to look at the effect of different types of traffic on the whole-life costs. The resulting study showed that stone sett pavements were more suited to heavy traffic situations due to their low maintenance

costs, even though they had a high initial cost. Water-bound macadam was found to be more suited to lower trafficked roads. The use of whole-life costing accelerated through the 1960s and 1970s due to the advent of modern computers.

The processes and systems have evolved with time and for road pavements this led to the development of PMSs. These were first implemented in the 1970s (FHWA US, 2012), providing the means of storing vast amounts of the data that is collected about a road network and using that to develop analyses and support decision making.

An initiative in the UK in the 1980s looked at developing a new PMS for use on all road types (Phillips, 1994) which resulted in what became known as the United Kingdom Pavement Management System (UKPMS). UKPMS was designed to produce one consistent framework under which systems could be developed which would make use of both existing visual survey data and machine surveyed data.

The UKPMS framework is still used routinely on the Local Authority (LA) network but the needs for the national network were different and a separate system was developed for use on those roads, called the Highways Agency Pavement Management System (HAPMS). HAPMS is also still in use and the work that has gone into developing performance relationships (such as the deterioration of rutting and deflection) has been used in different studies and for different networks.

In many cases the developed pavement cost models have evolved to include additional analysis tools to simulate condition deterioration, treatment selection and scheme prioritisation. The benefits of including all these tools alongside the data is that it allows users of PMSs to investigate a range of 'what-if' scenarios and support the decision making when planning maintenance.

2.3 Data

Robust data is critical to successful modelling. As with any such system, the output quality is reliant on the quality of data held within the system. Therefore both good

quality data and effective data management are crucial to the success of any such system and this is often the biggest challenge (Amador & Mrawira, 2008).

The main categories of data held within a PMS are:

- Network definition;
- Location;
- Condition;
- Construction;
- Network demand (e.g. traffic);
- Performance relationships;
- Policies and standards (e.g. maintenance standards); and
- Budgets.

On other specific networks there may be other data types that are stored; one example being climate data but this tends to be more relevant to networks that experience extremes of temperature or rainfall, unlike the Irish network. In Finland for example, following the winter freeze-thaw cycles there can be significant movement and deterioration in the road surface but the engineers know that large parts of these defects will settle over the warmer months and therefore in this case treating them when they first appear would be an over-reaction (authors own experience). In addition, any climate data for those types of road authorities is a driver for keeping the network open rather than as a direct mechanism for planning maintenance.

In PMSs the data used to identify immediate and future maintenance needs of pavements are often stored in a relational database (Manariotis et al., 2002) allowing data from different sources to be held in multiple tables and linked by common attributes.

At the outset of developing a PMS there tends to be a lack of good quality data; for example, the extent and location of defects, or a lack of time-series data over which to determine or validate deterioration relationships. At the outset of this research there was a lack of time-series data from which to begin to investigate performance relationships on the Irish network. During this research the National Road Authority, Ireland (NRA) have been undergoing a process to procure a PMS for use on their network and this has resulted in changes to their survey regimes and subsequent improvements in the data as that process evolves.

2.3.1 Condition data

Condition data is the main driver in underpinning the need for pavement maintenance. In combination with relationships on how the condition is expected to change with time and use, the data enables a PMS to be used to identify when different lengths of a network will exceed different pre-defined condition thresholds, thereby triggering the need for maintenance.

Rebbechi (2006) stated that a PMS should consider the following measures of condition when monitoring asphalt surfacing of pavements:

- Structural capacity/integrity;
 - Cracking (waterproofing);
 - Deformation/rutting;
 - Resistance to load;
- Serviceability;
 - Roughness (ride comfort);
 - User costs;
 - Condition;
- Surface condition;

- Flushing;
- Ravelling;
- Delamination;
- Safety;
 - Skid resistance;
 - Texture.

There are many factors that influence what data is collected by a highway authority and a PMS has to be customised for the particular network and be adaptable to cope with changing data availability and requirements over time. The vast number of highway authorities and the array of PMSs mean that many different approaches have been adopted.

Wang and Qiang (2008) used major distresses (e.g. fatigue cracking, rutting) and roughness to evaluate pavement performance. Similar data was used in Saskatoon (Prang et al., 2007) where an index was based on roughness and surface distress data.

Hunt and Bunker (2004) suggested there is anecdotal evidence that roughness deterioration as predicted by many theoretical models is rarely seen in practice e.g. relationships predict a rapid deterioration in roughness towards the end of the theoretical life of pavements but engineers seldom witness such behaviour on-site. In their research they argued that historic roughness can be represented by a linear relationship, although they could not establish a robust relationship for predicting future roughness. Hunt & Bunker also confirmed that roughness is the most widely used parameter, primarily because it's relatively inexpensive to collect, it's objective and is widely accepted as the most relevant measure of long-term pavement functional behaviour.

A significant number of pavement cost models tend to focus on the surface distress and ride quality parameters (e.g. ravelling, rutting, roughness, profile variance) leaving out consideration of the structural capacity of the pavement.

2.3.2 Structural data

The collection of data representing the structural condition of pavements is a more complex and expensive process than that for the collection of surface condition data. Structural data is not collected on a routine basis and is obtained for discrete lengths of a network, either using slow survey methods or invasive investigations. Many models therefore make use of surface condition data only and any modelling of structural data within a PMS has to contend with limited data availability.

However, the inclusion of structural data has been recognised as a means to improve the accuracy in identifying maintenance needs, both in terms of location and treatment design (e.g. Snaith and Orr, 2006) because the surface measurements themselves cannot be expected to give an accurate picture of the pavement layers below.

There are a number of non-destructive methods that can be used to gather information on the structural properties of a road pavement:

- **Ground Penetrating Radar (GPR):** GPS is a method that produces a representation (e.g. an image) of the subsurface by emitting radar pulses. Electromagnetic radiation is emitted which gets reflected, refracted or scattered and this is detected back at the surface. It is the changes in these signals that allow GPR to build up a better understanding of subsurface changes in materials. It can provide logistical advantages over traditional methods of coring or test pits but there are known limitations for its application (it does not work well in wet, clayey soil conditions where the dielectric contrast is negligible) (Prang et al., 2007).
- **Falling Weight Deflectometer (FWD):** The FWD generates a pulse by dropping a weight onto a damped spring on a loading plate which aims to represent a load that would be produced by wheel rolling over. (Rolt, 2004). The deflection bowl that results is normally measured by 7 geophones at set positions from the loading plate. It is undertaken at specific points on the network by transporting (often towing) the device. The resulting data can be used to determine structural

information such as a measure of the stiffness of a road surface, with the data usually loaded into computer software to undertake the calculations (authors own experience in Mauritius and Nigeria). This type of device is used commonly around the world in both developing and developed countries.

- Deflectograph: The deflectograph uses a beam resting on the road surface to measure the deflection, which in turn can be used to estimate the residual life of a road pavement. As the rear wheels approach the beam a deflection measurement is made. The measurements are generally made every 3-4m but the deflectograph vehicle only travels at up to 2.5km/h (WDM, 2011) therefore limiting the quantity of data that can be captured daily. Similar to the calculations made from FWD data, computer software is used to correct the measured data for temperature before estimating a residual life of the pavement based on the structural measurement.
- Traffic Speed Deflectometer (TSD): The TSD is a newer research tool that uses laser technology to measure the deflection response of road pavements. It is designed to work at traffic speeds, leading to a significant increase in the data collection rates, but relationships for its use are still being standardised (Kelley & Moffat, 2012). Due to running at traffic speed it can output continuous deflection profiles along a pavement and at a much faster rate than any of the previous methods. The novelty with this method is that it measures the velocity of displacement as opposed to the actual deflection. By measuring the velocity of displacement, the actual displacement can be derived through post-processing of that data (Greenwood Engineering, no date).

Omission of consideration of structural condition potentially results in either sub-optimal treatments or timings being suggested from the data. The city of Saskatoon, Canada, investigated the use of GPR and FWD data for their network, particularly where there were known heavy axle loadings from trucks (Prang et al., 2007). They found that GPR provided pavement condition data for similar outlay to other surface condition survey

techniques. However, urban environments are often characterised by more complex subsurface conditions, such as buried utilities, potentially making the interpretation of GPR more complex where the noise in the images increases as a result of those features. Roackaway & Rivard (2010) created a controlled section with common urban features (such as voids) in order to obtain GPR images from these known features. The images were then used to test areas of downtown Louisville in Kentucky, with both positive and negative results, highlighting the complexity of applying GPR in urban environments. Ground-truthing (validating the GPR results using other methods, such as coring) allows for increased confidence to be given to the GPR results (although perhaps at the expense of a fully non-destructive set of results) but this was not considered by Prang et al. (2007), although Prang et al. did also make use of FWD measurements in the same study.

Many studies document that structural data was included in analyses only after an initial model was developed with surface condition data (e.g. Sonyok and Zhang, 2008; Zaghloul et al., 2008) with the aim to try and improve the accuracy of the initial outputs. Understanding the need for including structural data evolves as understanding of the pavement analysis improves.

2.4 Deterioration relationships

Future maintenance is predicted by applying deterioration relationships to pavement condition data to simulate the actual performance of road pavements. However, the deterioration processes are complex and there is often no obvious single analytical solution (Wang and Qiang, 2008); some level of simplification is often required.

Even lengths designed to the same standards and experiencing similar usage can display different behaviour over time, influenced by factors such as the quality of work, materials, construction and maintenance. Kennedy (2004) demonstrated some evidence that pavements deteriorate faster for an asphalt surface than a chip seal, and that as expected those with a high traffic loading also deteriorate faster. In Queensland

(Australia) Martin et al. (2004) determined trends for both rutting and roughness but different treatments or road types were not significant factors. In a further Australian study, Hunt & Bunker (2004) found a wide variety of rates for pavements of similar ages reinforcing that other factors also influence deterioration.

A lot of the variation in the deterioration comes from understanding when the pavement indicates initial deterioration. Once it has begun to show signs of a defect then it is fairly reasonable to assume that it will continue to get worse. From that perspective the deterioration can cover two different aspects of change in a particular defect (Martin et al., 2004):

1. Initiation: Time or traffic carried to the onset of the defect; and
2. Progression: On-going deterioration of the defect.

It is widely accepted (e.g. Madanat et al., 1995; Martin et al., 2004; Henning et al., 2006) that both of the two aspects are relevant for cracking and fretting¹ but only the 'progression' stage is applicable for skid resistance, rut depth, longitudinal profile variance and deflection.

The format of relationships used to represent individual defects can vary in format from complex algorithms to simple linear approximations (European Commission, 1999). An 's' shaped curve is a common representation of deterioration. It begins with little or no deterioration in the early life of a pavement, followed by progression of deterioration from a later point. Whether the deterioration continues or levels-out later depends on the defect and factors such as those already discussed.

In order to derive deterioration relationships a suitable quantity of time-series data is required, along with confidence in the location of surveys carried out in consecutive years (Kenedy, 2004). Due to differences and inconsistencies in the survey intervals

¹ Fretting is where material is lost from the pavement surface, often simply due to the ageing of the surface.

along a length of road, accurate point-by-point comparisons cannot usually be made and some degree of statistical representation over longer lengths is recommended.

Despite all the preceding caveats, there has been enough research to say that general deterioration of pavements does occur. The difficulty is in determining general trends for wider use, resulting in studies determining relationships for specific local networks.

Given that the level of maintenance is fairly consistent on networks (based on historic budgets (DfT, 2012b)) similar lengths of the network must be moving from an acceptable to unacceptable condition each year which is one indicator of changing network conditions.

These examples demonstrate the difficulty in generating deterioration models and the importance of making sure any relationship is customised for local networks. Three key points were clear from the reviewed literature:

1. There are no discernible trends robust enough to apply in every situation;
2. It is generally agreed that deterioration of condition will occur, but at times even this can be so slow that it has been hard to prove at times for specific parameters; and
3. When deterioration does occur for a pavement, more than one mode of deterioration can act on the pavement at the same time.

2.4.1 Individual defect relationships

This section looks at individual defect relationships and the examples given are from a number of different models or studies and have been chosen to be representative of different networks and geographical locations.

In addition, the PARIS Project (Performance Analysis of Road Infrastructure) has been used as a source of reference throughout this section. The aim of the PARIS project was to develop deterioration models for use in pavement management systems at a Europe-wide level (European Commission, 1999) and resulted in data from 15 countries being

used in the research. The documentation of the developed PARIS deterioration models in this section provides a reliable Europe-wide comparison across the documented defects.

2.4.1.1 *Roughness*

The longitudinal profile, or roughness, is a measure of the unevenness of a road. Although it can be measured differently by different equipment, the outputs can be compared by being expressed as the International Roughness Index (IRI). Roughness is an important characteristic because it can result from structural deterioration and can influence the comfort of road users. When the unevenness increases it can also affect vehicle operating costs due to an increase in fuel consumption and wear on a vehicle.

The Highway Development & Management software (HDM) defines roughness as a function dependent on the following characteristics (World Bank, 2008):

- Age;
- Strength;
- Traffic loading;
- Potholes;
- Cracking;
- Ravelling;
- Rutting; and
- Environment.

This model has been used across many different countries and road networks and is probably the most recognised roughness model. However, it does rely on a number of different inputs and validation is also reliant on HDM-4 being calibrated for local conditions. If the correct input and calibration data is available then validation of this model has shown a good relationship between modelled and observed roughness values in studies (e.g. Aggarwal et al., no date). However, the significant level of calibration and

data inputs have led to the relationship being modified or other roughness models proposed.

Patrick & Bailey (2003) analysed roughness and rutting from New Zealand, focusing on roughness deterioration. For modelling roughness they used an equation (from HDM-3) that did not rely on knowing the roughness value at the time of construction and found that it was more appropriate than other HDM model forms in predicting the roughness levels of the pavements (Eqn. 2.1).

$$RN(Y2) = (RN(Y1)e^{(0.0153(t2-t1))}) + (5.7(1 + SNC)^{(-4.99)}EDA(t2 - t1))e^{(0.0153t2)} \quad (2.1)$$

where:

$RN(Y2)$ = roughness data at period 2 (unit-less)

$RN(Y1)$ = earliest roughness data (unit-less)

SNC = structural number² (a representation of the structural capacity of the pavement) (unit-less)

EDA = ESA's = equivalent standard axles (unit-less)

$t1$ = $Y1 - Y0$ (years)

$t2$ = $Y2 - Y0$ (years)

$(t2 - t1)$ = $Y2 - Y1$ (years)

$Y2$ = year of predicted roughness

$Y1$ = year of earliest roughness data

$Y0$ = year of construction or overlay

² The structural number represents the structural strength of the road pavement required to meet the design traffic loadings (Pavement Interactive, 2009)

The authors stated that this model was more appropriate on the roads in New Zealand which were generally well maintained.

Data analysis from the Australian road network described roughness as being a function of (Shiyab, 2007):

- Initial roughness index (IRI);
- Traffic loading; and
- Age (this was considered the main performance predictor as it takes account of traffic loading and climate, and their interactions).

Shiyab commented that the original HDM-3 roughness model (as used by Patrick & Bailey) requires significant data to be collected (e.g. initial roughness, pavement strength) which can present problems. Consequently it is often simplified, although the simplifications usually still require the structural number, which itself is not easily obtainable. Therefore Shiyab attempted to simplify it further based on using the initial roughness, traffic loading (ESAL's) and age. The full set of proposed IRI deterioration relationships is shown in Appendix B, an example of which is shown below based on using age as the variable:

$$IRI(\text{slow lane}) = 0.0035 \text{ Age}^2 + 0.0215 \text{ Age} + 0.769 \quad (2.2)$$

where:

IRI = roughness (unit-less)

Age = age of the surface (years)

In contrast to the previous models, the PARIS European study concluded that a linear progression was suitable to model the development of IRI with time (European Commission, 1999) (Eqn. 2.3).

$$y = A + Bx \quad (2.3)$$

where:

y = measured IRI value (unit-less)

x = age of the last overlay or age of the construction (years)

A = model parameter (intercept)

B = model parameter (slope)

Despite what might be expected, the PARIS relationship for IRI (Eqn. 2.3) did not take account of the condition of the overlay when it was undertaken. It is unlikely that a poor condition road would deteriorate at the same rate after an overlay as a better condition road that had an overlay. However, one reason why the condition may not have been included is because generally the maintenance treatments would be undertaken on lengths of road towards the poor condition end of the scale; because the start condition could have been similar in those cases it may have not been a dominant variable in their analysis. The effect however (if that is the case) is that this equation may not predict well in situations where the condition before overlay is significantly different from the reference dataset. This highlights an issue with transferring relationships between networks without some attempt to validate them.

As with the work of Patrick and Bailey, the relationship was tested against data from test sections that were mostly located on primary national routes and therefore mostly well maintained. A total of 578 flexible³ test sections and 77 semi-rigid⁴ sections were used in the analyses and most of those sections (from across Europe) showed a linear response.

³ A flexible pavement is one where the total structure experiences some deflection when loaded. The load is spread out through each layer meaning that lower layers experience lower loads.

From the data analysed within the study it was found that ninety per cent of the test sections exhibited a change in IRI of less than 0.1mm per m per year. In reality the change is deemed negligible, and at many locations it was not statistically different from zero, echoing the sentiments of some of the earlier discussions that it is sometimes difficult to find any deterioration for certain networks or defects.

2.4.1.2 *Rutting*

Rut depth is an important characteristic of pavement performance. It is a major driver of maintenance on some networks (e.g. English Trunk Roads) because it is considered to be a good indicator of structural condition for non long-life pavements and has implications for safety impacts and user functional requirements of ride quality. It occurs in the wheelpaths due to loading from the traffic and can affect the steering of vehicles in severe cases. As such it has safety implications.

Henning et al., (2007) described rut progression and deterioration for New Zealand as a three stage process:

- 1) Initial densification (in mm);

$$\text{Initial Rut} = 3.5 + e^{(2.44 - 0.55 \text{ SNP})} \quad (2.4)$$

where:

SNP = structural number (unit-less)

- 2) Stable or constant rut change (in mm per million ESA); and

$$\text{Rate (thickness} \leq 150\text{mm)} = 9.94 - 1.38 \times a_1 \text{SNP} \quad (2.5)$$

4 A semi-rigid pavement has a more rigid structure in the subgrade, often from chemical stabilisation of the sub-base or subgrade layers. Whilst not being a fully rigid pavement, it does mean that the loads get spread over a wider area of the subgrade.

$$\text{Rate (thickness > 150mm)} = 14.2 - 3.86 \times a_2 \text{SNP} \quad (2.6)$$

where:

SNP = structural number (unit-less)

a_1, a_2 = calibration coefficients

3) Initiation or accelerated rut progression.

$$\text{Rate} = \frac{1}{1 + e^{(-7.568 \times 10^{-6} \times \text{ESA} + 2.434 \times \text{SNP} - [(4.426, 0.4744) \text{ for thickness} = (0, 1)])}} \quad (2.7)$$

Where:

SNP = structural number (unit-less)

ESA = equivalent standard axles (unit-less)

Thickness = 0 for base layer thickness < 150mm, 1 for > 150mm

Using revised data for thin chip sealed (surface dressed) pavements, Henning & Roux (2008) did not improve on the models with the dataset available. They did note however, that on thicker asphalt-surface pavements, only slight increases in the rutting rate were experienced with time, implying a much more linear-like relationship.

Indeed, the PARIS report (European Commission, 1999) found that linear and power functions best described the evolution of rutting and overall the study concluded that a linear relationship was appropriate to model the progression of rutting (Eqn. 2.8).

$$r = C + Dz \quad (2.8)$$

where:

r = rut depth (mm)

z = age (years) or number of 100kN ESALS

C = model parameter (intercept)

D = model parameter (slope)

The resulting coefficients are shown in Table 2-1.

Table 2-1: PARIS rutting rates

Pavement Type	Traffic based (mm per million ESALS)			Age based (mm per year)		
	Min	Max	Median	Min	Max	Median
	Flexible	-1	14	6.5	0.2	0.9
Semi-rigid	3	10	4.9	0.2	0.7	0.55

(source: European Commission, 1999)

The minimum traffic based rate of -1 mm per million ESALS for the flexible pavement translates to mean that running vehicles on the pavement actually improves the rutting. In reality this is not going to be the case but there was an absence of explanation in the report. One possible reason could be due to measurement error, especially on the flexible pavements. With rutting on these pavements the effect of developing a rut can cause the material to laterally spread and bulge at the side edges of the rut which can cause the transverse measurement to record either a lower, or a positive rut compared to a previous measurement.

On UK local government roads, a network the NRA Ireland anecdotally compare a lot of their own network to, Stephenson et al., (2004) reported a linear increase over time for rut trends and analysis of smoothed 10m readings found the average rut increase was approximately 0.6 mm per year. This data aligned well with the wider reaching PARIS study, although the PARIS study did focus on national routes, as opposed to local routes.

Whilst rutting and other defects might be argued to deteriorate non-linearly, anecdotal evidence at a network level (authors own experience) and the reports described in this chapter show that for network level models they are commonly approximated to a linear degradation relationship.

Parkman et al., (2011) used data from the Highways Agency network across 45 sites collected between 1994 and 2006 to investigate rut trends for different pavement types. Analysis of the data showed time based relationships were more appropriate than traffic based relationships; for surface dressing and hot rolled asphalt surfaces a rate of 0.59mm per year was derived. Although to some critics a linear relationship oversimplifies the pavement characteristics, for network level analyses the studies presented show good agreement on the relationship type and rates achieved.

2.4.1.3 Skid resistance

Skid resistance is a major driver of pavement maintenance because of its direct impact on braking distances of vehicles. On the UK network, and more recently in Ireland, lengths of a pavement network are given an associated skidding investigatory level based on a number of characteristics (e.g. road layout, speed limit) and if the skid resistance falls below this level it requires investigation for maintenance (DfT, 2004).

The relationship used for predicting skid resistance in the UK has changed very little since the 1970s (Szatkowski and Hosking, 1972) (Eqn. 2.9).

$$sfc = 0.033 - 0.664 \times 10^{-4} q_{cv} + 0.98 \times 10^{-2} PSV \quad (2.9)$$

where:

sfc = skid resistance value⁵ (unit-less)

⁵ Used to represent the skidding resistance of a road as measured by the Sideways Force Coefficient Routine Investigation Machine

q_{cv} = commercial vehicle flow per lane (cv per lane per day)

PSV = polished stone value⁶ (unit-less)

Although the original equation has changed very little, some studies have attempted to further customise it for local conditions. For example, the New Zealand Transport Agency (2004) found that the predicted skid resistance values were being over predicted and produced their own equation (Eqn. 2.10).

$$MSSC_{av} = 0.0013 \times PSV + 0.10 \times e^{-CHCV} - 0.007 \times ALD + 0.44 \quad (2.10)$$

where:

$MSSC_{av}$ = average $MSSC$ ⁷ derived from 1998, 1999, 2000 and 2001 surveys

PSV = polished stone value (unit-less)

CHCV = cumulative heavy commercial vehicle traffic per lane in 32illions

$$= 0.0003 \text{ (operational days per year [300] / } 10^6) \times \text{Heavy Commercial Vehicles (>3.5 tonnes per lane per day) } \times \text{Surface age (years)}$$

ALD = averaged least dimension of the aggregate chip in the chip sealing⁸ (mm)

Skid resistance is generally measured in the summer months to record the lowest value, when there is less rain and more dusty material, resulting in a more polished surface with a reduced skid resistance (DMRB, 2004a) although the actual minimum skid resistance value can vary between years. Whilst the climate may have changed from the

⁶ The polished stone value grew out of research into road materials and skid-resistance. It is a measure of the resistance of the aggregate to polishing (from vehicle tyres).

⁷ Mean summer SCRIM coefficient, measured in this period because skid resistance is generally at its lowest during the summer

⁸ Chip sealing can be equated to the UK surface dressing treatment types

1998-2001 survey data used, the influence of climate is on when to take the measurements rather than as an explanatory variable.

2.4.1.4 Cracking

Cracking can take on a number of different forms (e.g. alligator cracking, longitudinal cracking and transverse cracking) and the different types of cracking can be influenced by factors including age, traffic loading, poor construction and binder content.

The modelling of cracking is often described in terms of the two different methods of deterioration – initiation and progression. Crack initiation is defined as being the first occurrence of longitudinal cracking, transverse cracking or alligator cracking (with a minimum length of 0.5m) (European Commission, 1999).

For wheel-path cracking progression a linear model was deemed the most appropriate form by the European Commission (1999); the important variables being the level of distress at the last inspection and either the age of the pavement surface or the number of ESALs carried by the pavement. For transverse cracking the main variables were climate and cumulative ESALs.

The most widely used models for crack initiation originate from HDM (Henning and Roux, 2008) which defines crack initiation as occurring when a surface cracks on more than 0.5% of its area. This deterministic model is primarily based upon knowledge of the structural number and the number of ESAL's (Henning and Roux, 2008). In developing a new model it was stated that one of the significant influences on crack initiation of asphalt surfaces is knowledge of the cracked status prior to an overlay.

2.4.1.5 Ravelling

Ravelling is where the aggregate particles separate and there is a loss of binder or aggregate from the surface of the pavement. The loss of aggregate can affect the ride quality and the structural quality of the surface and lead to an increase in noise levels,

and in cases of severe ravelling, the formation of potholes (European Commission, 1999). Key factors that influence ravelling are:

- The age of the surface;
- Asphalt density;
- Bitumen (or binder) content; and
- Air voids in the mix.

The report by the European Commission demonstrated the progression of ravelling values using both a logistic model and a linear model (Eqn. 2.11 & 2.12).

$$v = \frac{1}{\frac{1}{K} + E.F^x} \quad (2.11)$$

$$r = E + F.x \quad (2.12)$$

where:

v = total extent of ravelling (%)

x = age of last surface treatment, last overlay or construction (years)

E, F = model parameters

K = upper limit of ravelling that an occur (% , set at 100%)

It was concluded the logistic model provided greater accuracy at the lower and upper limits. The factors that influence ravelling relate to the properties of the asphalt mixture, as opposed to long-term performance factors such as traffic. As such, simply transferring the relationships between networks that use different materials and treatments may prove problematic, especially if there is limited data to validate the rules.

2.4.1.6 *Summary*

Validation of the models from the HDM models have shown a good relationship between modelled and observed data following calibration (e.g. Aggarwal et al., no date, Patrick & Bailey, 2003). The HDM models are not usually applied to networks with good condition roads (such as those in Ireland) although a recent study attempted to calibrate the models to road conditions in England for the Department for Transport (Odoki et al., 2012). In that study, deterioration models for rutting, cracking and roughness were calibrated using historic time series data, but other deterioration models were calibrated using more basic data and expert opinion. Detailed calibration of any models for the Irish network will be problematic without suitable time series data.

One of the issues with the particular HDM roughness relationships used is that they often required a significant amount of input data to be collected, in some cases also requiring information on the structural properties of the road pavement. For that reason, they have been simplified in some studies (e.g. Shiyab, 2007). Whilst this simplification allowed use on networks where there wasn't the full suite of original input data required, the effect on the results was not clearly documented. A sensitivity analysis of the simplified inputs would have increased the robustness of the outputs.

The PARIS project (European Commission, 1999) produced linear models for a range of defects (e.g. roughness, rutting) which were validated using data from a total of 655 sections from primary routes across Europe. Whilst these relationships were validated from a large source of data from different countries their very simple function can work against them in terms of their perceived robustness. Linear equations do have some assumptions that could impact on the model outcome that should be noted. Firstly, there is the assumption that the variables used as the predictors are assumed to have no errors in their measurement. In reality, especially for road parameter measurement (whether machine or visual based) this is unlikely to be the case and there is therefore a risk that some of the predictions are based on values that include an error term. Machine

surveys can take account of some measurement error in the delivery of data but this should be noted when considering any dataset for use.

Secondly, the same linear regression line can be determined from very different data sets and therefore for some of the simpler, single-variable linear equations it might be statistically stronger to include additional explanatory variables, such as with some of the more detailed relationships developed for the HDM models. However, with rutting especially, a number of other studies agree with the linear approach and this type of simpler relationship would be more suited to the development of a model for a network lacking in time series data. The relationship could subsequently be refined as more data is gathered and as better data and more variables are collected they could be tested for inclusion in the regression, but this would need to be a procedure that is checked and repeated as the datasets evolve.

One of the problems with validating any type of relationship for use on a network is that each specific data validation is affected by other effects that may or may not have been the same in other situations (e.g. climate, material specifications). In addition, the averaging effects over long time periods can result in very little change being seen across individual variables required for modelling the more complex relationships.

2.5 Maintenance treatments

Maintenance of road pavement networks has become more important following a decline in new construction and a move towards making best use of existing assets. In order to maximise the use of assets and get the best return on maintenance investments, the right treatment needs to be applied at the right location at the right time.

Deterioration relationships are used with current condition data to simulate the performance of the network and predict future requirements by identifying locations on the network that require maintenance. This can be done directly by engineers, or by pavement cost models using rules that replicate the engineer's knowledge.

The maintenance rules are based on maintenance treatments being identified when one or more condition parameters exceed a trigger value. In road pavement maintenance it is common to use two different triggers:

- An investigation level; and
- An intervention level.

The investigation level represents the first point at which, once exceeded, it might be appropriate to consider a treatment. The intervention level represents the point beyond which a maintenance intervention is essential and a treatment should be planned. This approach has been used extensively in modelling the UK road network and the work undertaken by Snaith & Orr (2006) made use of the different maintenance levels in their approach to asset valuation in Northern Ireland.

Asset valuation attempts to consider any deterioration in condition that reduces the value of the asset by including the value of the assets on an account. Therefore, a lack of funding effectively translates as a loss in value, allowing the funding deficit to be better represented. With roads, there is a maintenance process whereby a simple surface treatment can restore the value of the road back to an almost as-new condition if applied at the right time. Traditional accounting and linear depreciation did not take this into account for road networks. By associating condition and maintenance along the deterioration paths and their associated investigation and intervention levels, the accounting process used by Snaith & Orr presented a more practical approach for a road agency.

The two threshold levels represent a window in which most maintenance should occur, although there will be exceptions. For example:

- Some small lengths of good condition may get treated if they are sandwiched between significant lengths of poor condition road;

- Some lengths of the network may continue to deteriorate beyond the intervention threshold because the length of consecutive poor condition is too short to form a valid treatment; or
- A constraint (e.g. budget) prevents all the identified maintenance from being completed.

Either way, once a treatment is applied, the impact of the treatment is to reset the condition for the defects that triggered the intervention, thereby extending the life of the pavement. Additional defects may also get reset although this depends on the respective hierarchies of the treatments and condition data. For example, a surface only treatment would not be expected to correct any structural defects and therefore it would only be expected to restore some of the life back into the road pavement, because the deeper structural layers remain unmaintained. A full structural treatment would be designed to restore the pavement to at least its original condition. These effects of maintenance treatments are commonly referred to as Works Effects (e.g. Kerali et al., 2006) within models. The Works Effects models within HDM-4 are also used to determine the timing of the works and the associated cost estimations. Modelling the effects of any maintenance works is important because it allows the correct condition to be recorded at the end of each period, which is subsequently used to model future deterioration and future maintenance interventions.

Table 2-2 lists the three common forms of deterioration on an asphalt pavement surface and aligns them with three general treatments groups used by highway authorities.

Table 2-2: Maintenance treatments

Forms of asphalt deterioration (Rebbechi, 2006).	Treatment
Loss of skid resistance, through loss of texture, flushing or polishing.	Minor surface treatment (e.g. surface dressing)
Deterioration of asphalt mix, due to issues such as binder stripping, potholes, cracking, rutting.	Surface treatment (e.g. resurfacing)
An overall decrease in structural capacity and ride quality, following cracking and shape loss due to fatigue, deformation or strength loss of pavement materials.	Structural treatment (e.g. reconstruction)

(source: adapted from Rebbechi, 2006 and authors own experience)

Working down the list in order provides an indication of treatment hierarchies that are applied in reality (i.e. an agency would be very unlikely to undertake a structural treatment if the only defect present was a loss of skid resistance).

This format of treatment hierarchies is required by pavement cost models to determine the most cost effective intervention. For example, an engineer might consider bringing forward a more invasive treatment that would correct current and future defects, rather than undertaking two maintenance interventions in a very short space of time.

Successful timely intervention aims to prevent the pavement from going beyond its effective service life into a zone where the deterioration becomes much more rapid and can affect the entire pavement structure (Rebbechi, 2006). Assigning the correct

treatment at the right time is an important step in pavement maintenance planning in order to preserve the value of the asset and to get maximum value from the investment.

It is almost inevitable that there will be many more pavement sections identified for maintenance than a highway authority can fund. Therefore, the final stage in the development of a maintenance programme is to choose between all the sections identified for treatment.

In order to provide a cost efficient return and meet government policies and road agency objectives, the lengths in need of maintenance are compared against one another using one or more key criteria (e.g. cost). This process is known as prioritisation because it results in a prioritised output of maintenance lengths. The prioritised output is important in understanding when and where funds should be targeted and an understanding of the longer-term implications of each intervention adds robustness to the decisions made from the analysis.

2.6 Whole-life costing

The concept of whole-life costing for road pavements was presented in the introduction and is a well-developed concept for use in project appraisals for a range of disciplines. It is defined as an assessment of the costs over the life of an asset or product (Flanagan and Norman, 1983; Kirk and Dell'Isola, 1995). A significant proportion of the total costs of an asset are incurred during the life of the asset and the magnitude and profile of the future costs are influenced by the initial investment decisions. Making well informed decisions at the time of construction can lead to markedly different cost profiles during the remaining service life of the asset (Dale, 1993; Sinhal et al., 2001; Hooper et al., 2009). Therefore robust appraisals need to consider both the initial and future costs.

In BS ISO 15686-1 (BSI, 2000) whole-life costing is defined as

"a technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational costs."

Through the assessments that the standard recommends, it aims to ensure that a constructed asset will at least be operational and affordable for its design life by not selecting options that have low initial costs but unmanageable future costs. By promoting techniques to optimise the analysis of costs, service life planning has an increasingly crucial role to play by producing information that allows informed choices to be made at the outset of assessments.

2.6.1 Principles of whole-life costing

The principles of whole-life costing are well established; at the time of investment, if consideration of different options is restricted by only including the initial costs then it is unlikely that the option will return an efficient spend over the long-term life and this has been discussed in a number of studies (e.g. Flanagan and Norman, 1983; Bowskill and Abell, 1994; Hooper et al., 2009). The need to appraise alternative options on the basis of whole-life cost is now accepted as 'good practice'.

Whole-life costing works well as a principle because money in general provides an objective mechanism for comparing costs of dissimilar items (Robinson et al., 1998). However, it can be time consuming to obtain accurate cost data for use in detailed analyses, partly because organisations are protective of cost data.

The costs used are generally direct costs (e.g. materials, labour) which are more readily available than indirect costs (e.g. health impacts), explaining the traditional exclusion of social benefits or the environment in these models. For example, the only indirect cost considered in the majority of current pavement whole-life cost models is the cost of delays that road users experience (either due to maintenance or accidents).

Analyses are mostly undertaken over a fixed period (e.g. 30-60 years) due to the complexity and uncertainty associated with predicting over very long periods. Under these circumstances it is important to ensure that the analysis period is long enough to make the comparative evaluation of alternative options meaningful.

At the end of the analysis period attention needs to be given to the residual value of the asset; this is a value that gives consideration to the potential continued use of the asset or component beyond the analysis period by ensuring any 'value' remaining in the asset is included in the overall calculations. For example, if a maintenance treatment occurred in the penultimate year of the analysis this significant investment towards the end of the analysis should reflect that there is now a longer period until a future maintenance would be needed (i.e. there is a greater residual value locked into the pavement).

2.6.2 Benefits of whole-life costing

There has been widespread agreement that whole-life costing can bring significant benefits in making investment decisions, not least helping to provide the most cost effective return from available budgets (Bowskill and Abell, 1994; PIARC Technical Committee on Flexible Roads, 2000). For that reason, whole-life costing has been put to use for a number of highway authority assets that includes pavements (e.g. Sinhal et al., 2001; Flintsch & Chen, 2004), earthworks (e.g. Reid and Clark, 2000), structures (e.g. Weyers et al., 1984; Ugwu et al., 2005), tunnels (e.g. Bird et al., 2002) and footways (e.g. Atkinson et al., 2006). However, one potential criticism of the approach is that it will only find the minimum whole-life cost against the criteria that have been assigned costs. So, if a model only has maintenance costs and no other costs the minimum whole-life cost will only represent the minimum whole-life maintenance cost. Any user must be aware of the costs included and how outputs could be impacted by any excluded costs.

If whole-life costs are not considered in an assessment then it is acceptable to assume that the cheapest initial solution may be favoured but this may only meet the current minimum acceptable levels of mandatory standards (e.g. safety and durability) and not provide a cost effective solution against a longer time horizon. The role of whole-life costing is to inform and support the decision making process, not to determine it. There will usually be other drivers (e.g. affordability, policy requirements, safety etc.) that will need to be taken into consideration in making any final decision. In this context, another

benefit of examining whole-life costs is that it allows investment decisions to be made with a full understanding of the cost consequences of choosing different initial options e.g. ensuring that future operations and management of the asset are affordable.

2.6.3 Whole-life costing for road pavements

Robinson (1993) stated that the costs incurred during the life of the road pavement can be assigned to either the highway authority or to the road users. The whole-life costs of a road pavement are commonly agreed to consist of three elements:

1. Construction costs: The costs at the time of the initial construction, which include design costs, works costs, traffic management and any consequential costs (e.g. raising barrier heights);
2. Maintenance costs: The future costs of maintaining the pavement, which are influenced by the initial choice; and
3. User costs: The user costs are made up of a combination of:
 - Time: Time itself can be split into:
 - Delays experienced under normal traffic conditions, for example, as a result of congestion due to a lack of capacity or deterioration of the road pavement;
 - Delays experienced during periods of maintenance. This is the additional delay which is experienced due to the presence of road works on top of what would be expected under normal traffic conditions;
 - Vehicle operating costs: Represented through factors such as fuel consumption and tyre wear; and
 - Accident costs: The cost to users of an accident, represented by factors such as the accident rate on different road types and the costs of injuries or fatalities.

The importance of the various elements within a whole-life cost analysis may vary with the geographical location and the road type of the analysis. For example, in Western Europe traffic levels are high and the value of time for road users is also high therefore the delay costs can make up a significant proportion of the total costs. However, in developing countries, the condition of the road is likely to be in poor condition, the value of time for users is lower and therefore the vehicle operating costs (e.g. tyre wear) will form a much greater proportion of the overall cost (PIARC Technical Committee on Flexible Roads, 2000).

Where user costs are included, the models tend to only consider delays at times of maintenance interventions (Sinhala et al, 2001). If delays to road users under normal conditions were included in the total whole-life costs (e.g. when there was no maintenance but there was congestion on the road) it is likely that the user costs would form a significant proportion of the total costs and would swamp all other costs (e.g. annual costs of congestion are widely reported in the media to be up to £8 billion in the UK (CBI, 2012) and are predicted to rise sharply in the future; the budget for the management of the pavements on the trunk road network is ~£300 million). Because delays under normal conditions (when there is no maintenance) are unlikely to be significantly influenced by the choice of maintenance option only additional delays during times of maintenance are considered. However, this does ignore potential vehicle operating cost savings (e.g. vehicle wear, fuel consumption) that may result from an improved road surface following maintenance.

2.6.4 *Extension of whole-life costing*

Although whole-life costing is an accepted principle there are growing pressures on appraisals to be based on more than just the lowest whole-life costs of the maintenance works. For example, carbon emissions targets (Fankhauser et al., 2009) translate into a future need to consider carbon emissions within the appraisals so that emissions can also be minimised within maintenance prioritisation.

To meet the changing objectives, whole-life costing will need to be replaced by a broader, but no less rigorous assessment of whole-life value.

The Office of Government Commerce (2007) state that the whole-life costs of an asset are the total costs of ownership which should include not only design, construction and maintenance costs but also internal resources and departmental overheads, risk allowances, refurbishment costs, health and safety aspects and sustainability. Therefore, costs should include not only the direct costs encountered due to construction and maintenance but a wider spectrum of costs such as the costs imposed on the environment (e.g. users and society in general) throughout the use and operation phases.

Taking that into consideration, the costs used for assessing maintenance options need to include not just the construction and maintenance costs, but also the costs to road users (e.g. cost of delayed time, vehicle operating costs) and the costs to society (e.g. impacts of noise and emissions).

2.7 Modelling approaches

The two main modelling approaches used in pavement cost models are:

- Deterministic; or
- Probabilistic.

Deterministic models predict the exact future condition of specific sections of pavements based on historic performance information, assuming we know what will happen and when. Probabilistic models on the other hand, model the distribution of network condition in the future based on the probability of the pavement deteriorating to a certain condition.

Both of these approaches use data from the road network to predict future maintenance requirements. The process used and the form of the outputs vary between the two

approaches and continues to promote debate over the advantages and disadvantages of the two approaches.

2.7.1 *Uncertainty*

Within any modelling the issues of uncertainty need to be addressed to try and minimise their impact. There are predictive future inherent uncertainties associated with pavement maintenance. Butt, Shahin et al, (1994) state that the inherent uncertainties associated with predicting future pavement maintenance (e.g. the effect of material properties and environment on performance, traffic loading etc.) make the use of a deterministic approach unsuitable. They argue that opting for a model based on distributions and probabilities addresses the uncertainties, an opinion echoed by Chootinan et al., (2006).

However, the uncertainties could be addressed through multiple repeated analyses, where key variables are altered to assess their impact. This would result in a range (or envelope) of outcomes based on the variation of input data. The input data could be varied accordingly to the level of uncertainty surrounding the different variables, thus providing the modeller with a well-structured sensitivity analysis which could be easily achieved using a deterministic approach.

2.7.2 *Operational level and location*

One of the most important factors in determining the modelling approach to use is the level at which the model is going to operate; pavement models are used differently at network and project levels. At a network (or strategic) level the models are used more to generate headline results of network condition in relation to policy implications, with the results more appropriate for use by senior management. At a project (or scheme) level the models are used more to focus on choosing between different maintenance options at specific locations (World Bank, 2008).

However, in order for strategic results to be meaningful to engineers (and those who develop maintenance programmes) it is often required that strategic level tools show

where on the network the treatments and budgets need to be targeted. For this requirement then a probabilistic approach often lacks the ability to provide those answers. The main reason for this is that a probabilistic model functions by categorising the network into groups that have similar characteristics as defined by the user (based upon condition and traffic for example). However, when a network is collated into these groups of similar characteristics, the total lengths of those groups are not necessarily contiguous on the network any may be made up of individual lengths from across the network. By treating the total length of the groups as one item the specific location information is subsequently lost through this grouping process. It is the length of each of those groups that then get their respective deterioration applied to it, usually in the form of probability matrices that deteriorate the group across the range of condition bands.

Therefore with results from a strategic, probabilistic model it is not possible to get detailed locational information. That issue is often omitted from any discussions on probabilistic modelling or the use of transition probability matrices (e.g. Ningyuan et al., 1996). One of the advantages of a deterministic approach is that it is possible to model parameter values that can be specifically linked to lengths of the network, therefore fundamentally holding onto the location of the data within the network. If a road authority wants to compare strategic budgets with the associated pavement schemes modelled, it is still a possibility under a deterministic approach.

2.7.3 Other approaches

Other approaches new to pavement condition modelling are also starting to be used in addition to the two main methods discussed. Artificial neural networks is one such approach (Raja Shekharan, 1999). Neural networks are self-learning systems that consider all factors in predicting an outcome and are based on historical outcomes and the factors behind them. When more data becomes available, the system learns more about the decisions and factors, effectively training itself.

This technique has led to results being produced that can be validated against measurements but one difficulty is that relationships contained within the neural networks or the processes used to generate the results cannot be easily extracted (Tickle et al., 1998; Kahramanli, 2009). This is improving as new techniques are used to research how rules can be extracted but in addition to this issue, a significant amount of data is required for the learning stages of development. Therefore, artificial neural networks are not deemed suitable for initial model development unless there is sufficient time-series data.

2.8 Reporting and outputs

The information to analyse and report against is a key point in the planning stages of a pavement management system; it should not be left for consideration until after a model has been developed.

One of the main uses of the models is to investigate different budget scenarios and Snaith & Orr (2006) note that the objective function of models has become the maximisation of NPV⁹. They argue that this means there is not a full consideration of social benefits. In the same vein, if a model only uses the costs of the maintenance works to prioritise treatments then obviously the costs of the environment would be omitted from the main analysis. With more research into making integrated assessments that cover the range of criteria relevant to a road agency there is a better chance of allowing modelling outputs to provide a more complete picture.

To measure the impact of different maintenance programmes on a network Amador & Mrawira (2008) suggest that an overall indicator of resultant road pavement condition provides a useful measure. This can be used as an objective measure against which to evaluate and predict future scenarios and budgets and the effect those will have. This

⁹ NPV is the net present value of the benefits, defined as the difference between the discounted benefits and discounted costs. A higher NPV therefore represents a better return on an investment.

type of overall performance indicator can therefore be used both as a reporting measure and also as a metric in the life-cycle cost analysis for the model to prioritise against.

The outputs generated by a pavement cost model are inherently condition and budget driven. Even though local engineers bring additional knowledge to the maintenance programme development creation process (e.g. local information related to environmental and climatic conditions, traffic and historic behaviour) it would be expected that model output treatment locations would show good alignment with maintenance identified by engineers.

However, Brownlee et al., (2007) argue that any ranking system should serve only as a starting position from which road authorities can then go and undertake further assessment before compiling a programme. This is a key point which is often overlooked; a model cannot be expected to produce the final answers but instead should be used to add additional knowledge to the decision making process.

2.9 Review of existing systems

There are many asset management systems available in the market, covering the main infrastructure types of road, rail, aviation and utilities, all with the common aim of providing support for decision making. Some systems deal with only one asset type (e.g. HDM-4¹⁰ for road pavements) while others can be used across multiple asset types (e.g. dTIMs¹¹ whose use has included road pavements¹¹, bridges, water and safety systems).

The following review aims to assess systems currently available on the market in order to understand:

- What system is state-of-the-art?
- What functionality is commonly employed within the models?
- Are there any gaps in what the models currently deliver?

¹⁰ <http://www.hdmglobal.com/default.asp>

¹¹ <http://www.deighton.com/dtims9.html>

The main focus of systems and literature reviewed was from the UK, Europe, United States, Australia and New Zealand. With the fairly rapid pace at which new system versions are developed and the range and scope of what the systems cover, an all-inclusive review was impractical and certainly not within the scope of this thesis.

The assessments of each system can be seen in Appendix A, which contains a general overview of each tool and a table of the functionality of each reviewed model (see Table A-1).

The criteria used to assess the models were:

- Infrastructure type;
- Platform and interface;
- Location referencing; and
- Analysis features.

This information was used in part to later define the specification for a pavement cost model whilst also understanding if (and how) any models currently include 'value' parameters.

2.9.1 Common functionality

The review of systems showed that there are generally two categories of systems available on the market:

- General application systems: These systems represent what are commonly called 'off-the-shelf' solutions. These are marketed widely but they often require significant calibration if they want to be fully customised for local conditions; or
- Bespoke application systems: These systems are individually built around an organisation's needs and their data. Condition relationships tend to be fully customised to use locally collected survey parameters and data. One of the

downsides of that is that the customised rules and algorithms are less easily transferred to other networks and/or systems.

The degree to which the models fit into one of these categories is often ambiguous. To get the most benefit from an off-the-shelf solution there is significant calibration normally undertaken by the model provider or an independent consultant and the effort required (in time and resource) can often approach the effort required in the development of a bespoke system.

The level at which any model can be calibrated is influenced mostly by the quality and quantity of the time-series data available. In the case of the NRA there is a limited amount of historic data due to the survey frequency from previous contracts. This is due to improve under new contracts but it will take a number of survey cycles until the required quantity of data is available for robust data trending and calibration.

It was apparent that the use of a database platform is fairly evenly spread between Oracle, SQL and MS Access. None of these platforms present a problem in the development of the model under this research although the main driver for the choice of platform is one that is accepted by the NRA. The majority of systems make use of Geographical Information Systems (GIS) as the main interface, with Visual Basic, Java or web-based front ends also being used.

The most common level of operation of existing systems is at a network level (e.g. a road network is usually represented by a number of uniquely labelled sections which together form a network). There are some systems that operate at both the network and project level but what is unclear from the published information is if the same methodology (e.g. deterioration rules, treatment rules, scheme prioritisation) is used at both levels. This would be particularly relevant for any systems used to set or track a highway authority's progress against key performance measures. For example, if the key performance measures are being set and/or tracked at a network level then the

individual maintenance schemes (that influence the overall network measure) should be modelled and designed using the same methodology at a project level.

Overall, it was noted that systems included one or several of the analysis options listed in Figure 2-1 (with varying degrees of performance).

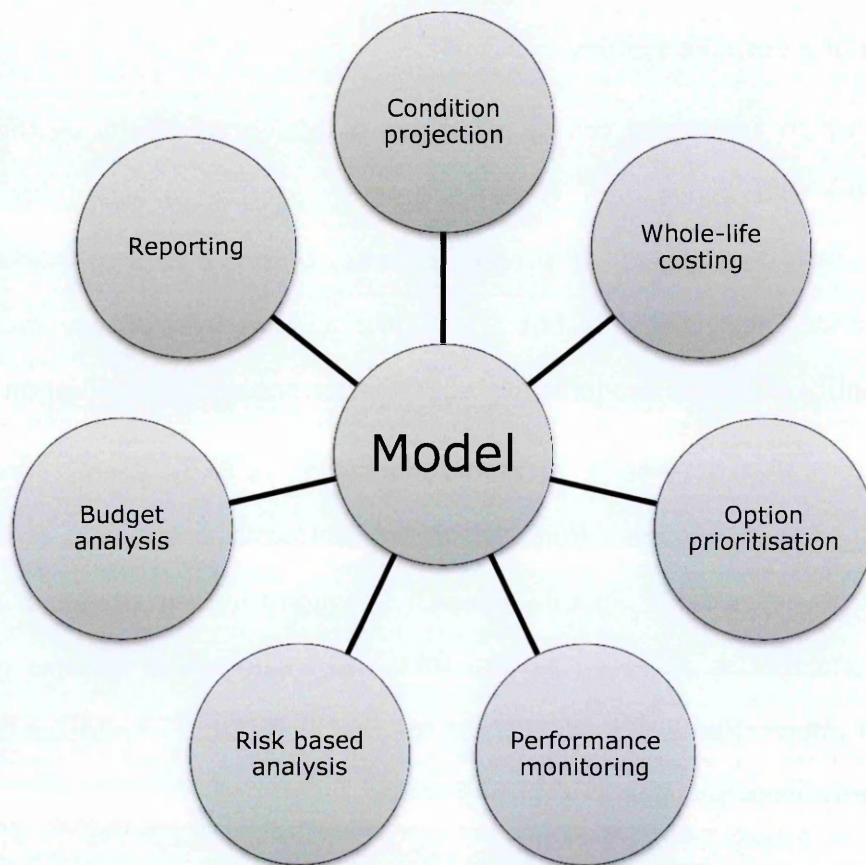


Figure 2-1: Common features of examined systems

2.9.2 Unique aspects of systems

There were aspects in the reviewed systems that were less common across all of the tools. Rather counter-intuitively, these unique aspects were found more in the general application systems (e.g. HDM-4, Confirm¹²) rather than the bespoke applications. One reason for this is perhaps because the unique aspect adds a specific marketing edge for

¹² <http://www.pitneybowes.co.uk/software/infrastructure-asset-management/confirm.shtml>

the product they are found in, hoping to set them apart from the competition of other general application models.

The unique aspects relevant within this research were:

- Asset valuation: The ability to determine the current value of an asset stock from within a system; and
- Data integration: The ability to allow data from different geo-referenced frames to be used together (e.g. referencing different data sources to a common frame, but still allowing the user to work with the individual reference systems).

2.9.3 Identified gaps

The review of models also highlighted gaps in the current systems on the market:

- There is limited inclusion of environmental issues within the modelling. HDM-4 has the option of including emissions, energy and noise but these inputs are far from common and most systems do not make reference to environmental criteria. In HDM-4 the vehicle emission pollutants are estimated as functions of the characteristics of the road, traffic levels, vehicle type and fuel consumption. Although these values are calculated they are not included in the economic evaluation (World Bank, 2008);
- The majority of current modelling frameworks require the user to already have selected locations where maintenance is to be considered. That is, the system is used to select the best treatment for sites chosen by the user, rather than selecting its own sections for maintenance; and
- Often the condition of the maintenance sites is represented in a simplified way, e.g. using single values for each of the defect parameters for the entire site. Using all the raw surveyed data would likely result in slow analysis times, but a more comprehensive representation of changing condition along a section would provide a closer representation of reality.

2.9.4 *Developing a PMS*

One clear option for developing a PMS is to draw upon elements or concepts of existing systems that have already been developed. This not only saves on development time but it also allows the use of previously proven methods and techniques to be used rather than starting from scratch. One example of this is the PLATO Engine (Pavement Life-cycle Analysis and Treatment Optimisation) which incorporates the Road User Effects models from HDM-4, and Road Deterioration and Works Effects models, originally from HDM-4 (but significantly altered to suit modern vehicles (Roberts et al., 2003)).

Two European projects looked at methodologies to generate a more integrated PMS for roads. RIMES (Road Infrastructure Maintenance Evaluation System) aimed to develop a framework for modelling road pavement performance and generate a common standard across Europe (Kokkalis et al., 2002). The ultimate aim of the project was to develop a framework for a life-cycle cost model that could assess alternative maintenance strategies for both pavements and structures. The framework for a project level tool included road user costs (vehicle operating costs, journey time and accident costs) along with the costs of maintenance, discounting all costs throughout the analysis period in order to compare the life-cycle cost for maintenance alternatives. At a network level, it was suggested that a probabilistic approach would form the pavement deterioration element in order to find an optimal solution for the condition distribution. The different approaches could be used either to investigate policy impacts (network level) or to develop a maintenance programme (project level).

The PAV-ECO project undertaken at the same time, had the aim of developing economic models that could be used by highway authorities across Europe within already existing pavement management systems (Ertman Larsen et al., 2001). A framework was developed that allowed for the life-cycle costs from competing maintenance strategies to be assessed, including both agency costs and road user costs. The project demonstrated how funds could be assessed against this type of model and distributed to different parts of the network using the more long-term costs and benefits rather than basing budgets

on historical trends. It was hoped that the implementation of the findings from this research would be disseminated by both high authorities and consultants. However, the complexity still surrounding these topics is demonstrated by the remaining lack of standardisation in modelling road pavements. Although it could be argued that the framework for many models is broadly consistent, the varied implementation of those frameworks by different highway authorities and private organisations results in very varied models and assumption.

2.9.5 Summary

The vast range of existing tools and the criteria used to assess them highlights the differences that exist across the available software (see Table A-1). It also highlights the core elements that are found between them, emphasising the base functionality that would be expected in most models and apart from risk-based analysis, this closely matched an outline of the functionality planned in the initial whole-life cost model (e.g. condition projection, whole-life costing, prioritisation).

However, despite the range of tools and the research undertaken into them there were still gaps that were apparent from this review. One of those in particular, the lack of inclusion of environmental parameters, aligns closely with this specific research. This gap however could also be indicative of challenges with incorporating the environment into road pavement tools; for example, the lack of enthusiasm from the industry to model and use the data. This was a point that was noted for further exploration in the planned consultations with experts because it could influence the level of acceptance in any outputs.

2.10 Summary

Modelling road pavements is a well-documented field and has led to numerous systems being used by road agencies worldwide. The systems store a vast array of data for use in modelling and the algorithms used (e.g. defect relationships) can vary from simple linear

relationships to complex, multi-variable relationships. The interactions and relationships between the data is a key element in developing a robust model.

Whole-life costing is a fundamental process in being able to identify an optimum intervention over a complete analysis period. In comparing whole-life cost approaches for different pavement analysis tools there is a common agreement of the costs that are included in the economic appraisals (works costs and delay costs). However, road agency objectives change and the current position centres on giving consideration to what best meets the needs of all those involved not just what is the lowest cost.

To meet the changing objectives faced by road agencies the principle of whole-life costing needs to be expanded to include assessment of wider stakeholder needs. This would mean the prioritisation of maintenance being made on a whole-life value basis that includes the consideration of externalities within the central appraisal and prioritisation of maintenance schemes.

Chapter 3 Externalities

As stated at the beginning of the previous chapter, the first research objective involves incorporating externalities in pavement maintenance assessments to take account of their impact in developing maintenance programmes. In order to develop modelling methodologies for the externalities of carbon and noise it was important to develop an understanding of externalities in road transport and how they can be measured. Therefore, this chapter reviews the available literature on externalities, with a specific focus on environmental externalities in road transport.

In the introduction, an externality was defined as resultant cost or benefit on an individual or an organisation from an action for which they were not originally responsible. There has been a growing recognition that externalities impose real costs on society and including externalities specific to road transport (e.g. health effects from noise) within appraisals has become an issue of growing importance (CE, 2007). This has been due to an increase in understanding that internalising external effects in the appraisal process can give a better understanding of their total value. Value for money is defined by the OGC (OGC, 2007) as

"...the optimum combination of whole-life cost and quality to meet the user's requirements."

3.1 Drivers of internalisation

Around 20% of overall emissions of CO₂ (Carbon Dioxide) in the EU come from road transport (European Climate Foundation, no date) and there is therefore pressure on the transport sector to act to reduce these levels.

A comparative assessment of greenhouse gases between road and aviation use and rail construction (which have significantly different emission models) used the avoided emissions from road and air journeys as one parameter within the justification for high

speed rail (Chang and Kendall, 2011). Including these externalities within the assessment showed the emissions from construction of the rail infrastructure were equal to the savings in modal shifts (from road and air) that would have occurred in just two years.

Separately, corporate responsibility has gained significant importance over recent years, making companies consider the impact of their activities on society (Mallen Baker, 2004). Coupled with this is the increasing awareness within and outside organisations of the importance of 'green credentials', not least due to a number of national and international directives and legislations that require accountability in new areas, e.g. Directive 2002/49/EC (2002) on noise. Alongside these directives targets have been set by parliament in the UK, such as the commitment to reduce carbon emissions (20% from 1990 levels by 2020, and 50% by 2050) (Fankhauser et al., 2009).

The road industry is already working with life cycle assessment methods to include and compare different environmental impacts. It is known that a significant amount of greenhouse gas emissions are due to vehicular traffic and some previous life cycle assessment studies have backed up that fact by the limited impact that a change in pavement maintenance or structure has on the overall emissions (Huang et al., 2009).

The relevance of incorporating noise as an externality in appraisals is important in order to acknowledge the health consequences (e.g. stress induced heart disease, sleep deprivation) that can be caused by noise. The continued forecast of the growth in road traffic will only emphasise the impacts in future years, as will an expected growth in complaints from users and residents. Noise mapping directives by highway authorities (and associated action plans) focused on mitigating the effects of noise; but these issues are expected to grow with traffic levels.

Some effort has been put into developing approaches to internalise externalities although they tend to be qualitative rather than quantitative and are generally applicable to individual projects only (e.g. NRA, 2011a) as opposed to a strategic modelling of a whole

network. Internalising environmental commitments allows for them to be included in mitigation plans in the design and construction phase. This is increasingly becoming an accepted part in the general project approval process (Ozbek et al., 2012). One problem with trying to develop robust approaches to internalise any externality is in defining a robust measurement method under which the costs or benefits of the externalities can be expressed and compared on an equal basis.

3.2 Monetising externalities

One of the challenges to overcome for the inclusion of 'externalities' within an investment appraisal process is the need to express 'value' as a comparable measure (e.g. monetary term) so that comparable assessments of investment options can be made (Hofstetter and Muller-Wenk, 2005). Monetisation, in this context, is complicated as the impacts of the externalities can be different for different stakeholders.

Defining value in monetary terms will need to take account of aspects such as:

- Stakeholders' understanding and concern about the impacts;
- Knowing which stakeholders are affected and how;
- The cost to society due to the impacts; and
- Society's willingness to pay to mitigate the impacts.

The objectives and opinions of stakeholders can help to define how 'value' can be monetised. Different stakeholders (e.g. funders, providers, managers, users) will have different value drivers and will place different levels of importance upon the different value aspects. The definition of value therefore relates to how different stakeholders perceive the issue in question and their expectations and requirements. In order to meaningfully define value the needs of all stakeholders have to be understood and considered (Environment Council, 2004) although it is unlikely that there will be one ideal solution that satisfies the needs of everyone involved.

The choice of method can impact the cost factors included and Hofstetter and Muller-Wenk (2005) therefore question whether values from different methods can be added or compared. As long as care and consideration is given to the factors included in the exercise to determine the value then it should not prevent attempts to internalise some of the recognised externalities.

3.2.1 Willingness-to-pay and willingness-to-accept

As Nijland and Wee (2008) have indicated, a lot of work has been carried out to develop methods that can be used to monetise externalities but there is still no consensus as to how this should be done. In determining monetary equivalents there are a number of potential methods that can be used and most make use of the concepts of willingness-to-pay (WTP) or willingness-to-accept (WTA).

WTP is the maximum amount that someone would be willing to pay to receive a product or benefit, or to avoid something undesirable. WTA on the other hand is the minimum amount someone would be willing to accept to give up a product or benefit, or to accept something undesirable. In terms of choosing between WTP and WTA Feitelson, Hurd and Mudge (1996) argued that WTP studies should be used because of the greater familiarity people have with making purchasing decisions which will therefore lead to more realistic answers.

3.2.2 Value estimation methods

The main methods used in environmental value estimation are (EcoSystemValuation, no date):

- Market price method: This reflects the costs and benefits of goods bought and sold in markets;
- Hedonic pricing method: Hedonic pricing is usually used to derive the value of impacts through variations in property prices. The principle is that as the environmental characteristics change, the price people are willing to pay (or

willing to accept) differs, which is reflected by a change in property value. This is based on the assumption that people value the characteristics of a good, or the services it provides, rather than the good itself. In reality, the scope of environmental benefits that can be measured this way is limited to things that can be related to property prices. If people are not aware of linkages between environmental attributes and benefits to them or their property, the value will not be reflected in the property prices. In Ireland a lack of recording historic property prices (and their change over time) leads to problems with adopting any hedonic pricing methods (Ozdemiroglu and Bullock, 2002).;

- Travel cost method: This is used to estimate the value of environment related recreational benefits by assuming that the value of a site or services offered is reflected in how much people are willing to pay to get there. Therefore the value of specific characteristics can be derived through differences in people's behaviour. As such, this is often referred to as a 'revealed preference' method;
- Damage cost avoided, replacement cost and substitute cost method: This assumes that if people incur additional costs to either avoid damages caused by lost environmental services or to replace them, then the value of the environmental characteristics must be at least what people are prepared to pay for a replacement. For example, if a woodland is lost then it is the amount people are prepared to pay to replant a new woodland;
- Contingent valuation method: Here people are directly asked, using surveys, how much they would be willing to pay (or willing to accept) for specific environmental services, often referred to as a 'stated preference' method, simply because it is asking people to state their values. However, it generates considerable controversy as a method because it is based on what people say they would do, rather than what they are observed to do. Some argue that there is a fundamental difference in the way people make hypothetical decisions compared to how they make actual decisions;

- Contingent choice method: This is similar to contingent valuation but rather than asking people to state values explicitly, the values are inferred from the choices or trade-offs that are made. On one hand this means that people do not have to put prices on non-market goods or services, which is often an unfamiliar and unrealistic task, but on the other hand it may force them to make choices they wouldn't normally make; and
- Benefit transfer method: This method uses information from studies already completed in another location and/or context. Therefore it may draw upon studies that have themselves used any of the previous valuation methods. However, it should be noted that unit value estimates can quickly become dated and therefore care should be applied in light of that. Additionally, results from studies should be considered within their geographical and demographic characteristics to further understand if they will hold up if used elsewhere.

Current research on costing environmental issues is focused around the hedonic pricing and contingent valuation methods, with the concept of benefits transfer also generating increasing debate.

3.2.3 Benefits transfer

Pearce and Howarth (2000) argue that the attractions of using the benefit transfer method are clear; it represents an easy first step for completing analyses because results from existing related studies can be used in different locations, meaning new pricing studies are not essential.

However, the relevance and justification of the transfer has been brought into question in some cases because the estimation of value can be very site specific (Powell et al., 1995; Longo et al., 2012). Common reasons for the differences between studies have been attributed to changes in demographics of the groups and also the physical location of the comparable sites. For example, the value of time (used in costing delays) is the same across the UK and that is a sensible assumption based on the economy, travel models,

road types etc. However, applying those values in other countries would not make sense due to obvious differences in those initial factors alone.

Even subtle differences in demographics at a local level can lead to differences. Unsurprisingly, people living near roads in the Spanish Pyrenees were willing to pay more to reduce the environmental impacts of noise and air pollution. However, particular demographic groups who were not directly impacted by the road were also willing to pay more; those being the younger, better educated and more environmentally aware groups (Lopez et al., 2012).

There is no doubt that the power of benefit transfer attracts much interest, not least because it saves expensive data collection exercises, but careful consideration of the differences between original study sites and new investigation sites is required. Morrison et al., (2002) concluded that benefit transfers between sites tended to have fewer problems than transfers between different demographic groups.

Hanley and Barbier (2009) discuss the merits of benefits transfer but note that the process to adjust data can often be ad-hoc. Transferring the benefit function (i.e. using data from the new policy site in a function derived from a study site) can also save considerable resources in being able to make use of data from other studies but the same caveats would apply. It would be a valid method to use in sensitivity analyses to understand how results could be affected by using relationships from other studies.

In any method, if data from other studies is used then consideration should be given to how the prices have been derived and whether they are influenced by any groups (e.g. pressure groups) resulting in deflation or inflation of the prices (Boiteux, no date).

3.3 Road transport externalities

This sub-section addresses the context of how externalities are currently considered by different highway authorities. Guidance documentation from NRA is discussed alongside the Scottish Transport Appraisal Guidance (STAG) and guidance from the New Zealand Transport Agency (NZTA). The comparison between these networks was made due to

them sharing broadly similar characteristics (see Table 3-1). In addition, the networks are all predominantly rural.

Table 3-1: Comparison between Irish, Scottish and New Zealand trunk networks

	Network lengths (km)	Motorway proportion (%)
Ireland	5,443	12
Scotland	3, 550	17
New Zealand	10,909	2

(source: NRA; Transport Scotland, 2014, pp.78; NZTA, 2009, pp.4)

Following a brief overview of the main criteria listed within the guidance documents, the environmental criteria within road transport are discussed in greater depth, particularly the externalities of carbon emissions and noise.

3.3.1 Current practice

The main transport cost components commonly discussed for inclusion as externalities are:

- Congestion – a measure of the delays experienced by road users;
- Traffic accidents – the impact of road accidents;
- Air pollution – the effects on local air quality;
- Noise pollution – the annoyance and health effects of road and traffic noise;
- Climate change – the effects of greenhouse gas emissions on global air quality and wider climate indicators;
- Nature and landscape – the damage to natural habitats and visual intrusion on the landscape; and
- Soil and water quality– the impact of runoff from roads into water bodies and the surrounding land.

The NRA's Project Appraisal Guidelines (2011a) aim to make sure that "best value for money is obtained on all national road projects", that benefits and costs are applied consistently and evaluated and assessed at key stages of a project.

Improvements can always be made and one area of improvements that the NRA (and other highway authorities) are trying to address currently centres on the way that the environment is considered within appraisals.

The scheme appraisal process that the NRA has in place considers impacts using both quantitative and qualitative measures, with some quantitative assessments being expressed in monetary terms. Regardless of how each impact is assessed it provides an estimate of the 'value' to the NRA. The project appraisal guidance lists five areas for assessment (NRA, 2011a):

- Economy – the impacts of the project on economic growth and competitiveness;
- Safety – the impacts on transport related accidents;
- Environment – assess a range of impacts, e.g. emissions, noise, habitat;
- Accessibility – the effects on those experiencing deprivation, isolation and mobility issues; and
- Integration – the effects of transport integration from the project.

These five criteria are also mirrored in the headline indicators used by STAG (Transport Scotland, 2012a). One difference with NZTA (Land Transport New Zealand, 2006) is that NZTA do not define 'integration' as a key criterion, instead including one labelled 'protecting and promoting public health'.

Both the NRA and STAG guidelines note all impacts should be assessed by either qualitative or quantitative measures, provided they are understandable and robust. The STAG guidelines recommend that along with benefit-cost ratios, economic activity and local impact measures, wider economic benefits need to be considered as well as the impacts of the environment, safety, integration, accessibility and social inclusions. The

monetary value of safety, environment and economic benefits should be used to calculate standard Monetary Impact Ratios, expressed as:

$$\frac{\textit{Present Value of Benefits}}{\textit{Present Value of Costs}}$$

The problem is in trying to arrive at a present value for the environmental externalities. All of the guidance documents further sub-divide the criteria into a number of sub-criteria. The remainder of this section focuses on the 'environment' criteria and the sub-categories which are used to make assessments of the various impacts.

3.3.2 Environmental elements

The criterion of the environment is broken down into the sub-criteria shown in Table 3-2 and these have been aligned (where possible) to demonstrate commonalities between the road agencies.

Table 3-2: Environmental sub-criteria

NRA	STAG	NZTA
Air quality and climate ¹³	Global air quality ¹³	Air quality ¹³
	Local air quality ¹³	
Noise and vibration ¹³	Noise and vibration	Road traffic noise ¹³
		Vibration
Landscape and Visual	Landscape	Visual impacts
	Visual amenity	
Biodiversity – Flora and Fauna	Biodiversity and habitats	Ecological impact
Agriculture	Agriculture and soils	
Soils and Geology	Geology	
Hydrology	Water quality, drainage and flood defence	Water quality
Hydrogeology		
Archaeological and cultural heritage	Cultural heritage	Special areas
Architectural heritage		
Non-agricultural properties		
Waste		
		Community severance
		Overshadowing
		Isolation

(source: NRA, 2011a; Transport Scotland, 2012a; Land Transport New Zealand, 2006)

The sub-criteria in Table 3-2 show a degree of similarity in environmental criteria considered by the three road agencies, which can be interpreted to mean that they face similar issues (although they may be addressed through very different standards).

¹³ Monetary values of the impacts are included within the respective guidance of the highway authorities

Bickel et al., (2006) state that a number of existing studies show environmental costs due to air pollution, climate change and noise are most relevant to transport because they are affected by the distance travelled. There are also commonalities with other industries. For example, in establishing a framework to consider externalities in water asset management Marlow et al., (2011) listed key externalities as air quality, health, travel disruption, habitat loss and land contamination.

As well as those commonalities there are also differences where a small number of categories are unique to one particular road agency, reflecting individual aspects specific to the country (e.g. location, governance, legislation, heritage).

3.3.2.1 Air quality

CO₂ emissions are used to assess global air quality issues whilst the impacts on local air quality are assessed based on other gases and particulates (e.g. NO_x, PM10). Due to the significant proportion of total emissions attributed to transport (see Figure 3-1) coupled with internationally agreed greenhouse gas emission targets, it is not surprising that infrastructure investment now commonly includes an assessment of the GHG emissions that will be generated.

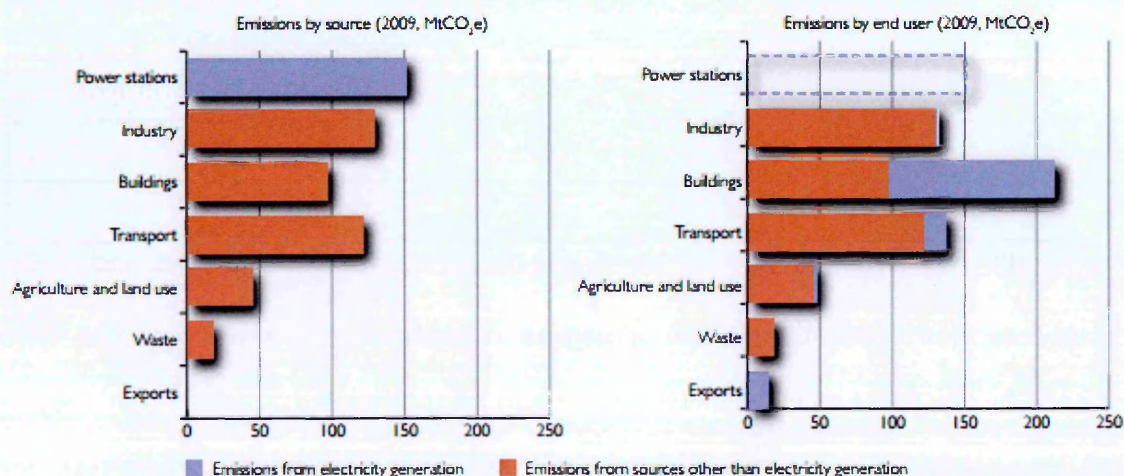


Figure 3-1: Significance of transport sector in CO₂e emissions (source: DECC, 2011)

Increasingly legislation aims to facilitate the uptake of methods to reduce carbon (and other) emissions and Ireland has introduced emissions taxes to encourage businesses to manage their environmental impacts. The advice from NRA guidance (2011a) is to use the number of journeys and emission factors to derive total emissions from the traffic, which are turned into monetary values by applying a cost to the emissions (€15.60 per tonne in 2012). Emissions from maintenance activities or different types of materials are not currently considered and therefore an approach will need to be developed for modelling.

The Scottish guidance recognises that air quality assessments at a network level are likely to be strategic, whilst more spatially defined detailed models may be used at a project level. Both levels are likely to be largely based on qualitative assessments and local air quality issues should be assessed through the change in the number of people affected. Any quantification of carbon should be valued if it falls outside of the traded sector, using the non-traded prices of CO₂ (€62.27 t CO₂ in 2012 (in 2010 prices))¹⁴ (Transport Scotland, 2012b). However, the guidance is centred on the assessment of new construction, and emissions from maintenance are not yet considered.

Guidance within NZTA also suggests quantification of emissions, although the assessment is focused on emissions from vehicles and not construction emissions and embodied carbon in materials. For valuations of CO₂ emissions an equivalent price of €24.43 per tonne was recommended in 2012 (in 2010 prices¹⁵).

¹⁴ The Transport Scotland prices were expressed in 2010 prices (at £55.20 t CO₂ in 2012). The conversion to Euros used the historic exchange rate as of the 1st January 2010 (£1: Euro 1.128) from <http://www.xe.com/currencytables/?from=GBP&date=2010-01-01>

¹⁵ The NZTA prices were expressed in 2004 prices (at NZ\$40 t CO₂). The 2004 prices were first uplifted to 2010 using RPI index values (2004 average RPI=186.7, 2010 average RPI=223.6). Secondly, they were converted to Euros using the historic exchange rate as of the 1st January 2010 (NZ\$1: Euro 0.51) from <http://www.xe.com/currencytables/?from=NZD&date=2010-01-01>

3.3.2.2 Noise

Noise is an issue which is increasingly relevant to road agencies in order to meet the needs of their users and neighbours. Noise barriers are an increasingly common sight alongside many roads due to the recognition of the impact that noise can produce (e.g. deterioration in health [Muller-Wenk and Hofstetter, 2003; Kluger, et al., 2004]) and efforts required to mitigate the noise.

The NRA guidelines (2011a) recognise that transport can be a major source of noise and noise is measured based on the methods in the UK (the Calculation of Road Traffic Noise (DfT, 1988)). The NRA guidelines propose methods to make suitable assessments that are based on quantitative reports of the number of properties affected and the number of properties where the noise cannot be mitigated. Both measures of the number of properties are expressed per kilometre for ease of comparison between schemes. The noise emissions considered by the guidelines are based only on the tyre-road noise emissions and not for any other related noise emissions, for example maintenance machinery or the extraction of the aggregate from the ground.

Guidelines on the assessment of noise and vibration (NRA, 2004) state that noise should only be assessed once the detailed design for the project has been completed and it is recognised that all new construction should have a design goal of 60 dB L_{den} ¹⁶ both at the time of completion and in 15 years' time (NRA, 2004). Economic values assigned to noise are obtained from WebTag guidance (DfT, 2012c).

STAG guidelines also stipulate a quantitative analysis of noise but fall short of valuing noise in economic terms. At a strategic level they state only the change in noise for affected populations should be quantified, accepting that data for absolute noise levels is unlikely to be available. The change in noise level is used to derive a change in the

¹⁶ L_{den} (Day Evening Night Sound Level) is the average sound over a 24 hour period. It is weighted with a penalty of 5 dB added for the evening hours or 19:00-23:00, and a penalty of 10 dB added for the night hours 23:00-07:00 to account for extra annoyance in those periods.

population annoyed. If there are issues such as sensitive receptors (e.g. schools or hospitals) which could affect any decisions and which are not apparent from the data then they should be noted (qualitatively).

Guidance set out by NZTA stipulate values for costing noise (\$160 per person per year per dB(A) of noise increase) and noise level predictions are carried out in accordance with the methods used in the UK (the Calculation of Road Traffic Noise (DfT, 1988)). In a similar approach to the STAG guidance, if there are sensitive locations that are affected by the noise then the analysis should be amended as appropriate.

Noise might be measured using common methods between these different agencies but there is no consistency either in how the noise values are costed or how it is used in scheme design and prioritisation.

3.3.2.3 Landscape

All three guidance documents acknowledge that changes due to transport infrastructure have the potential to alter and impact the landscape and the views that people have. They also acknowledge that landscape values are subjective and can mean different things to different people. Due to geography of the countries, particularly in Scotland and New Zealand, bridges, cuttings and embankments are often essential for maintaining engineering standards (e.g. curvatures and gradients) and the structures required can dominate sightlines. There are limited methods for assessment but recognition should be given to any change in character or quality of the environment caused by infrastructure changes. NZTA suggest a combination of using sightlines, viewpoints and affected properties/populations in the assessment of the visual impacts of a change in landscape.

3.3.2.4 Runoff and water quality

EU Water Framework Directive 2000/60/EC (2000) was adopted on 23 October 2000, setting an objective that all water (e.g. groundwater, surface water) should meet a 'good ecological and chemical status' by 2015. This is going to become increasingly important

for road agencies across Europe as milestones within the directive are reached, ultimately aiming to:

- Prevent deterioration of water quality;
- Protect and enhance areas of surface water; and
- Promote the use of sustainable water.

One key difference with this directive compared to others is that it advises on steps to take rather than setting out targets or limits that need meeting. Therefore, at least in the short-term, it provides limited quantitative options for modelling.

Runoffs from roads are primarily influenced by traffic volumes and road types. Other exogenous factors can also have an impact, for example the severity of winter weather leading to greater use of salt can impact on the quality of runoffs as chlorides can be a problem. NRA guidance states that consideration should be given to the change in diverted and generated traffic from any changes in infrastructure and how mitigation measures would change as a result of any new roads (which could be applied to maintenance).

The NRA and STAG documents discuss a qualitative assessment. For example, allowing for positive or negative impacts from changes in the flood response of a catchment to be recorded. Advice from NZTA adopts a more quantitative stance (advising direct measurements, chemical analysis etc.) although how this would be applied in the planning stage is not yet clear.

3.3.2.5 Cultural heritage

Cultural heritage can be an important issue within the scheme appraisal process on certain locations. For example the A303 project in Stonehenge for the Highways Agency (England) involved many groups of stakeholders from the design stage each with their own objectives. Cultural heritage was one parameter used to assess the proposed

schemes and it had a large impact on the overall assessment, and was eventually partly responsible for the rejection of the scheme.

The advice from both NRA and STAG is to list and describe all heritage sites that need special consideration and this qualitative assessment is incorporated into the overall assessment. The advice from NZTA more explicitly states that the value of a particular site will be specific to its location and the community around it and experts may be required to help determine the value of the site in conjunction with a public consultation.

Cultural heritage is more important for new builds and major improvements (compared to maintenance of existing roads) because new land is built upon.

3.3.2.6 Biodiversity

Assessments of impacts on biodiversity are usually concerned with flora, fauna or habitats, all of which are generally affected to some degree by changes to infrastructure. At both strategic and project levels the advice from all three guidance documents is that this will be a qualitative assessment which could include statements on:

- The effects of any damage to habitat;
- Creation of barriers to population movement;
- The presence of rare species; or
- The time taken for recovery.

3.3.2.7 Summary

In summary, it is clear that a range of externalities are documented in the guidance for these road agencies and considered during appraisals. This includes the environment and demonstrates the adaptation and advances that have been made in recent years in widening the scope of road project appraisals but there is still room for improvement.

Firstly, the assessment of the externalities is undertaken either as a purely qualitative assessment or on a quantitative scale that is not consistent with other externalities.

Therefore the ability to compare one externality directly against another remains limited. In order to be able to complete a full economic analysis of costs and benefits, greater consistency of the units of assessment would deliver better transparency and bring additional benefits.

Secondly, the guidance documents are focused on new construction and the impact and importance of some of these factors will be different when considered in the context of maintenance activities. In reality it will mean that not all sub-criteria defined in the guidance documents would be expected to have the same level of impact when considering alternative options for maintenance. There is a need to re-assess the guidance in terms of handling environmental issues in the context of maintenance and management of existing networks.

After accidents and congestion (which are now commonly included in road appraisal models), CE (2007) states that the next largest impacts are from noise and climate change and were selected for further research in this study. These two externalities remain external to appraisal models and therefore there is strong justification in developing a process for including them within the main appraisal mechanism. There are other externalities referred to in the CE report but these have not been included in this research for example, landscape is more relevant at the time of construction (when additional land is taken for road use) but has much less impact at the time of maintenance and potentially no impact if the road alignment does not change.

3.4 Carbon emissions

It has already been discussed that the emissions from transport and related activities contribute to a significant proportion of total national GHG emissions. CO₂ is considered the most important gas in emissions and is a key indicator in assessing global air pollution (DfT, 2009) but it is not the only GHG emitted. Some gases emitted are more potent than others and to enable comparative assessments of emissions, GHGs are

commonly converted to units of equivalent CO₂ (CO₂e). For each gas, the CO₂e is the amount of CO₂ that would be required to have the same impact on the climate (IPCC, 2007). This allows for a comparison of the impacts of all emitted GHGs.

Life-cycle assessments (LCA) refer to environmental impacts being assessed over the life of a product. Carbon accounting, or carbon footprinting, is a specific environmental accounting procedure for assessing the amount of CO₂ and other GHGs associated with a specific activity that has in part been driven by the need to report on GHG emissions. It can be used to assign the respective carbon quantities to the various stages of the life-cycle so that impacts can be better understood and acted upon.

The UK Treasury (HM Treasury, 2002) states that reflecting environmental costs alongside other costs delivers a more dynamic and competitive economy and Hope and Newberry (2006) concluded that by putting a price on carbon it more actively promotes the link between those that emit GHGs and the social costs they impose on society. Therefore, including carbon into assessments has value not just for the option appraisal process but also in making people aware of the impact of their actions and driving change.

Different categories of carbon emissions can be used in assessing transport related emissions. Perhaps the most obvious is the emissions from vehicles, commonly termed vehicle operating costs (VOCs). As the condition and roughness of a road changes so too does the fuel consumption of a vehicle, although because this relationship is driven by roughness it has a limited effect from maintenance when the change in roughness before and after maintenance is limited in magnitude. This is the case on most road networks in the developed world and demonstrated by less than a 1% change in VOCs that was modelled following a 25% reduction in maintenance budget over a 20 year analysis period (Parkman et al., 2012). If vehicle emissions are considered outside of periods of maintenance (i.e. across the whole operational life of a road) they tend to dominate the costs of the works and the huge VOC costs therefore become a driver. In the above report by Parkman et al. (2012) vehicle operating costs were nearly 35 times larger than

the cost of the maintenance. Operational emissions would be relevant for new construction where traffic might be generated (e.g. building a bypass versus not building a bypass) but there would be little change to traffic levels between interventions when considering only different maintenance options because the available road lanes, lengths etc. are not changing.

Carbon emissions from the maintenance activity itself are another source of carbon that can be included in transport assessments. This includes consideration of the embodied carbon within the material and from the machinery used to maintain the road (e.g. extraction of old material and laying of new material). This is directly influenced by the different maintenance options chosen and therefore will be the source of carbon emissions considered for inclusion in this maintenance model.

3.4.1 Pricing carbon

A lot of attention has been given to deriving a price for carbon, with different methods used e.g. taxation, 'shadow' prices or market prices based on trading schemes. The consensus changes and the 'in favour' method (and valuations) can change with time as governments change and debates and legislation evolve, such as with landfill tax which started off as the level necessary to internalise external costs but has evolved to be set at a level suitable to reach agreed targets (Friends of the Earth, 2008).

The Stern Review on the Economics of Climate Change (Stern, 2007) is a key report that brought the issue to the forefront for both academics and politicians. It dramatically stated that immediate action was required to avoid drastic effects on the environment and the benefits realised in the future would far exceed the costs of action. Delaying action however would have significant cost implications. The price of carbon put forward by Stern (and some of the assumptions he used) sparked significant criticism and many debates. Tol (2008a) questioned whether Stern had actually produced a price of carbon that was an outlier when compared to other estimates.

Within Tol's study of the analysis of over 200 estimates of the social cost of carbon the estimate from the Stern review was between the 90th to 94th percentile. From a ranking of the estimates it aligned more with those that had used a low discount rate and had not been peer-reviewed. This was indeed true of the Stern review, having used a near zero discount rate and no peer-review of the work prior to publication. The issue with the low discount rates was that the future costs counted for proportionally more and therefore reduced the impact of the short term costs (Hanley & Barbier, 2009).

There are other studies that have examined the social cost of carbon, based on a measure of the damage done by the emission of an additional unit of CO₂. Tol (2008b) and Anthoff and Tol (2013) argued that the social cost of carbon is highly uncertain due to the range of factors it depends on, a sentiment that is echoed by others (e.g. Clarkson and Deyes, 2002; Pearce and Howarth, 2000). The problems in deriving a social cost of carbon can be categorised into scientific and economic issues:

- Scientific:
 - Measuring current and future emissions;
 - Equating emissions to changes in carbon within the atmosphere;
 - Estimating the impacts from changes (increases) in atmospheric concentrations; and
 - Understanding physical impacts from any changes in climate.
- Economic:
 - Deriving monetary values for non-market impacts;
 - Predicting how the value of the impacts change in the future;
 - Deriving values where income levels vary; and
 - Determining the discount rate to apply.

Estimations of a carbon price have now moved towards a different approach, based on the abatement costs that will be needed to achieve agreed targets, effectively linking the approach more directly to targets (DECC, 2009). But the problems of deriving a social cost of carbon are still valid when deriving abatement costs.

The updated approach to costing carbon has resulted in a 'traded' and 'non-traded' price of carbon up until 2030 from which point they converge into a single value. The problem of setting carbon prices is far more challenging the further we look into the future and this is reflected in the sensitivity bands for the estimated prices, with an estimated uncertainty of $\pm 50\%$ in 2050, rising to $\pm 75\%$ in 2100.

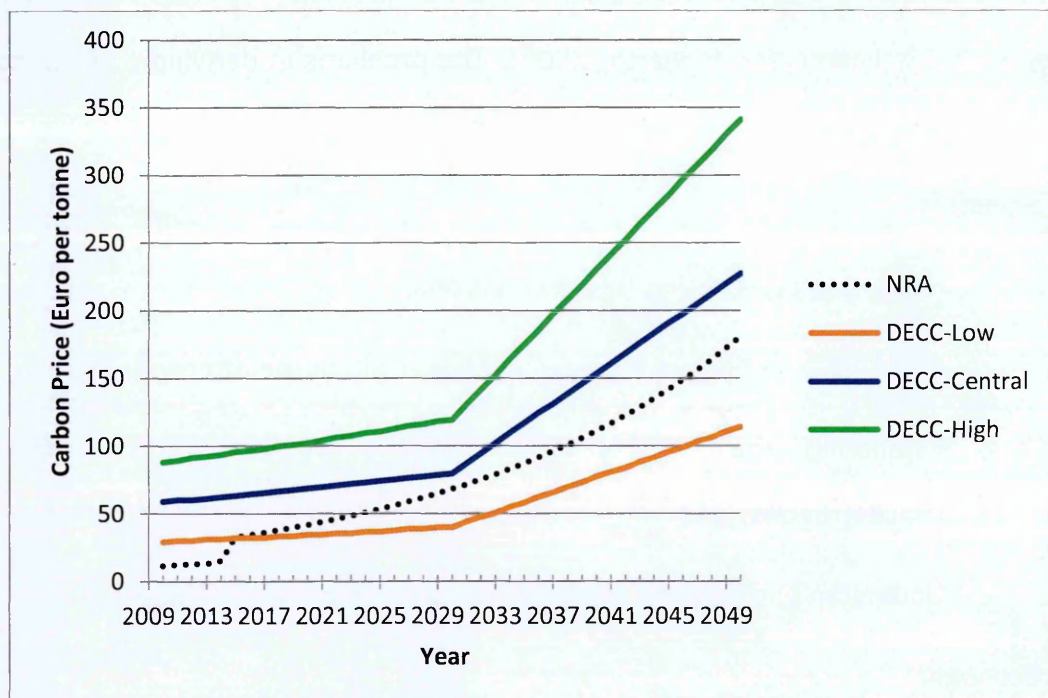


Figure 3-2: The price of carbon as documented by NRA and DECC (in 2010 prices)

The initial prices as detailed in the NRA document start off the lowest out of all the four estimates in Figure 3-2 but from 2030 to 2050 (the period at which non-traded and traded prices of carbon by DECC converge) the NRA estimates align more closely with the DECC-Central estimate. During my stakeholder consultation it became apparent that

the NRA used to use higher rates for carbon assessments but other government departments were not doing carbon analyses themselves. In an effort to introduce carbon accounting across all Irish government departments a set of prices were introduced which had to be adhered to, and that is what is shown in this graph. For the NRA themselves, this resulted in a significant drop in the price of carbon from what they had been using previously but one reason for the low introductory costs was to try and minimise the impact on all government departments, most of whom were only just beginning to assess carbon. For the period of the analyses which were undertaken in this research (i.e. 2013 and beyond) was mostly between the DECC low and central estimates.

The rise in price over time is due to progressively deeper cuts being required in the future in order to meet targets and because the cheaper measures are used in the earlier years, making it more costly to implement measures and technologies to achieve the cuts (ENDS, 2009).

3.4.2 *Discounting carbon*

Actions taken today that result in CO₂ emissions will not just affect current populations but will affect future generations, potentially on a greater scale. Boiteux (no date) asked how can we compare the loss that future generations have to bear with any gains that we might make now? A key question to address is in costing carbon so far into the future, how should discounting be applied to an effect with very long-term impacts? The DfT (2009) advise standard HM Treasury discount rates should be used for standard calculations in net present value calculations. This is a very different stance to the low rates used in the Stern review but it does provide a discount rate that declines over time, therefore representing costs and benefits beyond 30 years as having a greater significance (see Table 3-3). Tol (2008a) noted that in some studies discounting was not used and the monetary values irrespective of the time of occurrence were just added together.

Table 3-3: Green Book discount rates

Years from current year	Discount rate (%)
0-30	3.5
31-75	3.0
76-125	2.5
126-200	2.0
201-300	1.5
301 and over	1.0

(source: DfT, 2012d)

Discounting is a key issue in economic assessments which exhibit long-term uncertainty, such as when considering long-term environmental effects. If discounting is not considered it is effectively equal to using a discount rate of 0% (Pearce et al., 2003). A zero discount rate leads to the assumption that any component in option appraisal is as important at any time in the future as it is now. However, Cline (2007) used a zero rate for pure time preference based upon the argument (originally from Ramsey, 1928) that because future generations cannot be involved in decisions today a zero time preference is the only ethical value suitable for use in investment appraisals.

A zero time preference suggests future generations are just as valuable as those today. If this was really accepted, significantly more would be spent on addressing climate change now. Reality is that we do discount for time and one option is to use a discount rate that declines with time.

While a discount rate is used routinely for discounting direct costs (e.g. cost of construction, maintenance) there is greater uncertainty on the value to use with costs assigned to 'value' parameters. There is no doubt that justification of a discount rate is a fundamental aspect of giving confidence to modelling analyses involving carbon emissions.

3.4.3 Methods and tools for carbon assessments

If carbon quantities can be determined and coupled with appropriate costs, the carbon quantities could be used to calculate carbon costs for asphalt maintenance treatments. A number of tools have been developed with the aim of assessing GHG emissions from various activities.

CHANGER (Calculator for Harmonised Assessment and Normalisation of Greenhouse gas Emissions for Roads) was developed to measure and benchmark GHG emissions in road construction worldwide (CHANGER, 2010; Huang et al., 2012). As with many tools, the GHG emissions are converted into units of CO₂e. One of the goals of CHANGER is to provide a comparison of various road laying techniques and materials, expressed as a carbon footprint per km of road construction.

The National Asphalt Pavement Association (NAPA) produced a GHG calculator for hot mix asphalt manufacture (NAPA, no date). This calculator was based on a gate-to-gate analysis. A cradle-to-gate process looks at the process from extraction to the end of the factory process whereas a gate-to-gate process looks at one process in the production cycle therefore it is a partial LCA. In the case of the NAPA calculator, it estimates emissions based on fuel used in the plant combustion, fuel used by the plant equipment and vehicles and power used from the grid, within the boundaries of the gate process. Therefore, the calculator does not provide outputs required for a full cradle-to-gate maintenance process (for example the removal of the existing material and laying of the new material).

Forum for the Future and Fife Council developed a tool to help the council's procurement team meet carbon reduction targets (Forum for the Future, 2009). The tool has been designed to evaluate different options put forward by suppliers using CO₂ emissions as a key output, both as a quantity (tonnes) and a cost (£). It was hoped that the tool might encourage suppliers to change their actions in response to sustainability issues. The availability of tools themselves can help drive change and improvements in both data

availability and stakeholder behaviour and is one reason why tools like this should not wait until all the data or products are available before being developed.

In estimating carbon emissions for different options the DfT (2009) advises that estimates of the emissions should be calculated for 'Do-Minimum' and 'Do-Something' options, preferably resulting in a monetary value being produced, with additional sensitivity analyses around the price of carbon.

asPECT (asphalt Pavement Embodied Carbon Tool) provides a framework to calculate GHG emissions of asphalt in highways (Wayman et al., 2009) by using values of CO₂e per tonne of mixture to estimate the emissions over the full life-cycle of the asphalt pavement. The tool takes account of the CO₂ impact of building or maintaining a road, following the requirements laid out in BSI PAS 2050:2008. The protocol clauses within the software have been endorsed by the Highways Agency (HA), Mineral Products Association (MPA), Refined Bitumen Association (RBA) and the Association of Directors of Environment, Economy, Planning and Transport (ADEPT).

The tool calculates the CO₂ content of individual asphalt mixtures through a summation of the:

- Cradle-to-gate CO₂e from each constituent and ancillary material;
- Transport from the factory gate to the plant;
- CO₂e all of energy used to produce the asphalt at the mixing plant (except that used for heating and drying);
- CO₂e from the process of heating and drying the mixture and ancillary materials;
- Transportation to site;
- Energy from laying and compacting; and
- CO₂e from additional materials used on site.

If a full cradle-to-grave analysis is being completed then it considers the CO₂e used for excavating the material at the end of life.

The New Pavement Treatment Embodied Carbon Tool (PROTECT) has been developed for six surface treatments (RSTA, no date) with Surface Dressing being the treatment of most relevance to the Irish network. As with asPECT, it is PAS 2050 compliant and works along similar principles by allowing materials, plant, jobs and other data to be used to determine the carbon footprints of products.

An Environmental Product Declaration (EPD) is a standardised, certified environmental declaration that is developed in order to document the environmental performance of a particular product or system. Whilst not a tool itself, the outcomes from a carbon calculator should be capable of fitting this standard.

The declaration is based on a life cycle assessment, having been developed in accordance with ISO standards. The pioneers of this framework assessment are the Swedish Environmental Management Council, with the programme partly developed to meet the information needs demanded from the supply chains, as well as having the information to use for other applications such as marketing.

BS EN 15804¹⁷ (2012) provides the approach to ensure that EPDs in the 'construction, construction products and construction services' category are all derived in a consistent manner, in accordance with EN ISO 14025¹⁸. The standards set out what are referred to as core 'Product Category Rules' (PCRs) whose role is to:

- Define the parameters that need to be declared, collated and reported; and
- Describe which stages of the life-cycle are considered within the EPD (e.g. cradle-to-gate, cradle-to-grave).

The programme is voluntary and that in part may explain why there is a limited number of products currently included. As of January 2013 there were 400 EPDs documented for

¹⁷ Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products.

¹⁸ Environmental labels and declarations – Type III environmental declarations – Principles and procedures

products broken down into 200 organisations across 16 countries. With 'construction, construction products and construction services' being just one category within the overall range of EPDs it is no surprise that there are currently no EPDs that could be used specifically in this work, especially considering that they are often created for proprietary products rather than the more generic treatments required in a network level model.

In making carbon emission estimates using life-cycle assessment or carbon calculators there are a lot of assumptions and methodological choices that have to be made. These are considered in the development of the specific methodologies as part of this research.

3.5 Noise

Noise is the other externality that this research is addressing for inclusion in road maintenance scheme appraisals. Noise is not just an annoyance but it can also cause significant health impacts. The WHO definition of health relates to physical, mental and social well-being, not just the absence of disease or infirmity. The potential health impacts of road noise are apparent from the documented impacts on people through interference with communication, sleep disturbance, cardiovascular effects etc. (Muller-Wenk and Hofstetter, 2003; Kluger, et al., 2004). Indeed, Babisch (2006) reported that road traffic noise exceeding 65dB(A) during the day has been found to increase the risk of heart attacks in men by 20%.

Noise is one of the environmental impacts that road agencies assess in a quantitative way. The most common approach for valuing transport noise is through the use of hedonic pricing studies. Hedonic pricing studies estimate the monetary value of property characteristics by looking at the differences people pay for properties that exhibit different characteristics, noise being one of the characteristics. There may be a number of reasons for a difference in price between properties and so all factors that might influence the property price need to be examined (e.g. proximity to transport links, good schools, size etc).

There have been many pricing studies with the aim of using market prices to deduce the expected reduction in property value for an increase of 1 dB(A) (Table 3-4).

Table 3-4: Property price reductions due to noise

Research	Reduction (%)
Lake et al., (2000)	0.20
Noise & Vibration Worldwide (2004): Average	0.20
Noise & Vibration Worldwide (2004): US specific	0.08-2.22
Noise & Vibration Worldwide (2004): Canada specific	0.42-1.05
Noise & Vibration Worldwide (2004): Norway specific	0.21-0.54
Noise & Vibration Worldwide (2004): Japan specific	0.70
Noise & Vibration Worldwide (2004): Switzerland specific	0.90
Noise & Vibration Worldwide (2004): Australia specific	1
Noise & Vibration Worldwide (2004): Finland specific	0.36
Hofstetter and Muller-Wenk (2005)	0.6-1.2
Nelson (2007)	0.54
Litman (2009)	0.5
Brandt and Maennig (2011)	0.23

(source: various, see 'Research' column)

Nijland and Wee (2008) state that people are not normally aware of the impacts of noise beyond general annoyance (and possibly sleep disturbance). Therefore it is only essentially these factors that determine the monetary value when based on market preferences, meaning the true cost of noise could be even higher.

Whatever the differences are within the estimates of the cost of noise the sheer scale of the issue and the need to address it is clear. In Switzerland the external cost of noise has been estimated at over CHF 1 billion per year, with 90% of that attributed to reduced property prices and 10% to the cost of health impacts (Muller-Wenk and Hofstetter, 2003).

Differences in the threshold level for measuring noise and interpreting its effects will also impact any derived costs. Nijland and Wee (2008) stated that the usual threshold at

which noise impacts were considered is 50 dB or above, although this is far from consistent. For example, the UK use a threshold of 45 dB and France and the Netherlands use 55 dB. This difference in thresholds might also be important if data or rules are transferred for use elsewhere because the effect on hedonic pricing of increased noise levels is not consistent; an increase from a higher noise level has the potential to cause a sharper decrease in property price (Kruitwagen et al., no date).

For modelling the cost impacts of noise within pavement life cycle analyses, a number of approaches have been documented. The Noise Sub-Objective (DfT, 2012c) (which forms part of the WebTag guidance from the Department for Transport, UK) advises that if there is data available on either the number of properties or people affected by noise changes then a valuation study should be attempted. But in an assessment of noise is it better that a large number of people benefit from a lower reduction, or a smaller number of people benefit from a higher noise reduction? (Ausejo et al., 2011). By developing a model with noise effects integrated into the analysis these sorts of questions can be investigated and evaluated.

Chandler et al., (2003) assessed how noise from different types of pavement surfaces in-service increased with time. They used different average noise levels for the surfaces in the first 12 months of pavement life and modelled how this changed with trafficking. The studies concluded that at the time of laying, noise levels for thin surfacings were similar or slightly less than for exposed aggregate concrete surfaces but the rate of increase of noise was greater for thin surfacing's. In terms of whole-life cost analysis it is important to consider not just the noise level at construction or when a pavement surface is new, but also the degradation of noise level through the life of the pavement.

Veisten and Akhtar (2011) estimated noise benefits using estimated noise level changes over the life of a pavement surface and a monetised value per dB decrease per dwelling affected by the noise per year. The modelling used lookup values for different pavement surfaces and considered:

- Initial noise level;
- Averaged noise change over lifetime; and
- Average surface lifetime.

In a practical application, Kent Highway Services (2008) produced a method for prioritising their investment on using quieter surfacing options. The factors considered were:

- Noise benefits (reduction in noise) following resurfacing, based on the reduction of number of people annoyed, using relationships between nuisance and noise;
- The change in the number of people annoyed between maintenance scenarios; and
- Cost of carrying out the maintenance.

The proposed maintenance lengths were prioritised in the order of greatest noise benefit and lowest cost through to least noise benefit and highest costs. Therefore, although the externality was included within the prioritisation it was still as a separate measure alongside the works costs (i.e. in a non-monetised approach for noise).

3.6 Whole-life value

Whole-life value (WLV) assessments include factors that drive value and consider more than just the 'direct' costs. It is an extension of whole-life cost (WLC), where WLC aims to identify the minimum cost over a defined life.

WLV can include additional benefits over WLC (Bourke, et al., 2005):

- Stakeholder involvement;
- Whole life planning, whilst also giving rise to innovation; and
- Sustainable development.

The concept of externalities was introduced in the first chapter and has been discussed further in this chapter. Internalising externalities can enable the evaluation of the economic, social and environmental impacts within one central assessment.

Value assessments can include various aspects of sustainability in the design, construction, operation, deconstruction and where appropriate, re-use of the components of a built asset or its properties. It requires compromise and synergy between economic, social and environmental values (Waterman and Bourke, 2004) through establishing and understanding the needs of stakeholders. In the development of road maintenance programmes these needs have largely been considered externally if at all, rather than within the main analysis. WLV enables a balance between stakeholders' needs, opinions and priorities on the one hand and costs on the other.

What we are seeing now is that the parameters which were traditionally external to investment appraisals are gradually being considered within project appraisals, although the extent of internalisation is variable. For example, greenhouse gases included as a parameter within a construction assessment for high-speed rail (Chang and Kendall, 2011) or the visual impacts of siting off-shore wind farms (Landenburg et al., 2005). Both of those studies had a noticeable omission of any cost-data for the environmental assessments, ruling the environment out of a full cost-benefit analysis.

3.7 Summary

The literature review has shown that whilst there are stand-alone tools available that can be used for a preliminary assessment of some environmental elements at the scheme level, there is a lack of consistent methodologies and robust tools for monetising externalities at all levels. For example, there are tools for the assessment of the environmental impacts of construction and maintenance of various assets but they have generally been designed to be complementary to a costing process and not as methodologies to be incorporated into wider cost assessments.

Pricing carbon and noise internally within a network level pavement maintenance model will advance our understanding of how the impacts of these externalities can influence the overall cost and the development of strategies for road maintenance programmes. However, from a practical point of view few models routinely include monetised estimates of environmental effects because of the difficulties associated with the monetisation process (e.g. Hofstetter and Muller-Wenk, 2005; Hanley and Barbier, 2009).

The highway sector is under increasing pressure to reduce carbon emissions and an integrated whole-life cost tool will support the decision making process. Even with the availability of cost data (e.g. government recommended non-traded prices of carbon), pricing carbon within the framework for making road maintenance decisions is likely to be a contentious issue for some stakeholders. For example, just because an option might have the lowest total cost (of all monetised parameters) it doesn't automatically mean it should be chosen. As discussed, there might be other constraints (e.g. emissions targets) that need to be met in conjunction with the monetisation of externalities. Therefore to have a robust tool that can prioritise against environmental externalities, additional expressions of the constraints of the environmental parameters (e.g. carbon caps) would be needed alongside any monetisation.

Integrating noise with a whole-life cost model for the Irish road network presents different challenges. There is a clear body of work that has pushed forward the monetisation of noise effects and subsequently, with specific relevance to the highway sector, cost-benefit analyses for low noise surfaces. However, there is a lack of historic property prices which causes problems for hedonic pricing studies (Ozdemiroglu and Bullock, 2002). Equally, caution has to be exercised in transferring benefits from studies carried out in other countries (Morrison et al., 2002).

What would be interesting and useful is to develop the capability to evaluate the benefits and costs of different pavement surfaces taking account of differences in direct costs (construction and maintenance), expected life time and the noise impacts over the life

time (e.g. building on the approach of Veitsen and Akhtar (2011)). The analysis could be specifically useful when the same type of pavement can lead to different cost benefits at different locations (e.g. a lower noise but higher cost surface in a highly populated location compared to a more rural location).

Overall, although methods exist to help monetise externalities, no one method is documented as the most appropriate to use. The definition of value can be different for different stakeholders and this will need to be managed, particularly where it has an influence on how some of the 'value' elements are quantified and monetised for internalisation. Involving stakeholders in the decisions increase the strength of outputs and is important in developing these methodologies. It allows stakeholders to comment at an early stage of the development and for the development to align with their needs where possible (once those needs are known).

Incorporating the additional value measures into a modelling framework for cost-benefit analyses will enable greater accountability and consistency and it will allow project appraisals to address a wider remit of parameters. However, even with studies that appear to explicitly include environmental aspects, a lack of a uniform assessment measure (e.g. cost) precludes a full integration of parameters, resulting in a siloed approach.

Whatever pricing is used for carbon and noise, it will be important to carry out suitable analysis of the sensitivity around the inputs (Hormandinger and Lucas, 1996). Allowing for flexibility in modelled discount rates will present a further opportunity to undertake sensitivity analysis around contentious assumptions (Stern, 2007).

Chapter 4 Understanding stakeholder requirements

The third research objective is to develop methodologies to enable the impacts of carbon and noise from road maintenance to be integrated within a network level pavement whole-life value model. The level of importance that is placed on those impacts is different amongst the different stakeholders, who may have varying objectives. Any methodology needs to be capable of representing the different stakeholder needs. This chapter reports on the consultations that were completed to understand the stakeholder needs, which were used when developing methodologies for modelling carbon and noise impacts from road maintenance.

Emissions targets (Frankhauser et al., 2009) and the European Noise Directive (Directive 2002/49/EC, 2002) have led to increasing pressure on road agencies to minimise the negative impacts of carbon and noise impacts; option appraisal is a means to do that. The literature review demonstrated that whilst some externalities are considered in maintenance appraisal guidelines, there is a lack of methodologies and tools for modelling externalities at a network level (see section 3.3). When considered alongside the growing recognition that appraisal assessments need to take greater account of externalities this lack of tools translates into an inability for road authorities to perform network level assessments inclusive of externalities.

The recognition that the expectations and requirements of all stakeholders should be acknowledged has resulted in stakeholder participation experiencing greater use, particularly in the environmental discipline (Reed, 2008). The process of engaging key stakeholders is an important aspect of the planning stages of large projects. It may not always be easy to engage at the right level with all the stakeholders but it can provide the basis for managing their expectations (GHD, 2009; LSC, 2009).

4.1 Consultations

It is good practice to involve stakeholders in making decisions on situations that affect them (Baran & Jantunen, 2004; Environment Council, 2004). This not only leads to a wider viewpoint being considered but if done at the right time in a project it promotes early dialogue with the people who will be affected by the decisions, resulting in wider acceptance and buy-in.

The Carbon Trust and Defra (Stakeholder Consultation, [no date]) recognised this in their consultations during the development of PAS 2050¹⁹ when there was a well-structured consultation exercise using both a key stakeholder group and a review panel. The consultations provided approximately one thousand organisations and individuals from a range of industries both within and outside of the UK the chance to put forward their views and requirements on the development of the standard.

There is a need to embed 'sustainability' into investment decisions in order to consider issues from the planning stage but there are difficulties in measuring and assessing sustainability issues. Stakeholder consultation is one valued method used in many studies and a meta-analysis of 239 case studies argued there was good evidence that stakeholder involvement resulted in higher-quality outputs (Bierle, 2002).

4.1.1 Stakeholder influence

Arnstein (1969) presented the concept of stakeholder influence as an eight rung ladder whereby each higher rung on the ladder represented a greater level of participation (Figure 4-1).

¹⁹ PAS 2050 was developed by the British Standards Institute to provide a common assessment method of the life cycle greenhouse gas emissions of goods and services in 2008 and has been recently revised (BSI PAS 2050:2011)



Figure 4-1: Arnstein's ladder of participation

Similar to Arnstein’s ladder, the International Association for Public Participation (IAP, 2007) documented the increasing levels of public impact through their ‘spectrum of participation’ (Figure 4-2).

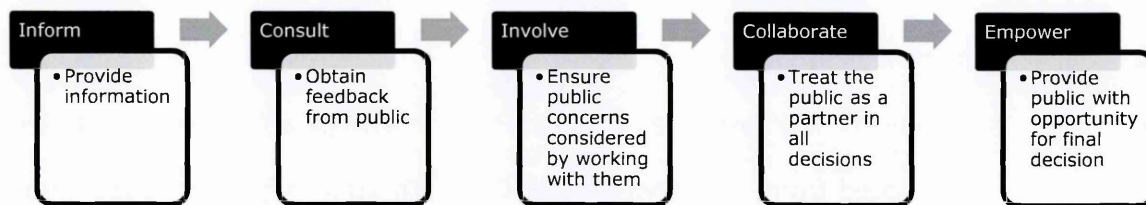


Figure 4-2: Public impact levels (adapted from IAP, 2007)

There is strong evidence to support the suggestion that involvement of stakeholders will add value through their participation. However there are multiple ways in which consultations can actually happen and the types of questions and decisions that need addressing whilst planning any consultations include (adapted from Baran & Jantunen, 2004 and Videira et al., 2006):

- What level of involvement is desired?
- Who should be included?
- How many participants are required?

- What is the knowledge level of the participants?
- At what stage do the participants become involved?
- How will participants be consulted?
- What outputs are the participants looking to address?
- What impact will they have on the resultant decisions?
- What language or terms might represent technical barriers?
- Do the participants need to be grouped to prevent any perceived cultural or social differences preventing a full gathering of opinions?

A balance has to be struck between all these issues so that the consultations achieve the desired outcome. For example, too few stakeholders would mean that key opinions may not be heard or that bias is introduced but having too many stakeholders could lead to 'infobesity' (too much information).

4.1.2 Consultation principles

Table 4-1 lists a number of key principles that can help to ensure effective consultation with stakeholders (adapted from The Environment Council's 2004 paper on consultation within the aggregate sector).

Table 4-1: Key principles and their associated value in stakeholder consultation

Principle	Value of using principle
Inclusive	Inclusivity leads to a wide level of stakeholders consulted. Some groups (e.g. marginalised) may require considerable effort in order to be included and it is important to bring together stakeholders who might either have an interest in the subject, or alternatively who might be affected by any outcome.
Transparency	Makes any information clear and open and makes sure it is understood by all groups concerned. Informs people at what stage(s) in the process they can contribute.
Independence	A neutral facilitator can help to build confidence in the stakeholders being consulted.
Commitment	Makes sure that the consultation has the resources and priority that it requires. The effort required to understand the opinions expressed by those consulted should not be underestimated.
Accessibility	Allowing people/organisations to be involved in different ways is a fair way of consultation and can lead to a wider response.
Accountability	Acknowledging contributions and communicating on how those consulted have contributed to the process keeps stakeholders aware of any final outcomes.
Resources	The process of communicating with the required stakeholders can take considerable resources. The effort required should be fully estimated so that resources can be properly planned to aide its completion. A lack of resources can undermine the whole process, losing support from stakeholders.

(source: adapted from The Environment Council, 2004)

4.1.3 Survey instruments and survey design

Surveys are a common method used to collect data or opinions and are used by government departments, university academics and other organisations (May, 2001).

They can vary from small scale surveys to very large surveys of several thousand people. Irrespective of the size of the surveys, a common factor is that they are aiming to engage with a sample of the population in order to determine the opinions of that population.

If a questionnaire is employed as a means of undertaking a survey (as opposed to focus groups for example) the type of questionnaire used will be determined by the population chosen, the type of questions being asked and the resources available for the questionnaire. May (2001) states that data collection is generally carried out through the use of one of the following questioning methods:

- Mail or self-completion questionnaire;
- Telephone questionnaire; or
- Face-to-face interview.

An additional type of questionnaire distribution not listed above would be internet based administered surveys. Mail or self-completion questionnaires are generally cheap in terms of data collection but once sent out, the control over the questionnaire by the researcher is lost and the response rate tends to be fairly low. Because the questions are written down there is no bias in how they are asked by an interviewer, but conversely it means that there is no interviewer present to elicit any additional information following responses to the questions. In a similar way to the mail surveys, telephone questionnaires are relatively cheap to undertake. However, the interviewer tends not to be able to elicit such detailed information as with a face-to-face interview. Face-to-face interviews required more resource (in time and costs) to undertake but the response rate can be high and the interviewer is able to keep better control over the situation.

What May (2001) alludes to from these points is that the design of the questionnaire depends significantly on the audience and the manner in which it will be completed. Once the stakeholders have been identified, the design of the questionnaire can be formulated and attention can be given to the issues that Gill and Johnson (2002) discuss, such as

the phraseology of the questions, the types of response that are expected, the ordering of questions and the overall presentation of the survey. At this point in the consultation effort should also be given to considering what analysis is expected from the results because this will also have an influence over the questions asked.

Design issues that will need to be considered and justified are:

- Format:
 - Focus: This refers to the level to which the questions cover the topic(s) being addressed. This also needs to consider that the questions go to the appropriate level of detail to get the most from the issues whilst remaining focused on the topic(s) and not including unnecessary questions.
 - Phraseology: Making sure that the questions asked are comprehensible and understandable to the respondents of the survey. An obvious important step in assessing this will be through the use of a suitable pilot study. The questions should prohibit bias from being introduced. If questions are sensitive in their nature, time is required to consider how they can be appropriately asked.
 - Necessary form of response: The information obtained needs to be able to be used in the research for which it is designed. This will have an impact upon the types of questions asked and also the response that is expected from the respondent. For example, which questions are suitable to be asked as open questions and which ones as closed questions. For those questions where it is most appropriate for the respondent to respond on a scale, what is the most appropriate scale?
 - Sequencing and presentation: The sequencing of the questionnaire will also be influenced by the way it is conducted. For example, a postal questionnaire will need to be set out very clearly for the respondent to guide themselves through it. However, a face-to-face interview allows

some extra flexibility and descriptions due to the interviewer being present. Issues such as conciseness, clarity, design and attractiveness of the questionnaire will influence the response rate. A covering letter can be expected to have an effect on the completion rate, as can other simple considerations such as a stamped addressed envelope for postal surveys.

- **Piloting study:** A pilot study allows for a trial run through of the research design with a subset of respondents. It is proposed that an internal pilot is completed first as the response rate is likely to be easier to follow up.
- **Data analysis and using findings:** A crucial aspect of designing the survey is to consider the analysis that is required to be completed on the returned data. This may have a considerable impact upon the types of questions that can be asked and the method through which respondents are subsequently expected to respond. Consideration should also be given to how long it would take to obtain the data from all returned surveys and make use of it in any analysis.

4.1.4 Sampling

At some point in the collection of data it needs to be decided what population is to be consulted (Gill & Johnson, 2002) and how they will be sampled (Bryman, 2001). For example, road users may have been identified as one of the groups of stakeholders that should be consulted during a consultation. However, it would not be appropriate to consult all road users and a sample of that group (e.g. freight operators/drivers, motorists, motorcyclists, cyclists, pedestrians, vulnerable users or combinations of those groups) might be selected.

Bryman (2001) states that when selecting a sample from a population there will inevitably be some sampling error between the sample and the population it is selected from. However, the job of the researcher is to limit the error to a minimum and work to reduce bias. To continue with the above example of consulting road users, the time of

day that any focus groups are held might be a further limiting factor on the selected sample.

The selection of a sample population may depend on a number of things, which include:

- Number of stakeholders identified;
- Timescale for the consultation; and
- Resources for the consultation.

Punch (1998) suggests that sampling has become less sophisticated, in part due to moving away from larger samples in qualitative studies and also due to difficulties with getting access to large samples. He further goes on to say that it is often the case that researchers will find themselves in the position of having to accept whatever sample is available to them. Whatever the sample is, the primary end-goal is to be able to make an inference for the whole population that the sample is meant to represent. The question that therefore needs considering is how representative is the sample of the actual population?

4.2 Consultation planning

The stakeholder consultation was designed to explore the perceptions of key stakeholders (such as managers and users of the pavement network) whose expectations and opinions would add depth and information to the development of the rules and algorithms to drive the modelling.

The consultations explored the background to environmental value elements through engagement with different stakeholder groups, for example policy makers, asset owners and road users. The different groups provided insights into their expectations, needs and requirements surrounding the carbon and noise impacts of maintenance.

It is important that stakeholders are given an understanding of the level of impact they can be expected to have on the research. This allows the stakeholders to understand

where they can contribute best and it provides facilitators with an understanding of what is expected from the different stakeholders.

4.2.1 Aims of this consultation

Road agencies are committed to responding to the needs and requirements of their stakeholders, whether they are high-level policy makers or road users. This is demonstrated by a recent European funded project, Stakeholders' Expectations and Perceptions of the future Road Transport System (EXPECT) that focused on developing a methodology that could be implemented by road authorities to address the high-level objective of meeting the needs of stakeholders (EXPECT, 2012).

The consultation process in this research drew on elements of a project developed methodology where appropriate, such as in the use of supporting material to use during focus groups.

The consultation process (see Figure 4-3) in this research was designed to:

- 1) Gather opinions from topic experts;
- 2) Inform the development of methodologies for value parameters;
- 3) Inform consultations with a wider audience;
- 4) Obtain information required for the development of a cost model; and
- 5) Be an iterative process that evolved as further consultations were completed.

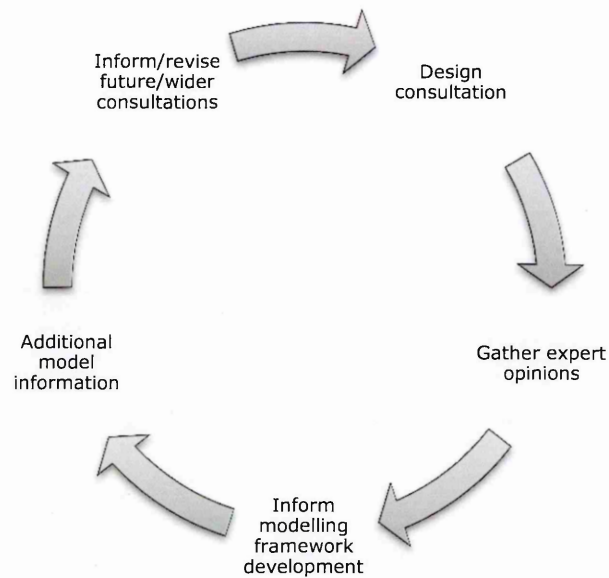


Figure 4-3: Consultation aims

The methodology for the stakeholder consultation process and what it was set up to achieve is described below:

- Determine the 'value' placed by key expert stakeholders from within the Road Agency on the impacts of carbon and noise externalities as a consequence of their network maintenance management strategies;
- Determine if there were groups/individuals who should be consulted who were not initially identified;
- Determine the 'value' placed by public users on carbon and noise externalities related to the road network, in particular due to maintenance activity;
- Inform the development of methodologies for modelling carbon and noise; and
- Include 'value' parameters within an economic model and prioritisation framework.

4.2.2 Identification of stakeholders

The stakeholders for this consultation were those individuals or groups who can influence, or be affected by maintenance activities carried out on the Irish national road network. This included those who set high-level maintenance policies, those responsible for their implementation as well as the general users of the road network. It is the responsibility of a road authority to balance the expectations, requirements and needs of all the different stakeholders and reflect the different views in the policies driving maintenance decisions.

Stakeholders providing a cross-section of industry, expert and general opinion were identified for consultation on the topic of modelling carbon and noise impacts from road maintenance. They were chosen to participate either because:

- They held expert and/or operational knowledge that could be used to influence the modelling methodologies; or
- Their perceptions and experiences on the road network would provide input to the modelling methodologies.

For the qualitative research being undertaken in these individual consultations the stakeholders were identified as above so it was very much a targeted sample but it had to be in terms of the specialist discussions that were required. However, the sample was also allowed to grow through snowball-sampling, where the sample grows more organically through the networks of people already consulted (Bryman, 2001). Bryman also noted that this is a valid method of selection where a population might be shifting (e.g. changes in organisational structures).

Figure 4-4 represents who the stakeholders are in the context of this research. It shows the groups and individuals that were consulted and the relevance of why they were chosen.

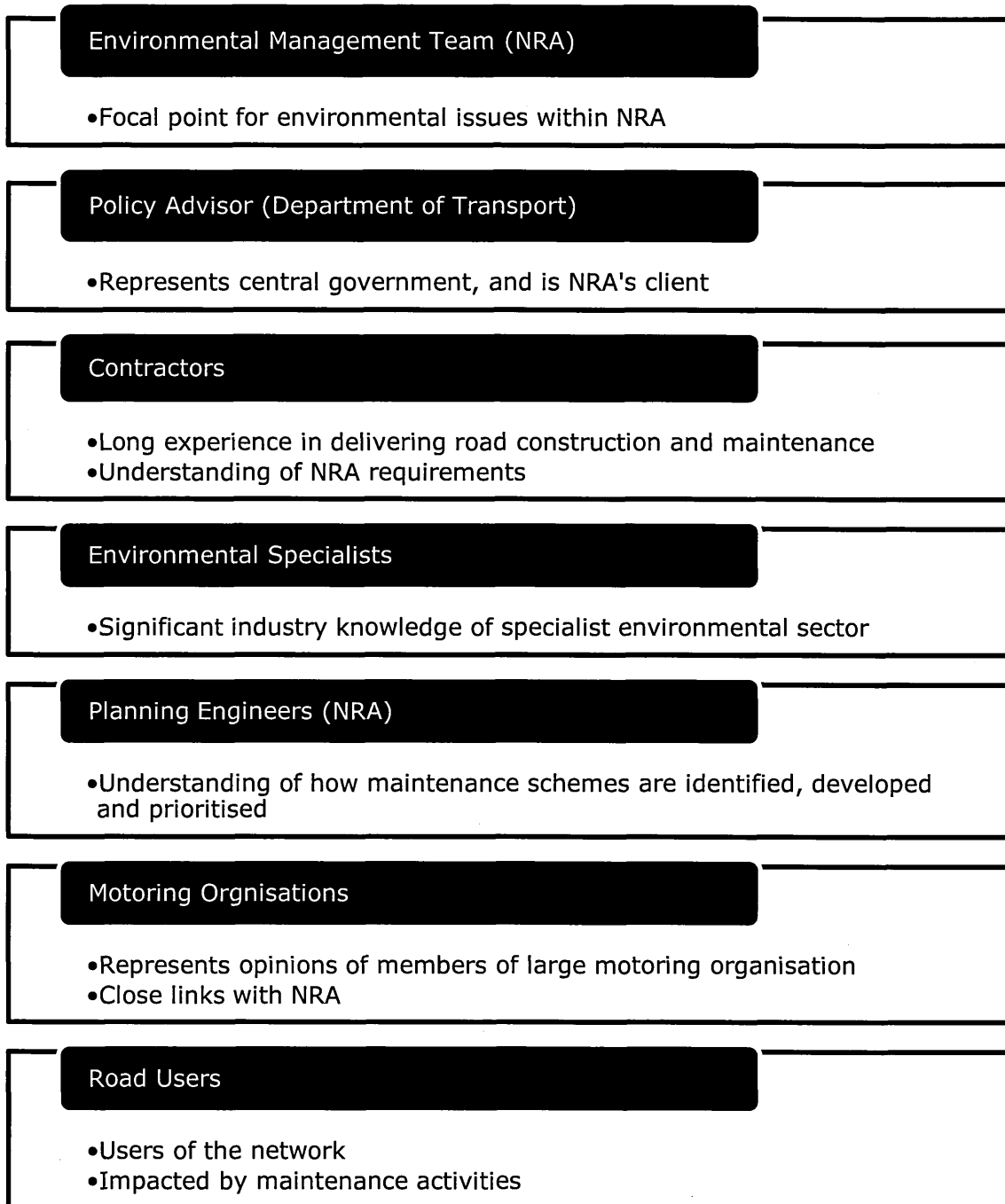


Figure 4-4: Key stakeholders consulted and their relevance

4.2.3 Design of this consultation

The consultations were designed to operate in a phased manner for a number of reasons:

- 1) It enabled the process to evolve as initial findings were made, or where gaps in information still existed;

- 2) It allowed different consultation methods to be used for stakeholders who were expected to participate in different phases;
- 3) It allowed additional categories of stakeholders to be identified for consultation in later phases; and
- 4) It allowed for greater flexibility in meeting the aims of the consultation (which were themselves designed as a cyclical concept).

This resulted in three phases of consultation being identified:

- 1) Individual interviews with high-level policy makers;
- 2) Individual interviews with topic specific experts; and
- 3) Focus groups with road users.

Figure 4-5 shows how the information was shared between the different phases of the consultation. The increasing size of each phase indicates the increase in the size of the consultations.

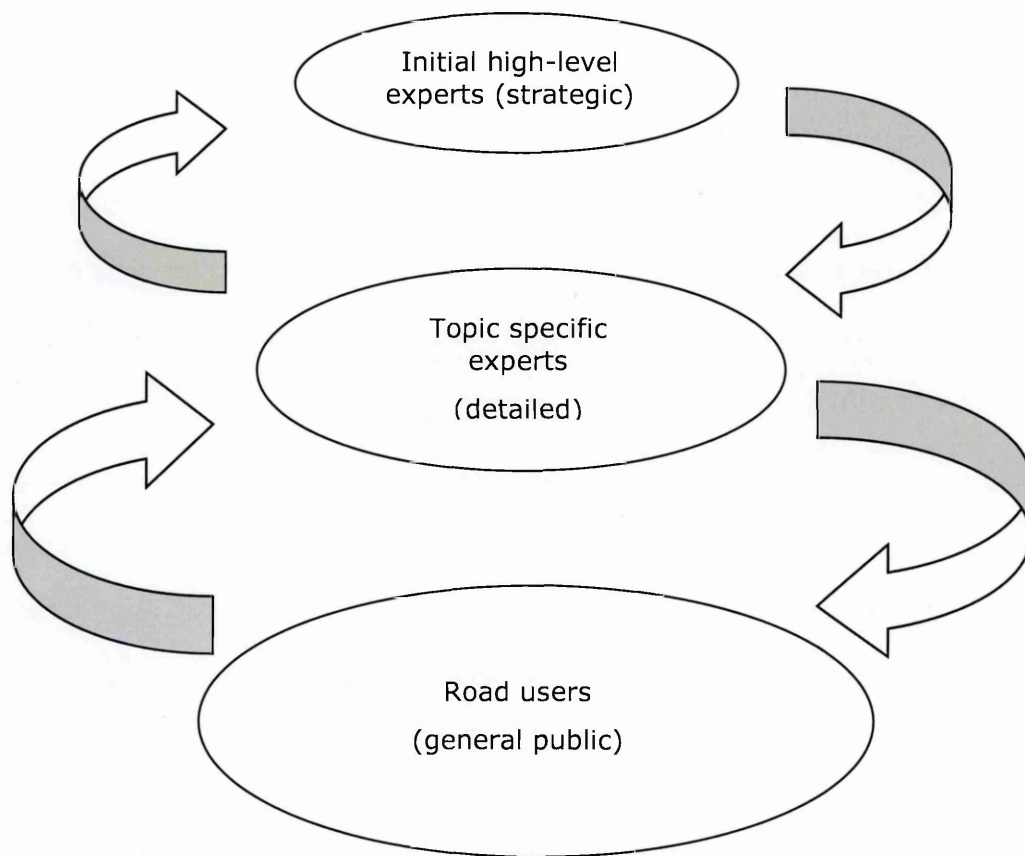


Figure 4-5: Information shared through different stages of the consultation

The approach was designed so that information obtained in earlier phases could be shared across the consultation for the benefit of other stages. The information obtained at each stage was cross-referenced against the information from earlier phases to identify both consistencies and inconsistencies between the responses.

To monitor the consultations a SWOT analysis was carried out after each phase of expert consultation. A SWOT analysis is a method that is used to record Strengths, Weaknesses, Opportunities and Threats within a project. This SWOT analysis was measuring against the end objective of 'Developing methodologies to include environmental parameters in a whole life value model' (see Appendix C and Appendix D).

The SWOT analyses allowed an assessment of the contribution of information from different phases and where there were gaps that needed addressing in future phases. By using the information obtained from later phases and matching it against previously

identified gaps it was possible to get a better understanding of where the future focus needed to be.

The information cascading down through the stages came directly from the preceding consultations and was used to refine the questions asked of future participants. For example, both strategic and topic specific experts proposed that users would not be concerned with the environment. When the users were consulted this preceding opinion of them was one item that was explored.

The consultations started with the individual experts and finished with the road users and no further consultations were held after those. However, the discussions and opinions that had been generated from the consultation process as a whole (and later the proposed modelling methodologies) were fed back to experts to close the loop and encourage their further feedback on the results of the consultation and the influence it had on the research.

All stages of the consultations were recorded with the participants' permission (except for one individual consultation where the participant requested not to be recorded) and transcripts were made of all the discussions which were then analysed.

4.2.4 Addressing the key consultation principles

Section 4.2.4 described key principles for successful consultations and those principles were considered in the design of these consultations to aim for more reliable processes and outputs. The principles were addressed as follows:

- Inclusive: A wide range of stakeholders were asked to be part of the consultations, ranging from topic specific experts to road users.
- Transparency: Significant time was given to the planning stages of the consultation and the development of a transparent topic guide which was presented to all identified stakeholders to encourage them to sign up to the consultation. The result was that all groups and/or individuals initially identified

agreed to take part in the consultation, thereby leading to the desired depth and breadth of stakeholders contributing to the research.

- **Independence:** Due to the depth of topics being discussed the individual consultations were facilitated by the researcher. In the case of the focus groups however, an additional facilitator attended in order that no points were missed and all users had a chance to comment. This was particularly useful when the groups divided to undertake exercises.
- **Commitment:** Significant planning went into the consultations and resources were allocated to this. No recruitment of stakeholders began until the material was fully written and reviewed (and trialled) appropriately.
- **Accessibility:** The consultations were flexible in their approach, location, setup etc. to enable as many requested stakeholders to attend as possible.
- **Accountability:** All documented contributions from the consultations were acknowledged accordingly but were anonymised for reporting. Feedback from the individual consultations was discussed with key NRA stakeholders after the consultations.
- **Resources:** As expected, significant time was required for the consultations both for planning and undertaking them. However, large amounts of time had been allocated from the beginning which resulted in no planning or consultations exercises having to be cut at any stage.

4.3 Individual consultations

The individual consultations with experts were split into two phases (Figure 4-5) and the process for making contact with the participants was iterative, focusing on gaining face-to-face consultations with predetermined experts but being flexible to include additional experts if appropriate or necessary.

Following initial contact with the individuals the same background note was sent to all participants to provide information on the aims of the consultation, the themes for discussion, along with a number of questions to prompt them into thinking about the information and opinions required (Appendix E). The background note was a key part in setting up the consultations (Figure 4-6).

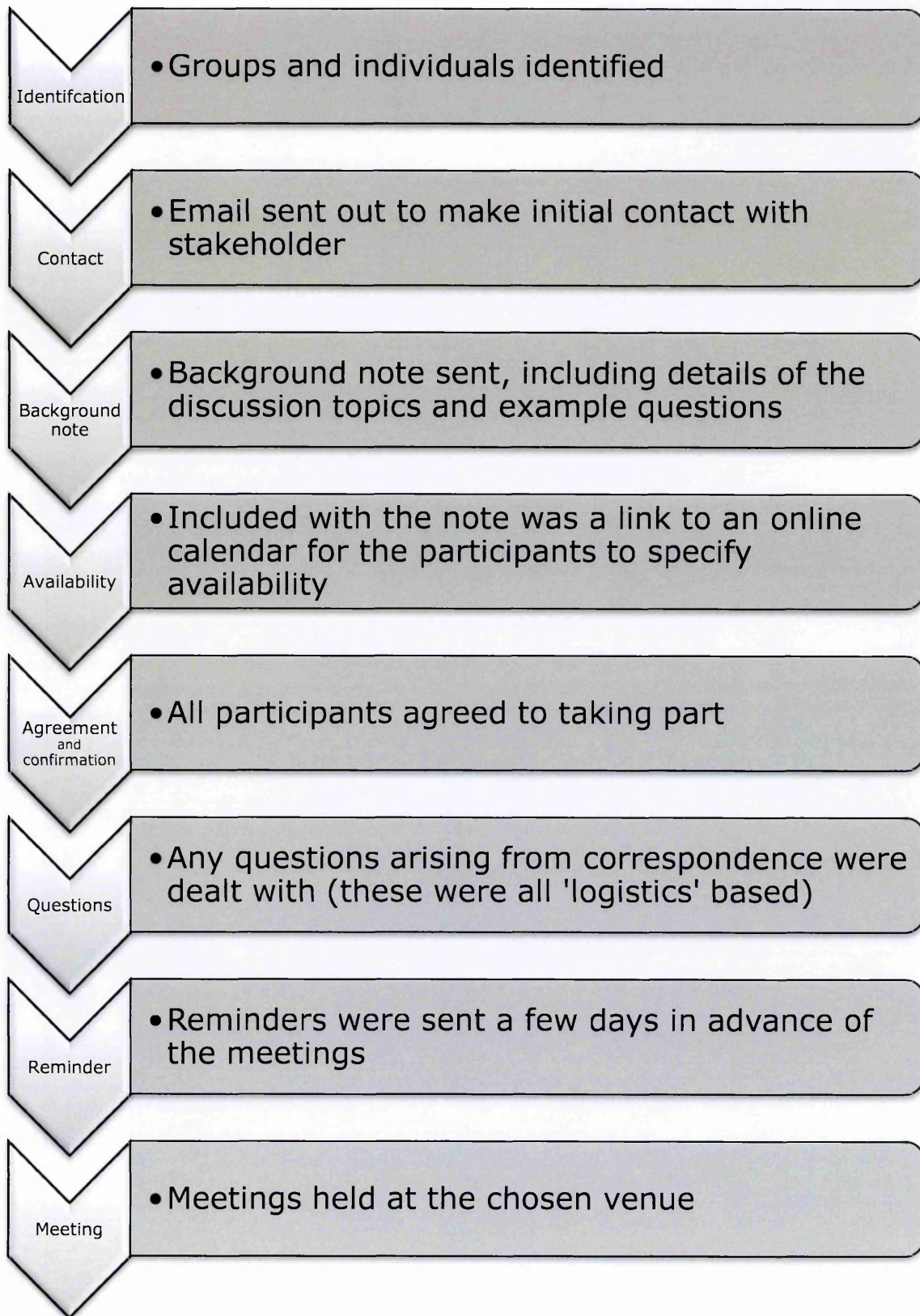


Figure 4-6: Process for setting up the consultations

The discussions followed the structure of the background note, but also allowed the participants to express any additional opinions they felt were relevant. The open nature of the discussions and the identified gaps in information from the first SWOT analysis, aided the identification of potential participants for further phases.

4.3.1 Phase 1

4.3.1.1 Planning

Two stakeholders were consulted in phase 1 in January 2011 (Table 4-2).

Table 4-2: Phase 1 consultations

Participant & Location	Role	Relevance
Environment Manager (NRA) NRA Offices, Dublin 25/01/2011	Responsibility for: <ul style="list-style-type: none"> All environmental issues associated with the planning, construction and operation of the national road network. Ensuring a consistent approach in the high-level policies adopted and/or developed by NRA. Reviewing policies. Keeping informed of environmental policies in other road agencies and countries, particularly in the EU (e.g. through involvement with European 	<ul style="list-style-type: none"> Focal point of environmental issues within Road Agency. Central role within Road Agency to obtain environmental information and data.

Participant & Location	Role	Relevance
	working groups).	
Principal Advisor (DoT) NRA Offices, Dublin 26/01/2011	<ul style="list-style-type: none"> • Advisor to NRA and involved in making funding decisions on construction and maintenance schemes. • Previous to 2010 when NRA took over the role of administering funds, was responsible for administering grants to LAs, used as supplementary resources for maintenance schemes. 	<ul style="list-style-type: none"> • Represents central government, and in effect is therefore the NRA's client.

(source: authors research)

4.3.1.2 Analysis

The individuals brought a range of experience and expertise to the discussions, with the discussions lasting between one to two hours. The key points to emerge from the first phase of consultations are summarised in Table 4-3.

Table 4-3: Phase 1 consultation outcomes

Participant	Key points
Environment Manager (NRA)	<ul style="list-style-type: none"> • The main focus for environmental assessment is towards new construction (as opposed to maintenance). • The issue for maintenance and environmental assessment is that the main environmental impacts are addressed at the initial time of construction only, not during maintenance. If a road already exists, the ability to change the environmental impact (e.g. landscape impact) is much reduced. • At a scheme level, guidelines on environmental issues for scheme design and post-Environmental Impact Assessments (EIAs) are produced to assist the planning and monitoring of impacts. • The environment team in NRA produced the first set of noise maps, which plot noise strategically in contours. • There are no noise limit values at a European level that road agencies have to meet but NRA have set design goals for all new roads of 60 LdB day and night 15 years after opening. • Of the 22 new construction schemes in the previous year [2010] only 1 scheme was directly noise-driven. 3 schemes considered using low-noise surfaces; the rest used noise barriers where noise was an issue. Often the low-noise surface

Participant	Key points
	<p>has other advantages (e.g. reduced spray).</p> <ul style="list-style-type: none"> • Noise during maintenance was not considered an issue that should be included in cost-benefit analysis. • Analyses related to carbon based emissions are targeted by local level analyses as opposed to national level analyses. At a regional level the contribution from roads towards the total Irish emission targets might be analysed although there is no formal procedure currently. • Safety was considered the biggest driver of maintenance. NRA considers ecological parameters, especially sites of special scientific interest, and also noise. Users are more concerned with litter than noise.
Principal Advisor (DoT)	<ul style="list-style-type: none"> • Anecdotally, noise was given a greater level of relevance than carbon in maintenance. • The production of noise maps has been driven by regulations. • The use (or not) of low-noise surfaces can sometimes be influenced by the need to keep the roads open which limit the potential curing time available (and therefore the choice of material).

(source: authors research)

One clear point coming from the consultations in phase 1 was that noise was of more importance than carbon in road maintenance decisions. The primary reasons for this were that firstly, noise is more widely accepted as a potential issue and secondly, the need to comply with the EU noise mapping directive. However, the noise maps have been produced to meet the regulations for mapping but limited use (i.e. noise action

plans) has been made of them to date, primarily because the only requirement is to produce the maps. Therefore, although it is a more widely accepted issue, it could be argued that noise maps would not have been produced without the regulations.

At present carbon is seen as less important and is not an issue considered in scheme or network maintenance. The perception of the experts was that road users would also hold that same view but there is recognition that it may grow in importance for a road agency.

For both noise and carbon the discussions highlighted that there is no standard or common methodology used to assess their impact, either in terms of reporting the impact or in terms of costing the effects of the impact. Although little progress was made in identifying a methodology or values and costs that could be used, the Strategic Planning team within NRA was identified as a key stakeholder whose job is to provide some measurement of all the scheme criteria and externalities. That team was added to the contacts for the phase 2 consultations.

The results from the first SWOT analysis (Appendix C) are discussed in the following two paragraphs. One of the weaknesses perceived when the SWOT analysis was completed after phase 1 was that there were no defined methods for assessment of the environmental parameters. However, this was also classed as an opportunity because of the wider, far-reaching debate on monitoring and measuring externalities. The lack of any defined methodology can be seen as an opportunity, giving more room for innovation.

An identified threat from the first consultations was that carbon and noise were perceived to be of limited importance, especially to road users. This does not stop the model and outputs being relevant to an asset manager and it should therefore not stop any model development because the discussions show those issues are becoming more popular. By acting now in developing a model it prevents any lag that would occur if development did not start until the issues were raised in importance. In addition, the

development of the methodologies themselves might drive some of the understanding and importance of the parameters and drive the desire for this data to be collected. It will be important during the development to be aware of this conflict so that outputs from the case studies can be designed to be meaningful and presented in a way that aligns with expectations, thus supporting the need for the whole-life value approach.

4.3.2 Phase 2 consultations

4.3.2.1 Planning

In phase 2 of the consultations five stakeholders were consulted in March 2011 (Table 4-4).

Table 4-4: Phase 2 consultations

Participant & Role Location	Relevance
<p>Operations Director (Contractor)</p> <p>Contractor Offices, Dublin (video conference)</p> <p>23/03/2011</p>	<ul style="list-style-type: none"> • Responsible for strategic operations in the West of Ireland, Belfast and the UK. • Strategic-level role in contractor organisation • Long experience of working with NRA in delivering road construction. • Looking to generate more income from maintenance contracts. • Understanding of NRA requirements and how they are assessed and delivered. • Understanding if, and how contractors

Participant & Role Location	Relevance
	<p>consider wider benefits in maintenance schemes from the problems they have encountered in trying to get particular schemes approved.</p>
<p>Regional Manager (Contractor) Contractor Offices, Dublin (video conference) 23/03/2011</p>	<ul style="list-style-type: none"> • Focused on West Ireland management and operational delivery of other specific projects • Management and operational role in contractor organisation • Long experience of working with NRA in delivering road construction. • Understanding of NRA requirements and how they are assessed and delivered. • Understanding if, and how contractors consider wider benefits in maintenance schemes from the problems they have encountered in trying to get particular schemes approved.

Participant & Role Location	Relevance	
Environmental Expert (Consultant) NRA Offices, Dublin 23/03/2011	<ul style="list-style-type: none"> • Independent environmental consultant. • Previously sat on NRA board. 	<ul style="list-style-type: none"> • Primary environmental interests are waste and energy. • Feels focus has shifted from waste management towards carbon and noise. • Has worked closely with industry and witnessed the shifts in environmental focus.
Strategic Planning Engineer (NRA) NRA Offices, Dublin 23/03/2011	<ul style="list-style-type: none"> • Involved in scheme assessment and cost-benefit analyses. 	<ul style="list-style-type: none"> • Involved in assessing schemes and their eligibility against guideline criteria. • Has an understanding of how schemes are scored and costed for prioritisation. • Identified in phase 1 when discussing environmental data for modelling (e.g. carbon and noise costs).

Participant & Role Location	Relevance
Director of Policy (AA Ireland) Hotel, Dublin 24/03/2011	<ul style="list-style-type: none"> • Communication focused role. • Ranges from talking to high-level government and NRA staff to road users and radio chat shows. • Outward facing vocal point of large transport members group. • Works closely with road users and their expectations and has understanding of the issues currently important to them.

(source: authors research)

4.3.2.2 Analysis

The second phase of consultations led to a wider base of participants being consulted. This allowed previously discussed opinions to be further explored and new information to be recorded. The topics discussed were the same as in the first phase and the resulting discussions were similar in length, lasting between one to two hours.

Investigations were made to use automatic voice transcription software to transcribe the first phase of consultations. It quickly became clear that this was not going to be successful, primarily due to:

- The software not being trained with the voices of the participants;
- Conversations that overlapped;
- Use of specific technical terms; and
- 'Jumpy' or half-finished sentences which prevented the software from using the context of the discussion to predict words.

In the second phase of individual consultations the transcription process did make use of the software. The interviews were listened to through headphones and simultaneously spoken back into the software through an attached microphone. This allowed the software to transcribe the whole discussion. Using this method, the interviews were able to be transcribed at a speed of between 0.8-1 of the real-time recording. With this revised procedure I would deem the software used²⁰ to be an efficient method to transcribe my interviews in terms of both time and cost.

The key points to emerge from the second phase of consultations are summarised in Table 4-5.

Table 4-5: Phase 2 consultation outcomes

Participant	Key points
Operations Director (Contractor)	<ul style="list-style-type: none"> • Users are interested in whether they will be inconvenienced, not by environmental factors.
Regional Manager (Contractor)	<ul style="list-style-type: none"> • Although there are limited noise design thresholds, noise has a set of more tangible methods for measurement and assessment; carbon is significantly less important in scheme maintenance. • Although the main driver for noise is the EU directive, any directive would not normally be expected to apply to maintenance. • Noise limits on the network (60 dB) are only relevant for works that require planning permission. If part of the network already exceeds the noise level, the requirement states the noise levels after maintenance should not be higher than existing noise levels.

²⁰ Dragon Naturally Speaking, <http://www.nuance.co.uk/dragon/index.htm>

Participant**Key points**

- The 60 dB could be achieved through low-noise surfaces or barriers. Generally the low noise surface is cheaper. Sometimes, even with a low noise surface planning requirements still require noise barriers to be installed.
- Currently no effort is made to monetise noise, and the effect on society of noise impacts is not calculated.
- Historically road authorities have controlled maintenance specifications tightly which has limited innovation in scheme design.
- Contractors would like to use more of their design ideas than they are permitted to, which they also believe would benefit the environment. But they need to remain competitive so there is no incentive to do more than the minimum required if it doesn't benefit them (e.g. designing the road to carry a set number of standard axles within a design life may or may not be the best whole-life cost solution but their design would have to meet the criteria for axle loading).
- It is difficult to get novel proposals or departures from standards accepted.
- Public Private Partnership (PPP) schemes have more freedom to design different scheme solutions because their contracts are governed by overall hand back criteria, not by individual scheme contracts.
- Examples were given where schemes included elements which brought an environmental benefit. One scheme

Participant	Key points
	<p>changed the central barrier design from steel to concrete because it was agreed and accepted that there was a lower whole-life cost with the concrete barrier, even though it had a higher initial cost. Another scheme used a grassed water channel as opposed to a concrete option which brought environmental benefits and lower carbon expenditure.</p> <ul style="list-style-type: none"> • A model that can demonstrate environmental benefits in schemes might help drive innovation in scheme design and solutions. • Recycling road materials is not a priority issue in Ireland as the older networks have a number of surface dressing layers that are not appropriate to recycling. There is not the volume of material available that would make it effective. It was not thought Ireland would follow the UK in the amount of pavement recycling.
Environmental Expert (Consultant)	<ul style="list-style-type: none"> • Industry is perhaps more closely aligned with PPP schemes on the NRA network, where hand back criteria allow the operator of the PPP to also benefit from minimum whole-life cost maintenance expenditure. Conversely, individual road schemes do not always consider minimising whole-life costs because the scheme criteria are often just concerned with the lowest initial cost that meets the requirements of the specification (having no commitment or obligation once the scheme is

Participant	Key points
	<p>complete).</p> <ul style="list-style-type: none"> • The emphasis on the environment has changed with time e.g. moving from waste management (in order to meet EU requirements) to energy, particularly its impact on climate and energy security. • Changes in government can have a noticeable effect and their support for specific energy initiatives can dramatically change industry focus (e.g. a change in Energy Minister resulted in a change from a position of promoting wind energy to one where no further investment in wind energy was expected). • The cost of options impacts on the carbon but there is a limit on importance, especially during times of recession when driving down costs tends to be the main driver. No examples were known where lowering carbon emissions was a decision driver. • Noise has more of a 'real' impact on people and is possibly becoming a bigger issue. • The waste industry did have to deal with noise disturbance issues, which lead to action such as window replacements at a local level. • The driver for the public is price because that is when the public notice a direct impact.
Strategic Planning	<ul style="list-style-type: none"> • In the current scheme assessment process environmental

Participant	Key points
Engineer (NRA)	<p>issues such as archaeology, protected views and landscapes are assessed qualitatively on a score of 1 to 7. There is a partial cost-benefit analysis because NRA are not monetising everything. But quite a bit of effort goes into appraising the criteria which are not amenable to monetising.</p> <ul style="list-style-type: none"> • Overall, the environmental parameters have a weighting of about 10% within the scheme assessment. • Out of 25 sub-criteria (from the 5 main scoring criteria) users perceive 1, journey time, with other criteria on environment, safety, economy, accessibility and integration not being relevant to users. • In 2009 the Department of Finance revised the carbon prices for all agencies, starting at €13 in 2009, rising to €39 in 2050 and remaining constant from then on. Although it lead to the cost of carbon being included in wider government appraisals in Ireland, the NRA had to lower their adopted prices when previously they were more in line with European levels. • A positive step in 2009 was the monetisation of non-GHGs which means health impacts are now monetised. • Carbon emissions do not feature significantly in the outputs of appraised schemes. Approximately 80% of scheme benefits are user benefits, most of the rest are safety. A previous exercise to get the benefit cost ratio to 1 lead to carbon being priced at €500/tonne to cancel out

Participant	Key points
	<p>the time savings, far in excess of the current pricing levels.</p> <ul style="list-style-type: none"> • It was thought NRA values noise at around €25 per decibel at any level and makes use of spatial household data in noise calculations. If it hasn't been monetised in the past, it will be soon.
<p>Director of Policy (AA Ireland)</p>	<ul style="list-style-type: none"> • The environment is not a relevant issue to users. Environmental concerns were expressed more around 2007, but this has since dropped due to the recession. In a survey on buying fuel, environmental concerns of users ranked the lowest. Environmental concerns fall below economic ones. • There is a carbon tax on fuel, on top of excise duty. This is expressed per tonne to distinguish it from the existing tax, but it is not spent on green issues, therefore it is questionable as to what sort of green tax it is.

(source: authors research)

In phase 1 the participants suggested that the users were not concerned with the environment. This was made even clearer during the phase 2 consultations and the experts felt that users were only concerned when they were directly inconvenienced. The difference from the phase 1 consultations was that the lack of environmental concern could be seen to be matched by a lack of ability that the contractors felt in being able to

demonstrate wider environmental benefits in scheme designs. The contractors felt that more flexibility in scheme control would allow for wider benefits to be realised.

Additionally, in discussions with the planning engineer, the environment was thought to command a weighting of around 10% in scheme assessments which lead to the idea of the methodologies allowing the weighting of any included criteria to be changed. This would provide the ability to change the weighting of different elements within the prioritisation, allowing the impacts and prioritisation of maintenance to be investigated as the weightings are changed. In terms of the consultations, this led to the idea of using an exercise within the focus groups that would allow different prioritisation weightings to be captured between the elements of works costs, user delays, carbon emissions and noise.

Even if contractors did have more freedom in scheme design, it does not mean they would necessarily propose different schemes or different designs for schemes. However, what was clearly missing was a tool to enable them to at least show and discuss the impacts of different options with a road authority.

Although it was discussed that there is a general lack of innovation in designing schemes, partly due to the strict requirements of the client, there were some examples (e.g. change of central reserve barrier material) where scheme design demonstrated additional benefits beyond the set requirements, some of which were environmental and whole-life cost benefits. A tool that could demonstrate these benefits (whether it is on a whole-life cost or whole-life value basis) would address a current gap in the NRA's processes for assessing externalities alongside works costs.

Echoing the discussion from phase 1, noise has more of a 'real' impact on people and it was thought people's annoyance with it would grow with time. Carbon, like in the previous discussions, is of limited importance currently and this appears to be exaggerated by the recession when lowest cost is the main driver.

Environmental externalities (e.g. landscape, cultural heritage) were considered in scheme assessments but sometimes only assessed qualitatively and not included in a cost-benefit analysis because they were not monetised. One of the gaps clearly identified was in assessing those measurements (e.g. the environment) alongside the traditional costs and having a way of understanding the effect that some of these categories have on developing a network programme and budgets.

On reflection, even though more people were spoken to in phase 2, the general consensus with regard to environmental issues has not changed markedly. That is, the environment is still an issue that people are debating and are aware of but it hasn't made its way into programme development or maintenance budget planning, especially at a strategic level.

The lack of consideration of the environmental issues may, in part, be driven by the tight specifications set for the works. This can limit different approaches being used that may otherwise bring environmental benefits and until there is a tool that can be used to demonstrate the effect of some of these benefits it will be hard to make progress.

The exercise to undertake a SWOT analysis was repeated following the conclusion of phase 2 of the consultations (Appendix D). It remained clear that there were no set approaches for assessing environmental methodologies alongside traditional costs (e.g. maintenance) but that was still classed as an opportunity.

The lack of current quantitative environmental appraisal approaches meant that technical details relevant for modelling (e.g. applying discounting to environmental costs) were not discussed.

4.3.3 Overall

The clearest message from the phase 1 and 2 consultations was that environment is not a current driver of maintenance needs and the experts do not expect users to be concerned with environmental issues in road maintenance.

With tighter budgets expected in the future and different constraints put upon the network managers, contractors and road agencies accept (and their actions back this up) that just keeping the status quo would ultimately lead to problems and those groups remain open to new methods of scheme appraisal and assessment. It was felt that one alternative would be for greater responsibility to be given to contractors which might ultimately lead to better value for money.

From the SWOT analysis two main points stood out that were important for shaping the research to come:

1. It was clear that there were no formal approaches for assessing environmental methodologies alongside traditional costs for road maintenance. That was seen as both a weakness (because there was a lack of existing material to work from) but also more importantly as an opportunity, because it reinforced that this research would lead to new knowledge; and
2. There was limited technical discussion on approaches used to value the environmental factors on a monetary basis simply because those processes were not in place. Therefore issues around cost data and associated parameters (e.g. discounting) were not discussed. Development of costing elements for valuing the carbon emissions from maintenance and traffic noise would have to use the wider academic literature as the primary data source (as opposed to industry experience).

4.4 Focus groups

In consulting a larger group of stakeholders such as road users there are a number of different methods that can be used (e.g. surveys, focus groups) and different ways they could be delivered (e.g. in person, online). They each have different advantages and associated success rates and allow for different ways of communicating with the participants.

Following a detailed planning exercise exploring the types of information required, one of the key requirements identified was to enable road users to interact with the topics being discussed through planned exercises in a face-to-face setting and thereby explore issues in as much detail as possible. Section 4.1.3 discussed that face-to-face interviews allow for greater information to be extracted from individuals and allow for the facilitator to keep greater control over the direction and of the topics.

Focus groups provide a face-to-face method for consulting larger groups, particularly members of the public and they provide a way of controlling the discussions whilst also giving the facilitator the flexibility to adapt the questions based on directly hearing the feedback and answers from the users. They allow for a range of question structures from tightly controlled questions to unstructured and open-ended questions, the latter being more general questions that allow for different topics to be discussed without needing to pre-plan all questions in their entirety (Punch, 1998). They also create the situations where it is possible to gather information from a group of individuals at the same time (Onwuegbuzie, 2009).

The advantage is that they allow probing questions during the consultations and allow information beyond the participant's initial responses to be obtained. This is particularly useful as user opinions are often driven by recent unfavourable experiences and remote surveys (e.g. online or telephone questionnaires) do not easily provide the means to probe views or the reasons behind them. In addition, the focus group provides the capability to keep the participants focused and engaged and ensures they have an acceptable level of understanding of the specific technical discussion topics.

In the initial planning for the focus groups I worked back through the stages of what would allow me to get the necessary information to accomplish my goal of a whole-life value model, considering some of the practical aspects suggested by Punch (1998) such as who am I trying to contact, how will I contact them and why am I contacting them.

What do I want to analyse in a whole-life value model?



What data allows me to create methodologies for modelling carbon and noise?



What questions do I need to ask to get the level of information required?



What groups of people might give different answers?

By working through the above from outcome to input the aim was to focus on what needed to be asked, rather than asking questions and hoping the data would be suitable for analysis.

During the planning process an ethics approval process was completed due to the involvement of human participants. The approval process required completing and submitting the following documentation to the TRL ethics committee:

- The completion of a checklist, with questions asking, for example, if participants will have an increased risk of harm, does the project include children, is there any deception of or withholding of information;
- Answering an 'Ethical Approval Application' form which compiled information on areas including the general project aims and objectives, where it will be undertaken, whether payments will be made and the data collection methods;
- Submission of documents related to the project that covered:
 - Participant consent form;
 - Participant information sheet;
 - Questionnaires and interview guides to be used;
 - Letters used to contact participants.

The committee approved the application based on the submitted documentation without the need for further consultation.

4.4.1 Participants

Two focus groups were organised and held a week apart at TRL. Although the individual consultations were Irish based there was an obvious trade-off between the significant extra resources that would be required to organise, recruit and run the focus groups in a different country and any expected difference in public opinions between England and Ireland. From discussions with the relevant experts it was concluded that there would not be a significant difference of opinion between users in the two countries in terms of the common spectrum of environmental impacts from road maintenance and it was agreed to run the focus groups in England.

Certain cultural differences can lead to big differences in outcomes. Thames Water experiences different water usage patterns in small pockets within some regions primarily due to localisation of ethnic groups and the different religious practices influencing water usage differently (author's previous unpublished research). For example, the effects of Ramadan mean that some communities require very little water during the day in that period but require more than usual prior to sunrise, affecting the pressures the water network needs to be maintained at.

Conversely, a road user perception study carried out for the DfT (Ramdas et al., 2007) was undertaken in different parts of England for regional differences in road user expectations. The end result was that there weren't any differences across the regional focus groups.

Although it is a potential limitation, the Irish and UK road networks, climates and environment are similar and the environmental opinions are unlikely to offer much difference at the level being investigated and it was deemed acceptable to hold the focus groups in the UK. Whilst the UK network might be argued to be more mature than the Irish network, both networks have undergone significant upgrades in recent years so

that the standards of the roads and constructions are much more similar than in the past.

In the planning for these consultations, the information sharing between phases of the consultation approach (Figure 4-5) allowed for the focus group results to be fed back to and discussed with the relevant Irish experts thus allowing the UK focus group opinions to be tested against expert Irish opinion.

4.4.1.1 Recruitment

The participants were recruited from an existing TRL database of people who had previously signed-up to take part in trials and focus groups. Ten participants were recruited for each focus group which is within suggested group sizes (Bryman, 2001; Onwuegbuzie et al., 2009), roughly split between genders and with different levels of driving experience and road use (e.g. newly qualified drivers, frequent high-mileage drivers). Table 4-10 and Table 4-12 show the breakdown.

Each recruited participant was sent a letter describing the aims of the research and provided information on attending the focus groups. Included in the letter was a consent form to complete, agreeing to take part in the focus groups and consenting to the conversations being recorded. The participants all responded positively.

Bryman (2001) commented that a significant problem with focus groups is no-shows and therefore it can be a good tactic to over-recruit for the number of participants required. Restrictions on budget meant that this was not possible if all those recruited did indeed turn up but fortunately at each focus group only one of the recruited participants cancelled, resulting in nine participants taking part. It was recognised that if the focus group participants did fall significantly from the recruited number then more focus groups would be required.

4.4.2 Focus group material

4.4.2.1 General theme and introduction

The experts consulted in the individual consultations had expressed a general view that the road users would not have sufficient understanding and awareness of environmental aspects in relation to highway associated impacts. Therefore suitable topic introductions were planned to enable all participants to achieve an understanding of common topics and terminology so that they could more readily express the detail of their stated opinions.

Whilst drafting material the initial focus had been on asking the users how carbon and noise should be weighted compared to works costs and if they felt the benefits from carbon and noise savings. On reflection they were not issues to easily conceptualise or to be aware of and so the value to my research would inevitably be limited.

My research needed to understand how value measurements can be modelled and how their importance can be represented. The key questions the focus group needed to ask the users were about trade-offs they would accept between different environmental impacts, which in turn would then influence the type of maintenance. This moved away from asking about absolute costs which would have been difficult to conceptualise.

In order to stimulate the thinking of the participants as they arrived a selection of images was played on a screen, mainly to give an indication of the types of topics that would be discussed and secondly to help put the participants at ease by giving them something to focus on as they arrived. Examples of the images used are shown in Figure 4-7.

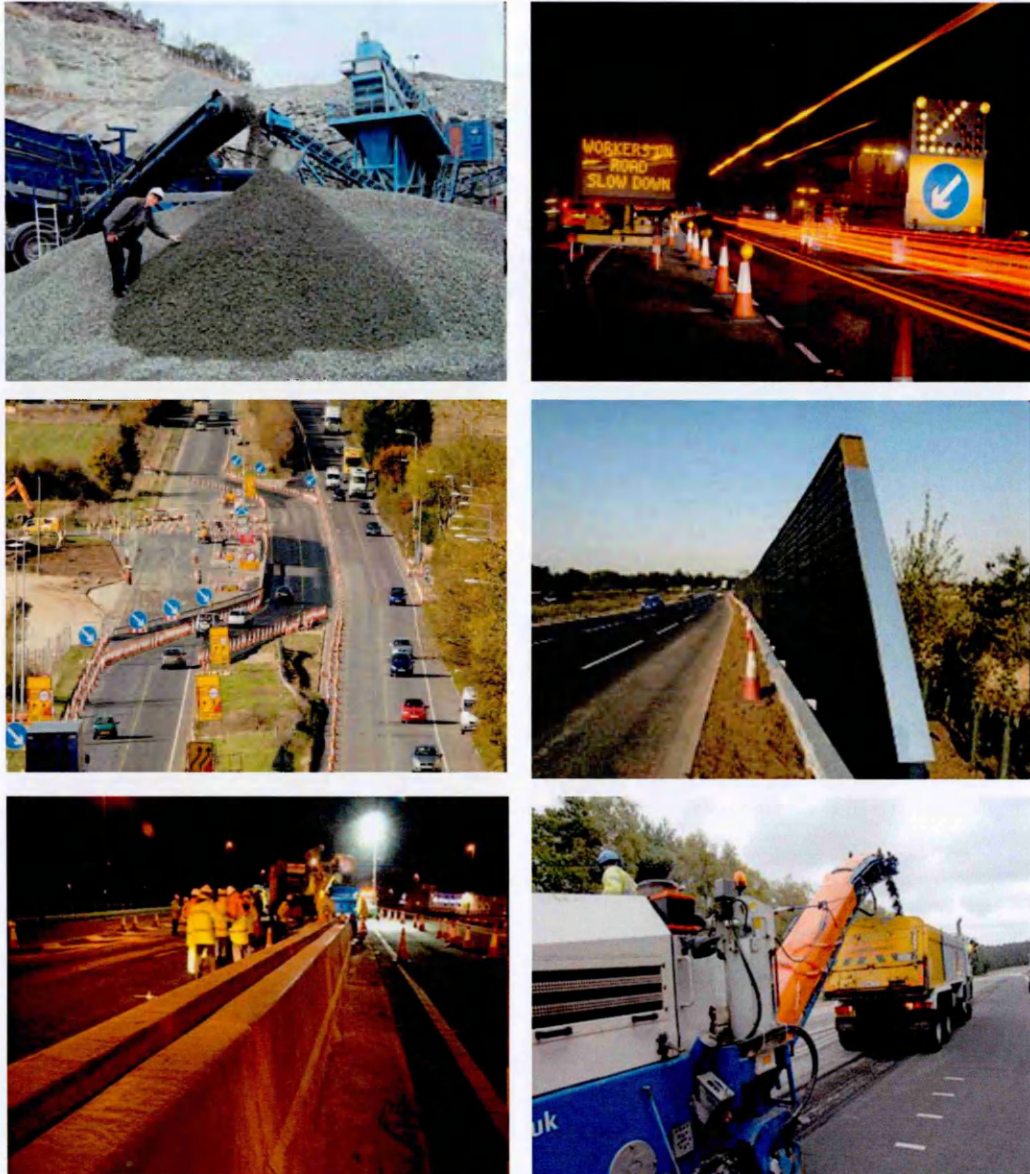


Figure 4-7: Example images displayed when welcoming participants

The focus groups were planned to start with everyone introducing themselves and providing a brief comment on the type of road user they were (i.e. what vehicle(s) they regularly drove, how often they used the roads). This information was gathered to understand if any particular themes that emerged during the subsequent analysis could be attributed to specific types of road users.

4.4.2.2 *Discussion topics*

A topic guide was created for the focus groups to act as an aide for the topics, questions and exercises that had been planned.

The initial part of the focus groups consisted of an open discussion centred on transport, road maintenance and the environment. The open discussion was designed to make the participants feel comfortable and contribute readily to the discussions. As the discussions progressed, if individuals had not contributed much it was attempted to try to draw them into the conversation so that their opinions were also heard.

The types of questions and topics discussed included:

- What does the group notice on/along roads that influences their use of roads?
- In what ways do environmental concerns impact on their everyday lives?
- Are people aware of environmental considerations within road maintenance?

The topic guide for the first focus group can be found in Appendix F.

4.4.2.3 *Exercises*

As well as general discussions, a number of exercises were planned to be undertaken with the participants during each focus group. The exercises were designed to test the participants' opinions in a range of scenarios and analyse the answers for consistency or a lack of consistency. Gregory et al., (2003) noted that some activities challenge participants' thinking and lead to inconsistent results and so the ability to compare results between exercises and groups was included in the planning by picking some exercises that had defined scales for their answers for example. One of the advantages of the types of exercises that were planned was that they presented a good way to test for the reliability and consistency of opinions. Punch (1998) stated that consistency is formed of two-parts:

1. Consistency over time – where you understand if the same peoples were asked the same questions at a different time, would the answers be the same; and

2. Internal consistency – which is the extent that responses given by different participants given are consistent with other responses and point to a common opinion.

The consistency over time could be tested by the fact that the first individual consultations were held over a year before the last focus group. The internal consistency was designed to be tested by splitting each focus group into smaller sub-groups to examine the consistency between the sub-groups.

4.4.2.4 *Maintenance trade-offs*

In the trade-off exercises participants were given a range of scenarios, each of which was designed to highlight a different trade-off that might have to be addressed when making decisions on maintenance.

Trade-off scenarios planned for the focus groups included:

- Night working versus fewer delays: If work is done at night it means less delay to road users during the busier traffic periods in the day but less maintenance can be completed under set budgets because night costs are typically higher, therefore a greater proportion of the network remains in poor condition.
- Night working versus energy: If work is done at night it requires extra energy for lighting etc. but this can be offset against energy savings due to less delay.
- Lighting energy use versus safety: Having lights on versus saving energy. If a road is not busy are users happy for lights to be switched off to save energy? What about if they are unfamiliar with the road?
- Material choice versus performance: If a road surface uses a higher proportion of recycled material or leads to lower traffic noise but deteriorates faster, are users prepared for future maintenance interventions to be required sooner?

- Material choice versus environmental impact: If a concrete road lasts longer than a black top but is worse for the environment which surface would the users choose?
- Noise versus cost: If a low noise surface or noise barrier adds more costs to the scheme it will mean that less maintenance can be done overall under the available budget.
- Noise versus night working: If maintenance work is completed at night it will lead to reduced delays during peak periods, but at the expense of creating additional noise at a sensitive time when people are trying to sleep.
- Noise versus tunnels: If road agencies construct tunnels it will remove a significant amount of noise from the local area. However, the expense of the projects will rise significantly meaning that less work can be done overall under the set budgets.
- Hard-shoulder running versus new construction: If hard-shoulder running allows a road authority to increase capacity by using existing infrastructure and reduces new construction (and therefore limit environmental impacts) are users happy to use this method of increasing capacity?

For each given scenario participants were required to identify what was more important to them and where the balance of importance lay. To help visualise the options they were being asked to choose between, images were used to represent some of the trade-offs (see Figure 4-8 and Figure 4-9).



Figure 4-8: Trade-off images for lighting energy²¹



Figure 4-9: Trade-off images for hard-shoulder running

4.4.2.5 Ordering

An ordering exercise presented the participants with a list of issues that are relevant during maintenance and they were asked to order the issues in importance. The aim of the exercise was to understand how the perceptions of the impacts of maintenance can be different depending on how the person is personally impacted by the maintenance (e.g. a local road user, a local resident or neither).

The initial planned list of items for ordering in the focus groups is shown in Table 4-6, divided into a 'during' and an 'after' maintenance item to distinguish whether there was any change in importance for some items when maintenance is actually occurring.

²¹ Please note, printed pictures may appear darker than pictures actually used

Table 4-6: List of items for focus group 1

Focus group 1
Avoiding peak times (during)
Clear signing (after)
Clear signing (during)
Considerate to environment (during)
Good lighting (after)
Good lighting (during)
Improved road markings (after)
Improved road surface (after)
Limited pollution (after)
Limited pollution (during)
Looking pretty (after)
Looking pretty (during)
Quiet (after)
Quiet (during)
Reliable journey time (during)
Rest areas (after)
Rest areas (during)
Shorter journey time (after)
Sustainable construction (e.g. recycling) (during)
Visibility (after)
Visibility (during)

(source: authors research)

The participants were split into two groups and asked to prioritise the list for given scenarios. Both groups were initially asked to order the list based on what was important to them (without any set conditions). After this initial task the two groups were each given a different scenario and asked to order the list based on their given scenario.

The scenarios were:

- Participants in group A live in town A alongside the road that is to be maintained. From their houses they can all see and hear the road and they use it on a daily basis.

- Participants in group B live in a rural town B, 5 miles from town A. They cannot see the maintenance works or be affected by the noise but they drive along the road works most days.

After the ordering exercise was completed the participants were brought back together to discuss the differences between the prioritisations and why they made their choices.

4.4.2.6 *Pairwise comparison*

A pairwise comparison exercise was planned for the focus groups. Pairwise comparison, or analytic hierarchy process, allows relative scales to be derived using judgements on a standard scale (Saaty, 1990). In this research the judgements were undertaken as comparisons between pairs of items.

Saaty also commented that making judgements is much more effective when comparing pairs and the point of the exercises was to give the participants something that they could manage to complete without specialist knowledge and that would be repeatable in different groups.

In this planned exercise the participants were presented with the four parameters to be brought together in the whole-life value model in order to determine the relative scales between them:

- Costs of the works²²;
- Additional delays experienced by road users during maintenance;
- Carbon emissions from maintenance; and
- Traffic noise as a result of maintenance.

²² During the planning and completion of the focus groups only the maintenance works were presented as a cost because no decision had been made as to how the other parameters would be used within the model. Furthermore, in the planning of the focus groups it was apparent that the cost of carbon (for example) might not be a clear concept to most participants.

As a group, the participants were asked to rank the importance of one parameter against another for each possible pair, using the scale:

- Very much more important;
- Much more important;
- Slightly more important;
- Equal;
- Slightly less important;
- Much less important; or
- Very much less important.

The participants' responses were entered into a spreadsheet (Figure 4-10) which was setup to produce weightings based on their information. (In the spreadsheet the data entry was based on assessing the importance of the row against the column). This method was chosen because it allowed me to determine a weighting score for each of the items, whilst only requiring the participants to compare the items in pairs.

	Works Cost	Delays	Carbon	Noise
Works Cost		equal	equal	equal
Delays			equal	equal
Carbon				equal
Noise				very much less much less slightly less equal slightly more much more very much more

Figure 4-10: Pairwise comparison spreadsheet and example data entry

To derive weights from the pairwise comparison, the lookups were assigned weights in a matrix based on a fixed scale (see Table 4-7).

Table 4-7: Lookup weights for pairwise comparison

Lookup	Weighting
very much less	1/7
much less	1/5
slightly less	1/3
equal	1
slightly more	3
much more	5
very much more	7

(source: authors research)

The spreadsheet determined the weights for each category using the following method:

- Derive the weight for each pair (in a four by four matrix) based on the lookup text and associated lookup table. (NB: Participants only had to enter results for 6 pairs because the remainder of the pairs could be derived from the opposite weightings or they were equal weighting by default, e.g. works costs vs works cost.);
- Divide each cell of the matrix by the sum of the weights in each column; and
- Average the values across each row to derive a weighting for each element.

4.4.3 Focus group trial

In advance of the first focus group some of the concepts were trialled in an informal setting with a small group (Table 4-8) of road users but with no detailed knowledge of the project and the focus group task. This aligned with one of the steps Punch (1998) suggested should be undertaken in constructing a measurement instrument, which was that it should be tested with a small group. It is not the actual responses that are important in this trial, but the way in which the individuals interpret and understand what is asked of them and how they make their responses.

Table 4-8: Trial group participants

Focus Group	Participants driving experience (& gender)	Location & Date
Trial	1. High-mileage user, both work and leisure (Male); 2. Average user, drives for daily commute (Female); 3. Low-mileage driver (Female); 4. Average user, drives for daily commute (Female); 5. Average user, both work and leisure (Female); and 6. Average user, both work and leisure (Male).	Private house 04/03/2012

(source: authors research)

4.4.3.1 Revised material following trial

The concept of the ordering exercise was understood by the participants and it was completed as requested. However, whilst the trial participants understood the majority of the listed items they were asked to order they did suggest some changes. 'Rest Areas' caused confusion due to the variation in standards across different parts of the road networks (e.g. simple laybys to large motorway services) and they were removed from the activity. It was suggested that 'Considerate to Environment' was changed to 'Considerate to Wildlife' to be more focused. Therefore a revised list of items for the ordering exercise was drafted for the first focus group (Table 4-9).

Table 4-9: Revised list of items for ordering exercise in focus group 1

Focus group 1
Avoiding peak times (during)
Clear signing (after)
Clear signing (during)
Considerate to wildlife (during)
Good lighting (after)
Good lighting (during)
Improved road markings (after)
Improved road surface (after)
Limited pollution (after)
Limited pollution (during)
Looking pretty (after)
Looking pretty (during)
Quiet (after)
Quiet (during)
Reliable journey time (during)
Shorter journey time (after)
Sustainable construction (e.g. recycling) (during)
Visibility (after)
Visibility (during)

(source: authors research)

In the trade-off exercise during the trial it was hard to get participants to think in terms of only the trade-off pairing that was being discussed. For example, in discussing the carbon footprint versus the cost of concrete and steel barriers the group could not stop bringing safety into the discussions and this is a potential limitation of using this trade-off technique. This reinforced that during the main focus groups it was important to keep the group on track within the context of the individual trade-offs being discussed.

4.4.4 Focus group 1

The participants for focus group 1 are listed in Table 4-10. There was a time when probability sampling was much more common in qualitative research (Punch, 1998)

when selecting a sample. However, the sample selection process has adapted with time and this sample was selected with some purpose so that it sampled a mixture of different driver-types (e.g. high-mileage, low-mileage, regular commuter low user) in order to respond widely to the research questions. The same was also true of the second focus group.

Table 4-10: Focus group 1 participants

Focus Group	Participants driving experience (& gender)	Location & Date
1	1. Everyday driver, low-mileage (Female); 2. Retired, low-mileage. Used to do high-mileage driving for work (Male); 3. Low-mileage driver (Female); 4. Average user, drives for daily commute (Female); 5. High-mileage, drives 3hrs per day with work (Male); 6. Average user, drives for daily commute (Female); 7. High-mileage user, both work and leisure (Male); 8. Low-mileage weekday driver (Female); and 9. High-mileage driver (Male).	TRL 06/03/2012

(source: authors research)

4.4.4.1 Revised material following focus group 1

Topic guide

Changes were made to the topic guide following the first focus group and in advance of the second focus group. These included changes to how the introduction topics were structured, their ordering and the emphasis of the discussions. The main changes were that the introduction topics were split to introduce and discuss in turn:

- General carbon emissions;
- Transport and carbon emissions;
- General noise; and
- Road noise.

The main purpose of this was to reduce the breadth of what the participants were expected to answer at each stage and also to try and discuss the environmental topics in more general terms that could relate to any aspect of life, prior to moving on to transport specific discussions on the environment.

For example, rather than beginning by discussing carbon emissions and noise in road maintenance, the emphasis was changed so that general environmental topics were discussed so that users could discuss examples from any aspects of life (e.g. recycling at home) before moving to specific road maintenance discussions.

More use was made of visual aids following the first focus group to try to put some of the descriptions into graphics to support the explanations given throughout the evening. The order of the ordering and trade-off exercises was also reversed, the reason being that having done the ordering exercises first in the first focus group it resulted in difficulties for the participants being able to narrow their options back down to two options being discussed in each of the trade-offs.

The revised topic guide can be found in Appendix G.

Maintenance trade-offs

The content of the trade-offs was consistent between the focus-groups. Some slight changes were made to the text used to introduce each trade-off in an effort to make them more succinct. The main change was that extra graphics and images were used to display some of the trade-offs that were previously introduced with only text. Although the graphics produced were simple, it gave the participants a better understanding as a group of each trade-off being discussed (see Figure 4-11 to Figure 4-13).

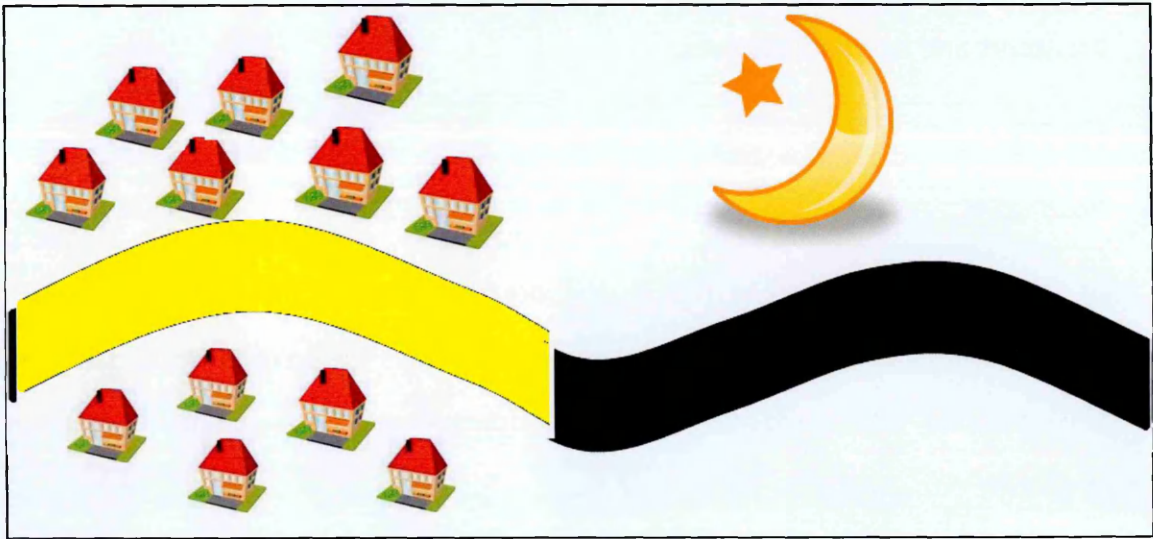


Figure 4-11: Trade-off graphic for night working

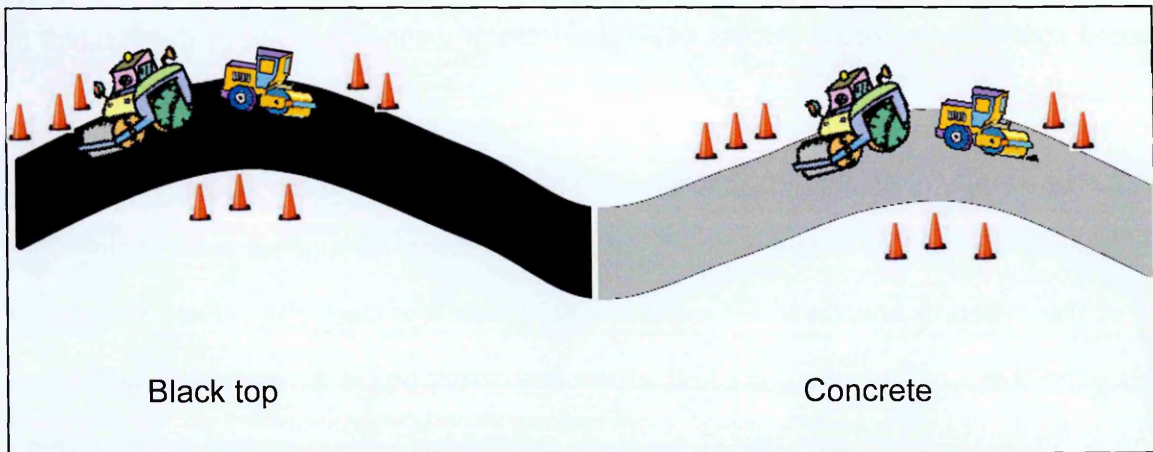


Figure 4-12: Trade-off graphic for material choice

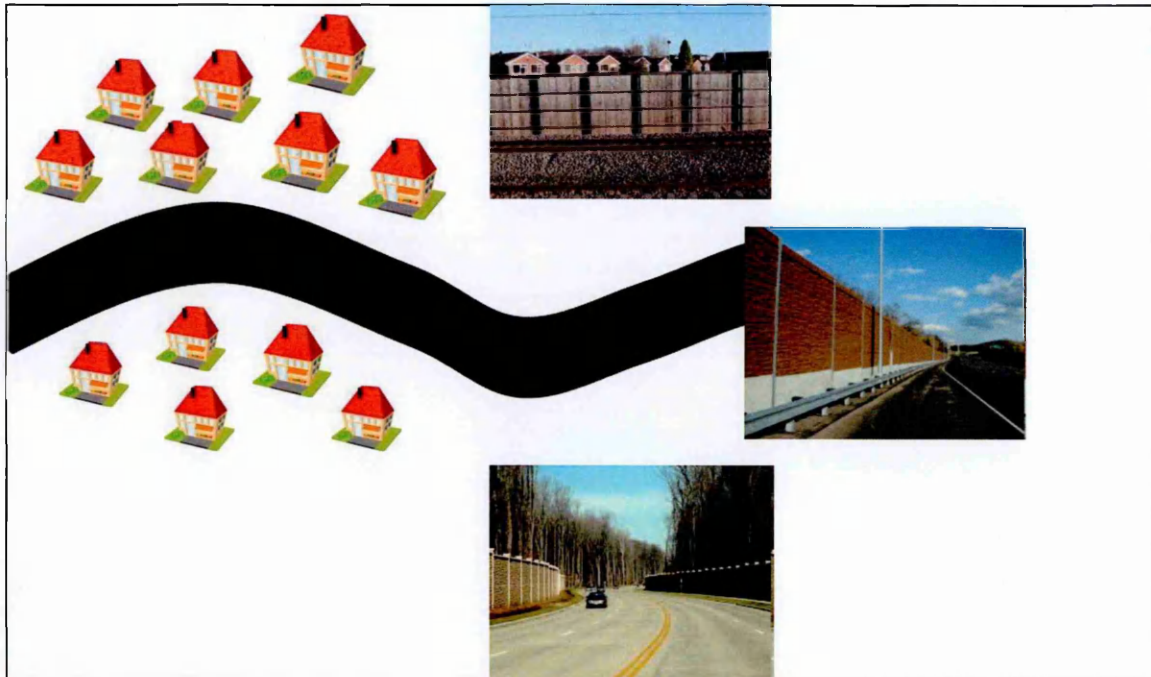


Figure 4-13: Trade-off images for noise choices

Ordering

Following the first focus group the list of items the participants were asked to work from in the ordering exercise was shortened (see Table 4-11). The reason for the shortened list was that the distinction between 'before' and 'during' maintenance had caused difficulties for the participants and therefore had taken more time than allocated. The shortened list was designed to capture the main elements of the previous list, combine some of the detailed descriptions (e.g. signing and road markings) and remove those that complicated the task and were not critical to the overall outcome (e.g. visibility).

As before, the participants in the second focus group were split into two smaller groups and were initially asked to prioritise the list of maintenance items based on what was important to them.

Table 4-11: Revised list of items for ordering exercise in focus group 2

Focus group 2
Avoiding delays
Clean and dust free
Clear markings/clear signing
Green construction (e.g. recycling)
Limited pollution
Quiet
Well lit

(source: authors research)

Following the initial prioritisation, the text to introduce the second part of the ordering exercise was amended to read:

"There is a road that is going to have 6 weeks of maintenance to lay a new surface due to the existing one being in poor condition. At the same time the existing junctions will be improved. The result at the end of the 6 weeks will be a newly surfaced road that will be able to accommodate increased traffic flows, resulting in less delays."

The change from the previous focus group was that each group was asked to reorder the list for both of the two scenarios given in the first focus group (as opposed to each group doing one scenario only).

To help the participants understand the scenarios, a cartoon graphic was produced for the second focus group to provide an illustration of what was being conveyed to the participants (see Figure 4-14).

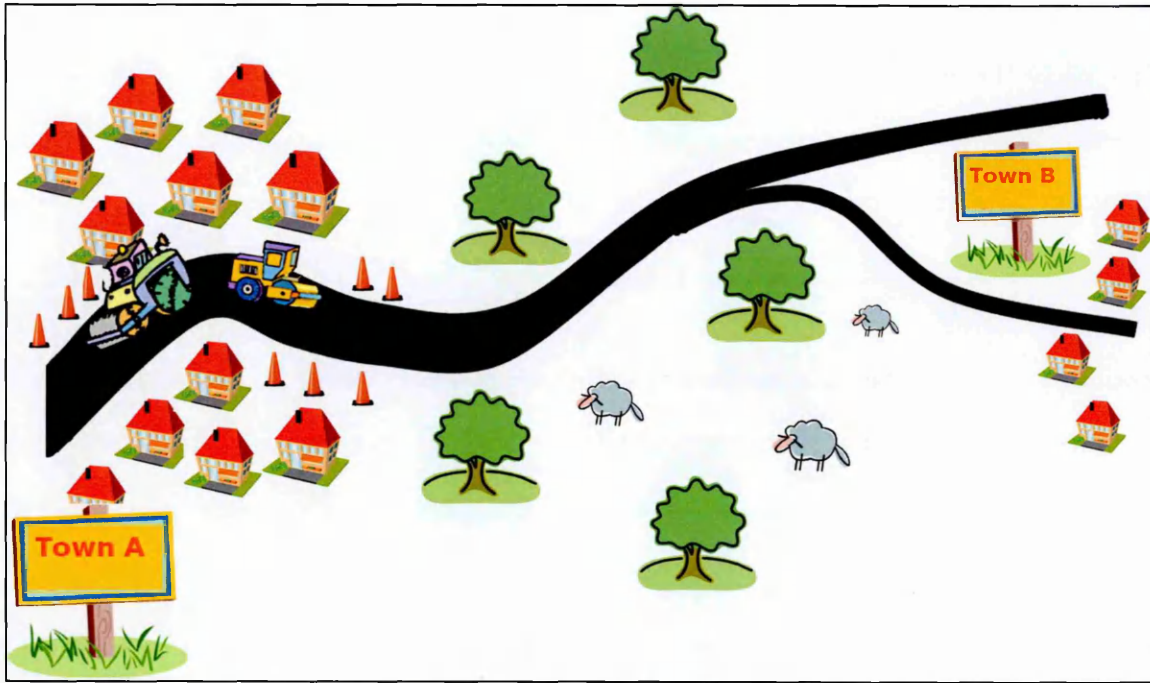


Figure 4-14: Graphic illustrating scenarios for ordering exercise

4.4.5 Focus group 2

The participants for focus group 2 are listed in Table 4-12.

Table 4-12: Focus group 2 participants

Focus Group	Participants driving experience (& gender)	Location & Date
2	<ol style="list-style-type: none"> 1. Car driver, but also uses train (Male); 2. Use to do high-mileage, but now low-mileage driver (Male); 3. Low-mileage driver (Female); 4. Average user, drives for daily commute (Female); 5. Newly qualified driver (Male); 6. Average user, drives locally (Female); 7. Average user, both work and leisure (Female); 8. High-mileage driver (Female); and 9. Car driver and motorcyclist, average-mileage (Male). 	<p>TRL</p> <p>13/03/2012</p>

(source: authors research)

Compared to the first focus group, there were less high-mileage drivers and there was one newly qualified driver in this group. There was one participant who was also a motorcyclist. The gender ratio between the two groups was the same.

4.4.6 Analysis

A reworking of the order of the discussions from the first focus group to the second resulted in a better flow for the participants (e.g. generalising the discussions around the environment first, rather than going straight into discussions on carbon and noise in transport). This resulted in the second focus group having significantly more discussion, of which a higher proportion was from the participants (Figure 4-15). From a statistical point of view, it also resulted in more information on carbon and noise.

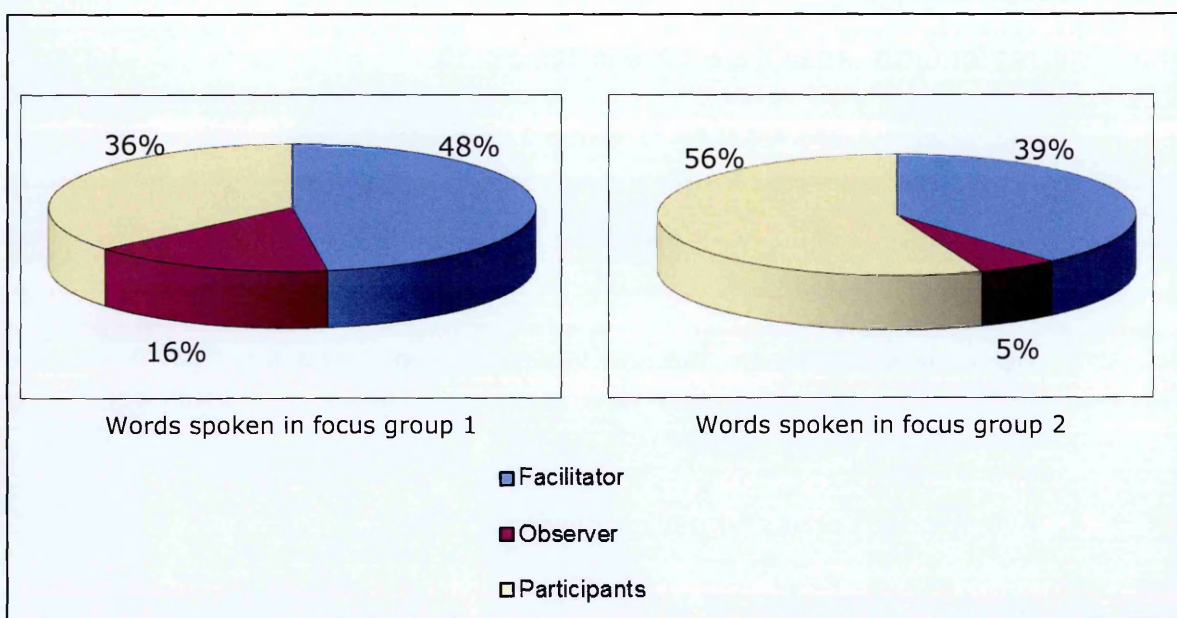


Figure 4-15: Statistical analysis of focus group input (number of words spoken)

4.4.6.1 Environment discussions

The participants talked about the environment but not in an emotive manner, and the economic crisis was suggested as a reason why people felt consideration of environmental issues was now a much lower priority. It was suggested that people

(individuals, companies, government) are doing things because they want to be seen to be doing the right things, rather than because they believe it is the right thing to do. When the participants were asked whether they felt this was wrong they all agreed that if it is still working towards the same end goal then it doesn't really matter.

Across all participants there were no opinions on whether enough was being done to meet targets of improving climate change because the participants were generally not aware of the targets. They had not been impacted by any such schemes and there were also general negative opinions towards carbon offsetting schemes because people did not see them as transparent in how the funds were used.

The participants of the focus groups were aware of the choices they could make on environmental issues such as greener cars, electric cars and low emission zones but not one of those choices invoked strong enough feelings capable of making people actually change their driving habits (e.g. buying 'greener' vehicles for low emission zones, or using the car less).

It was felt that an individual can have little impact on the environment and a lack of a consistent understanding and acceptance of environmental issues meant that people did not feel (or understand) enough to act collectively and take action.

A lot of comments centred on being inconvenienced as a result of additional traffic delays. When any maintenance is underway it doesn't directly influence the amount of tax local people pay and so the general feeling was that when maintenance is occurring, they don't mind what is actually going on as long as the inconvenience is minimised.

These feelings were fairly consistent across all participants although one younger driver did say that he would be prepared to accept longer delays for a lower cost, but that opinion was in the minority. The type of comment that summed up the feelings about the impacts on the environment was:

"...for me personally with the green side it wouldn't matter, it is just inconvenience of being held up, speed of movement through traffic, speed of movement through the works being done."

In summing up the participants' comments from each of the focus groups, the top 100 words from the general discussions on the environment are displayed in Figure 4-16 and Figure 4-17.



Figure 4-16: Participants' top 100 words from their general comments about the environment in focus group 1 (software used: tagxedo.com)

In the first focus group the concept of environmental issues being pushed onto users was discussed a number of times (shown by the large size of 'pushing'). This was in the context of "they push the emission zone in London" or pushing greener technology or public transport. The participants demonstrated a lack of engagement on environmental issues.

In the second focus group it should be noted that the general discussion on the environment was much larger in size than the first focus group, and this was attributed to the reorganisation of how the general topics were introduced in the topic guide.

When prompted about their feelings towards the environment the participants were aware of the issues of noise, car, road, electric, run (energy plants) and fuel as also shown by the more frequent (larger font) word responses. In the same context though, they are equally if not more concerned with 'time', in the context of not having anything impact on their time, regardless of the maintenance option and cost.

When maintenance is being undertaken and when users are held up in delays, the participants' time is the only tangible measure of theirs that is impacted upon and they simply want any loss of time to be minimised. This agrees with the expert's opinion of users not being concerned with the environment.

When looking at both images together what becomes immediately clear is 'think' and it backs up the general opinion that the participants think about the environment but are passive in what they do about it, taking little (or no) action.

"I think I could manage quite well on an electric car because I only drive locally but the cost of an electric car...well I just couldn't afford it."

From the discussions held, the environmental impacts are not great enough to make the road users change their behaviour.

4.4.6.2 Carbon

The participants found it difficult to equate carbon emissions with any direct impacts on themselves (e.g. health) and therefore working practices that try to address carbon in maintenance (e.g. sustainable construction) were not considered important by any of the participants.

However, a small minority did show signs of their opinions being based around making 'value' judgements. Essentially though, with this small group who voiced these opinions, none of the environmental benefits outweighed any other factors (e.g. aesthetics in the case of wind power).

"In power, I mean, nuclear is fantastic but there are some very bad side effects. Wind, lovely, but who wants to see every coastline full of wind farms."

There was strong scepticism towards carbon off-setting schemes with participants feeling that it was not clear who benefited. It was commented that in times of economic downturn people are less inclined to focus on the environment, a feeling that has run through the whole consultation process with all stakeholders from the very beginning.

4.4.6.3 Noise

For comments on noise impacts in their everyday lives, noise annoyances experienced by users ranged from building redevelopment noise to aircraft noise but road traffic noise was deemed to be one of the least annoying noise sources amongst all participants. The greatest sources of noise annoyance were aircraft noise or construction noise (especially construction around some local stations at the time of this focus group). Most of the participants agreed that this type of noise has been distracting to them recently (for example, when in the garden or on the telephone at work) but noise from roads or road maintenance itself was not deemed annoying.

Examples were given of road noise causing annoyance (e.g. driving on concrete sections of road) but the participants agreed that (as a driver) this is normally addressed by simply turning up the volume of the radio. In relation to noise as a driver of maintenance this would imply that road users do not currently see noise as a sole driver of maintenance

"I can honestly say though that in this part of the world, road noise is just constant background... the only time you don't hear road noise is when it is seriously snowing."

and would not expect maintenance to necessarily be undertaken to lower the noise. A

benefit of a new surface might be lower noise but the road users consulted would effectively deal with noise in their own way. This is a difference of opinion from the individual experts consulted.

However, one participant commented that (as a resident) when she hears cars from her back garden, the noise from car radios is more annoying than the road noise itself. This demonstrates the fine balance between being a noise emitter and a noise receiver and how opinions can change depending on the locality of the noise to your property. The differences in these perceptions could also translate to differences in being a user of a model that attempts to target noise (e.g. a road agency) and a stakeholder who is being influenced by the outcomes of a model (e.g. a road user influenced by the maintenance and its effects, such as changes in condition and noise levels).

Where traffic noise was an issue, for example queuing traffic outside someone's house, it was the passenger induced noise (e.g. radio) that was most annoying (compared to the noise of the car or road). Either way, in those situations participants did expect that some sort of noise mitigation should be considered when it impacts residents.

4.4.6.4 Ordering exercise

Although the list of issues for the participants to choose from was revised for the second focus group, in both groups there was very little consideration given to the environment or sustainable construction, such as using recycled material.

From scenario A (where the participants were told that they live in the town where the maintenance is occurring) it was quite apparent that the most important criteria to all groups was quietness. It was also clear that pollution and avoiding delays were highly ranked. At the other end of the scale it was clear that sustainable construction and any visual elements (e.g. looking pretty) were less important (Table 4-13).

Table 4-13: Responses to ordering exercise for Town A scenario

Focus group 1: Group 1	Focus group 2: Group 1	Focus group 2: Group 2
Quiet (during)	Quiet	Quiet
Limited pollution (during)	Limited pollution	Avoiding delays
Avoiding peak times (during)	Clean and dust free	Clear markings/clear signing
Visibility (during)	Avoiding delays	Clean and dust free
Shorter journey time (after)	Clear markings/clear signing	Limited pollution
Quiet (after)	Green construction (e.g. recycling)	Well lit
Limited pollution (after)	Well lit	Green construction (e.g. recycling)
Improved road surface (after)		
Reliable journey time (during)		
Clear signing (during)		
Improved road markings (after)		
Looking pretty (after)		
Visibility (after)		
Good lighting (after)		
Clear signing (after)		
Sustainable construction (e.g. recycling) (during)		
Good lighting (during)		
Considerate to wildlife (during)		
Looking pretty (during)		

(source: authors research)

When the participants were presented with the alternative scenario B (living in a neighbouring town), delays and safety (visibility and clear signing and markings) became higher ranked items with quietness becoming much less important, even being ranked lowest by one of the groups (Table 4-14). The overwhelming consensus was that if you

are not near the maintenance 'avoiding delays' was the main priority - "just getting there" was how one participant summed up their interests.

Table 4-14: Responses to ordering exercise for Town B scenario

Focus group 1: Group 2	Focus group 2: Group 1	Focus group 2: Group 2
Visibility (during)	Avoiding delays	Avoiding delays
Improved road surface (after)	Clear markings/clear signing	Clear markings/clear signing
Reliable journey time (during)	Well lit	Well lit
Avoiding peak times (during)	Limited pollution	Limited pollution
Shorter journey time (after)	Quiet	Clean and dust free
Visibility (after)	Clean and dust free	Green construction (e.g. recycling)
Clear signing (during)	Green construction (e.g. recycling)	Quiet
Good lighting (during)		
Good lighting (after)		
Improved road markings (after)		
Clear signing (after)		
Quiet (after)		
Quiet (during)		
Considerate to wildlife (during)		
Limited pollution (after)		
Looking pretty (during)		
Looking pretty (after)		
Limited pollution (during)		
Sustainable construction (e.g. recycling) (during)		

(source: authors research)

What this exercise effectively showed was that the issues with moderate impact on the user (e.g. noise, delays) were ranked as having greater importance.

In terms of how their priorities changed between the two scenarios it all came down to location and the proximity of the issue, essentially a NIMBY (Not In My Back Yard). In this exercise people wanted better noise mitigation if it affected them, so contrary to some of the general discussions it could be deduced that if noise affects a population, the opinion of the users is that the noise should be addressed wherever possible.

Noise, dust and pollution all became more important when users were located adjacent to the maintenance. But when they were living far enough away from the maintenance so that they were not directly affected by it their primary concern was about being delayed by the road works.

Noise was one of the main issues but one group stated that the effects of pollution survive a lot longer than the effects of noise. This begins to show some thinking around longer temporal considerations which begins to resemble a whole-life approach but it was not a strong enough opinion to be reflected in the ordering results.

During the exercise some participants commented that they felt 'selfish' to desire the noise impacts of maintenance to have a lesser impact only if it was local. This highlights a different opinion between road users and residents and this should be reflected through the developed methodologies.

4.4.6.5 *Trade-offs*

Carbon

One of the carbon trade-offs presented to the participants was based around night working, in that work at night needed extra energy and resources but resulted in a decrease in delays to users. The participants recognised the wider impacts of reduced delays, with people losing less travelling time and the general "*cost to society is less*". As

before, the road users were ultimately concerned with their own time and cost - *"we pay for fuel whilst sat in the traffic whereas the council can pay for the lighting"*.

All participants agreed to do the maintenance at night to reduce delays at road works during the day. Translating this into a modelling framework would be through the use of enforcing night working on certain routes or where traffic levels would reach a certain threshold during the day.

Energy (and carbon) can be saved by turning lights off. It was felt that if lights along sections of the network are consistently on or off users can adapt to that, but frequent changes from lit to unlit sections can be problematic. From the responses given, opting for the safer option prevailed over saving energy but one individual did comment on the balance between lighting and light pollution.

"I think there is a dangerous balance of what people are used to and the light pollution. Personally I can't stand the light pollution."

Other trade-offs also failed to give priority to any carbon considerations (e.g. recycling materials for construction) with the participants wanting the best performing option regardless of environmental consequences. For any maintenance option that resulted in increased durability, the roads users *"would be prepared to take the environmental cost on the chin"*.

Noise

In the trade-off exercises users agreed they would rather drive on a noisy road than be delayed in traffic. But they recognised that opinion would differ if they were a resident, and there was clearly less tolerance for a noisier road if it was going to affect the participant as a resident rather than a road user.

Noise barriers are one common mitigation measure. In a trade-off between having higher noise levels versus the visual appearance of a noise barrier, the participants

stated that barriers should be installed because their appearance can always be softened with time (e.g. planting) whereas “you can’t get rid of noise if it exists.” It was felt that barriers should be funded if noise exceeded a certain threshold.

Overall, the participants were more open to discuss mitigation measures for road noise than other environmental impacts (e.g. reducing carbon emissions). This reflects the general consultation responses that noise is more important to a user because it is a more tangible issue and something that affects them directly.

4.4.6.6 *Pairwise comparison*

The pairwise comparison exercise was completed as a whole group exercise in each focus group.

Table 4-15: Pairwise comparison results from focus group 1

How important are these against each column		Cost	Delays	Carbon	Noise
	Cost		very much less	very much more	much more
	Delays			very much more	much more
	Carbon				slightly less
	Noise				

(source: authors research)

Table 4-16: Pairwise comparison results from focus group 2

How important are these against each column		Cost	Delays	Carbon	Noise
	Cost		equal	slightly more	slightly more
	Delays			very much more	very much more
	Carbon				equal
	Noise				

(source: authors research)

As stated by Barker & Zabinsky (2011) the instrument of pairwise comparison, or analytical hierarchy process, should be used to inform decisions around factors that are usually hard to assess. This approach was adopted in this research because asking focus group participants to weight the parameters of cost, delays, carbon and noise would have been a difficult task, even with just those four parameters. However, asking them to try and determine the relative importance of each pair using qualitative descriptors becomes a more manageable exercise for non-specialists.

The results from the pairwise comparison (Table 4-15 and Table 4-16) were generally consistent in identifying the dominant element in the judgement of each pair between the focus groups (see Table 4-17). Where there were differences, focus group 2 had identified cost versus delays and carbon versus noise both as equal in importance, whereas focus 1 had selected delays and noise as being the dominate element in those respective pairs.

Table 4-17: Results of comparison of pairs

Comparison Pair	Focus Group 1	Focus Group 2
Works Cost vs delays	Delays	(Equal)
Works Cost vs carbon	Works Cost	Works Cost
Works Cost vs noise	Works Cost	Works Cost
Delays vs carbon	Delays	Delays
Delays vs noise	Delays	Delays
Carbon vs noise	Noise	(Equal)

(source: authors research)

Although the dominant element in each pair was generally consistent, the scale of importance varied, resulting in a range of weightings for the core elements (Table 4-18).

Table 4-18: Pairwise comparison weightings

Cost Element	Focus Group 1 Weighting (%)	Focus Group 2 Weighting (%)
Works Cost	26	33
Delays	59	49
Carbon	5	9
Noise	10	9

(source: authors research)

There is a defined measure of consistency that can be calculated for the overall completed pairwise comparison responses. This is used to understand the consistency of responses and the measure of consistency is considered adequate if the consistency ratio is less than 0.1 (or 10%) (Triantaphyllou & Mann, 1995; Ozbek et al., 2012). The consistency of responses for these focus groups was 0.23 and 0.03 for the first and second focus groups respectively. The relatively inconsistent responses for the first focus group would mean that it would not be wise to use those weightings directly in any analysis without first revisiting the exercise. In reality, the response for the first focus group should be dropped in favour of the more consistent response from the second focus group if it was being used to derive budgets or actual maintenance programmes for implementation.

Triantaphyllou & Mann (1995) acknowledged that perfect consistency is rarely found in reality, but they did state that results from analytical hierarchy processes should only be used to aide and support decisions and should not be used solely on their own for justifying decisions. Therefore any analysis using these results would be prudent to investigate the sensitivity around the weightings due to the issues with consistency and trying to improve the consistency is one area where users of the analytical hierarchy process should be concerned (Saaty, 2008). However, in this exercise, the relativeness of the cost parameters was able to be extracted from the responses given.

However, despite the issues surrounding the consistency of responses, the results from the exercise echoed the general discussion point that "*delays have a direct effect on you*

but cost doesn't". During road works, all the user wants is to minimise the delay from the road works. The method of working (sustainable or not) is of no concern to a user at that point because they are not paying any taxes. This exceeds the importance they attribute to cost, which can translate to the efficiency of spending their taxes. Both of these far exceed (by multiple times and even an order of magnitude) the level of importance placed by users on choosing maintenance based on environmental grounds that minimise the impacts of carbon or noise.

Some users expected carbon to be ranked low because everyone likes to consider themselves green but they noted that this opinion tends to disappear once it starts costing them. However, the same users were surprised noise was also ranked so low.

What it does emphasise is that users do make choices and to meet their needs a road authority needs to design and implement maintenance activities to minimise the disruption experienced at road works. In reality, this has to be balanced against demands from other stakeholders.

4.4.6.7 Overall

Overall, the focus groups confirmed the opinions that were expected of users following the individual expert consultations. Fundamentally users are primarily concerned with issues that directly affect them and whilst this rarely includes environmental issues (e.g. carbon in maintenance materials) it does include noise. However, the most prominent issue by far to affect users was delays and as a group they would generally be prepared to accept negative impacts on the environment if it meant a reduction in their personal disruption.

Environmental issues rose in importance when users put themselves in the position of a resident and very quickly it was possible to see a NIMBY attitude emerge towards some of the issues that have a more immediate effect on someone nearby (e.g. noise, dust).

As the discussions progressed it became apparent that users do make some attempt (whether consciously or not) to undertake their own trade-offs when deciding how they

value different issues (e.g. when discussing clean wind farm energy versus the aesthetic impacts). Therefore, even though they were saying they are not concerned by the environment they are also describing thought processes in their own discussions that are effectively trade-offs (albeit simple ones in some cases).

4.5 Discussion

To measure the success of the consultations in obtaining the desired information it is important to map the outcomes against the initial aims. As a reminder, those aims were (from section 4.2.1):

1. Gather opinions from topic experts;
2. Inform the development of methodologies for value parameters;
3. Inform future (wider) consultations;
4. Provide information required for the development of a cost model; and
5. Be an iterative process that evolved as further consultations were completed.

Addressing the last aim first, the preceding sections described how the consultations evolved through the whole process, resulting in improvements in the participants responses.

Sections 4.3.1.2 and 4.3.2.2 specifically discussed the outputs from the individual consultations (Aim 1), section 4.4.2 discussed how the individual consultations informed the focus groups and section 4.4.6 highlighted the analysis of the focus groups (Aim 3).

The remaining aims are discussed in the remainder of this section, specifically:

- Outlining any information obtained that was used in developing the base whole-life cost model (Aim 4); and
- How the consultations were used to provide input into the development of modelling methodologies for carbon and noise (Aim 2).

4.5.1 Information for developing whole-life cost model

There was general support from the experts for the development of a PMS to support longer term planning. Some of the experts felt there was a lack of whole-life assessment given to some existing maintenance decisions and a suitable tool would add greater support to the decision making process. It was also said that there was no minimum level of service or intervention levels used on the network and therefore any rules used in the model had to be implemented clearly and robustly for key stakeholders to gain additional confidence in the maintenance assessment and appraisal process.

No existing data parameters in any appraisal guidance (e.g. NRA, 2011b) were planned to be updated and therefore any required lookup values (e.g. discount rates, appraisal periods, costs) could be obtained from the existing guidance.

The main driver for identifying maintenance was a pavement becoming unacceptable. Cracking, skid resistance, texture and safety were all noted as specific drivers, and to a lesser extent, rutting.

Journey time can also be a driver for maintenance when the condition impacts upon it. Maintenance works on the network are split between day and night working at a current ratio of approximately 60:40 split respectively with traffic levels being the decisive factor.

A number of expert stakeholders felt that the bulk of future maintenance would rise on the secondary network. The primary network was thought to have weathered well and although the secondary network was in poorer condition it was being maintained close to a steady-state condition. However, recent severe winters and flooding incidents have accelerated the deterioration on the secondary network due to problems such as inadequate and ageing drainage and old and deteriorated structural conditions.

Following one consultation a summary of costs of works (Table 4-19) were provided for maintenance works on different road types (these included traffic management

allowances in the rates). These costs were used in lookup tables when developing the model but were updated prior to the main case studies being completed.

Table 4-19: Works costs obtained through the stakeholder consultation

	Surface Dressing (€/m ²)	Surface Restoration (€/m ²)	Road Reconstruction (€/m ²)
Regional	4.5	7	25
Local Primary	3.5	7	19
Local Secondary	3.5	7	15

(source: authors research)

4.5.2 The status of environmental issues

The consultations showed experts debate the handling of environmental issues and whilst businesses acknowledge that those issues need to be addressed in organisations they have a limited impact within the transport sector. The experts considered that users would not be concerned with the environment and the focus groups directly confirmed this. Generally there is little concern among users and some stated that they would be prepared to accept the consequences from environmental issues for a 'good' road.

The low status given to environmental issues within road maintenance can be linked to two fundamental issues that emerged from the consultations:

1. There are no current tools to demonstrate the (dis)benefits that the environment might experience when developing road maintenance programmes, and therefore for all the hype that exists, there is little impetus to act on the environment; and
2. The belief that individual user choices make little impact on overall targets, which ultimately leads to no collective action.

The second point is important because there has been much media coverage over recent years of the UK signing up to emission targets with associated coverage on what we might have to do to meet targets. However, there appears to be less coverage of where we are on the journey of those targets, providing little information to those who are not

specialists. Perhaps part of the problem is that whilst the overall target might currently remain the same, the interim targets are discussed in such a way that they appear more flexible, partly down to the fact that as more or less progress is made than expected, it means less or more drastic action is respectively required in the future. If the interim targets and actions to meet them move then it is likely that individual and even organisations will encounter uncertainty in the address they need to address and how they should go about addressing it.

To really have an impact against any targets, the 'value' savings in road maintenance need to be driven centrally by road agencies or governments to reflect both the relevant policies and stakeholder expectations.

4.5.3 *Linking actions with environmental consequences*

Should carbon issues command a higher level of priority than users currently give them? If improvements in meeting targets are required, undoubtedly the answer needs to be yes. Targets have been set for 2020 and 2050 which need to be met and transport is a key sector for potential savings, contributing around 20-30% of total UK carbon emissions, although this includes vehicle fuel consumption as well as maintenance operations of which the latter will be a smaller proportion.

Carbon accounting is gaining importance and HA Maintaining Area Contractors have to record the quantities of different materials used in maintenance to calculate the associated CO₂e quantities. Itoya et al. (2012) stated that tendering for highway construction is increasingly including requirements on carbon emissions in order to drive low-carbon selections. If organisations have to plan or report on the materials used (and therefore the carbon used) a link between maintenance schemes being selected in the future to minimise the carbon impact is not so far-fetched. Road agencies want to support growth and limit carbon usage and therefore it should be a priority and with the time to meet targets getting shorter, the importance of the issues will grow. However, Itoya et al. (201) also commented on how the decisions making process is not straight

forward and will result in trade-offs having to be made in order to address the (often conflicting) issues.

The discussions on noise within the consultations focused heavily on the production of noise maps (specified by the EU Noise Directive in 2002). The NRA had produced the required noise maps but little use had been made of them to date. The second period of the directive required additional mapping due to a halving of the traffic threshold used to determine the roads required to be mapped. This significantly increased the areas which required mapping. The need to integrate noise management into PMSs is also expected to grow with rising traffic levels. As with carbon, it doesn't require large steps to see that maintenance schemes in the future might be prioritised by the noise reduction they offer.

Modal shifts in transport have a benefit to help decarbonise the transport sector, being one of the key objectives of the EU. Taking freight off the roads has the greatest potential to reduce emissions in terms of a modal shift (e.g. schemes such as T-REX²³ or GULF STREAM²⁴). These schemes have the effect of decarbonising the network but they primarily work because they offer tangible transport cost savings to the freight hauliers. Without financial savings the improvements in emissions alone would unlikely be strong enough to drive their use. Therefore different options for reducing the carbon impact in the transport industry need to be pursued.

4.5.4 Understanding the impacts of environmental choice

Other large scale consultations have been undertaken and reported within the roads sector. Road user satisfaction surveys are one source but they are more focused on the tangible aspects of the network, road condition, maintenance, congestion etc. The proportion of questions given to environmental details is limited and the substantial number of environmental focus groups tends to be based around studies of street furniture and shared- or green-spaces.

²³http://ec.europa.eu/transport/marcopolo/files/success-stories/modal_shift_t-rex_en.pdf

²⁴http://ec.europa.eu/transport/marcopolo/files/success-stories/modal_shift_gulf_stream_en.pdf

Other studies (e.g. Upham & Bleda, 2009) show that few people have a “*top of the mind awareness*” of environmental issues. This was echoed in the outcomes from my consultations and focus groups. There is scepticism about targets and although there is a willingness to change, there is little enthusiasm to act (Upham & Bleda, 2009). The participants found it difficult to make the link between the measurements of value criteria, what it means to them and how it impacts on them. With carbon especially, people do not see the impact that their actions have and therefore they do not have strong views about it. Whilst user opinions need to be considered in the decision making, the action to drive environmental improvements (e.g. through choosing lower carbon materials) needs to be driven centrally, where the bigger impacts can be made.

A parallel can be drawn with the carbon labelling initiative for supermarket products, trying to identify the different carbon footprints associated with different products (e.g. Berry et al., 2008; Sustainable Development Commission, 2007). To an average consumer what does 1g of carbon mean? And even if we make years of low carbon choice in the shops how does that equate to an extra car journey or a flight? The low priority that users place on the environmental parameters is understandable with all the complexities of choice, measurement and impact.

However, this can change with time and appropriate communication. At the launch of the low energy appliance rating in 2002 less than 10% of fridges were rated as ‘A’ but by 2005 this had increased to over 75% (Environmental Audit Committee Inquiry). The public do not actively relate their fridge (or wider) energy use to particular environmental damage but by being presented with ‘environmental’ choices in terms of a rating scale, they felt they could make informed choices. It was not a change driven by the public but it was embraced by them, and it led manufacturers to strive to get their appliances into the higher bands.

With road maintenance, as with fridges, the public (users) might embrace the outcomes of any changes in working practices but they would be unlikely to either demand or drive change. Action is needed by road agencies or contractors at the point of choosing

materials for example, where the large benefits can be realised. If road maintenance takes account of the carbon emissions of different materials that could act as an additional driver in the production of lower carbon alternatives, especially if it allows material suppliers to gain a stronger position in the marketplace. Currently there is little integration of carbon or noise into network level pavement models. This was demonstrated by the consultations and focus groups, but the importance of those discussions was that it highlighted ways in which road users might be willing to accept trade-offs between costs and the environment, which could be developed into methodologies for modelling, both of which are explored in the next section.

4.5.5 Using the consultations to inform modelling

4.5.5.1 Developing maintenance rules and options

The trade-offs with the focus groups provided an understanding of how maintenance options could be modelled to reflect a balance of the costs and benefits they bring. For example, when assessing maintenance options for noise, additional suggestions put forward were:

- Traffic above a certain level or near a certain population size could have costs for noise barriers included;
- Make sure that any road which has greater than a certain traffic level in a certain population area has additional budget to surface it with a low noise surface; or
- For any schemes that fall within areas above or below a certain residential population make sure that specific working patterns (e.g. day working) are enforced in order to limit stress caused by maintenance noise.

An alternative methodology would be to adopt an approach where for each scheme, the model calculates the whole-life costs for the following options:

- Do Minimum;

- Do Something – standard;
- Do Something – low noise; and
- Do Something – more invasive by treating additional defects, not just those above the threshold.

Where the 'Do Something – standard' is the treatment that is set to treat just the failed defects and the 'Do Something – more invasive' is a more invasive treatment (correcting more than just the issues that have triggered a treatment) or a larger treatment area for the same treatment. All of the above would have a carbon cost calculated to assess the carbon impact, rather than using a specific low carbon treatment.

A second alternative would be to include a 'Do Something – low carbon' option into the above list of options that represents treatment options that contain less embodied carbon (e.g. lower binder content, or higher recycling content). Forcing the model to choose between all modelled Do Something options for each scheme would allow for the impacts of scheme options with different environmental characteristics to be investigated and compared.

By incorporating representative data for the different Do Something treatments (e.g. treatment lives, deterioration coefficients) the treatment profiles would result in different whole-life cost profiles, allowing a modeller to more realistically understand how the different options compare over the long-term (e.g. a quieter performing surface but one that requires more frequent maintenance).

4.5.5.2 *Costing*

For all scheme options the costs of carbon and noise emissions from maintenance needed calculating for each scheme. This would allow all impacts (works, delays, carbon and noise) to be assessed in the development of works programmes.

The carbon cost would be calculated based on the type and volume of materials used with that particular treatment. The noise cost would require data on the change in noise

levels with different surfaces, the difference in treatment lives and the populations affected. This would allow a cost for noise to be determined for the whole analysis period, including the change in noise of the in-traffic periods between interventions that are affected by the different maintenance interventions during the analysis period.

4.5.5.3 Weighting sets

The pairwise comparison outputs are a set of weightings that could allow the individual cost elements to be weighted differently in deriving an overall total cost for prioritisation. The weighting sets could allow a user of the model to investigate how a works programme would change when different impacts are emphasised (Table 4-20).

Table 4-20: Example weighting sets

		Weighting sets...			
Works Cost		A ₁	A ₂	A ₃	A ₄
Delays	Default	B ₁	Road B ₂	User B ₃	Contractor B ₄
Carbon		C ₁	agency C ₂	C ₃	C ₄
Noise		D ₁	D ₂	D ₃	D ₄

(source: authors research)

For example, in the consultation with a contractor one of the issues raised was that they would like to be able to undertake alternative maintenance solutions but they had no clear, consistent way of being able to demonstrate any of the associated costs, benefits and effects on a long term maintenance programme. This approach would allow a contractor to demonstrate how the whole-life value changes when different priorities are emphasised.

There could be multiple weighting sets that derive works programmes based on different objectives and drivers. Model analyses could be undertaken using different weighting sets to investigate the different maintenance programmes that would be created.

4.5.5.4 *Sensitivity analysis*

The modelling approaches will need to consider the scenarios that a highway authority would want to examine to ensure that the model is capable of assessing the impacts laid out in the research question. Those questions include:

- Understanding the change in resulting maintenance programmes if:
 - Only the low carbon schemes were selected;
 - Only the low noise schemes were selected;
 - Different combinations of the cost categories are included in the prioritisation; and
- Allowing the model to include prioritisation options for environmental parameters. For example, the next carbon target is 2020, and at that point there might be a tougher stance on carbon and only low carbon options could be selected within a maintenance programme following that date.

4.6 Summary

The consultations allowed for a range of stakeholders to be included in further understanding the needs and requirements that a road authority has to address. The individual experts provided a detailed view of the processes and regulation which governs the inclusion of information in appraisals (e.g. the inclusion of some qualitative measures but a general lack of formal assessment of environmental externalities).

The focus groups demonstrated that road users are not currently concerned with environmental issues related to road maintenance and are primarily interested in whether they will be delayed on their journeys. If the maintenance is being completed locally then some issues (e.g. disturbance) rise in importance but not across the whole network. The road users are not engaged enough with the impacts of the environmental issues to be in a position to feel passionate.

However, the opinions from all stakeholders were analysed in order to understand how they could be used to inform the development of methodologies for modelling carbon and noise emissions from maintenance.

The next stage of the research focused on developing both a whole-life cost model and methodologies for modelling carbon and noise emissions from maintenance which could be incorporated in the whole-life costs model to lead to a whole-life value model.

Chapter 5 Whole-life cost model

This chapter documents the pavement whole-life cost model that was developed to:

1. Allow the NRA to meet their requirements of developing strategies for the maintenance of their pavement network on a whole-life cost basis (research objective 2); and
2. Function as the base whole-life cost model (herein termed 'base model') into which the main research outputs of modelling the externalities of carbon and noise emissions from maintenance could be incorporated (effectively acting as the base equipment for research objectives 3 and 4).

A pavement cost model was developed which was tailored to represent the Irish network by customising the analysis parameters and the input data. The base model was structured in a modular form so that following completion, modules for the externalities of carbon and noise could be added to develop the planned whole-life value model. The modular approach brought the advantage of making it easier to add new modules in the future, or substitute modules if different modelling approaches were required (e.g. a change in the deterioration rules used).

This chapter documents the developed base model, drawing heavily on the previously published manual (Buckland, 2011a). The data structure of the model was formulated to be generic so that it could be applicable for other road agencies and road networks. The model framework and approach was designed by the author as part of this research but discussed with the NRA that it would need their needs. All the programming work and database administration in developing the model was completed by the author.

The methodologies for modelling carbon and noise emissions from maintenance, and how they are incorporated into this base model are documented in chapter 6.

5.1 Data structure

The base model was designed as a computer-based data-representation of a road network and the data fields and interactions were important in the development. There were two databases that the base model was designed to use, reflecting the different data types, data sources and the frequency at which they would be updated in the future (see Figure 5-1):

1. Network database: A representation of all the data required to model a road network, representing where the network is and what its associated condition is. This data is primarily gathered from surveys of the road network, most often machine based surveys. For the purpose of this model, network data can itself fall into one of three categories:
 - a. Inventory: These data are used to determine where the roads are, what types of road they are (e.g. motorway, single-carriageway) and characteristics of a road that are generally fixed and do not change until a major upgrade occurs (e.g. number of lanes, road widths, road lengths);
 - b. Condition: These data are a representation of the condition of the network following surveys of the road network (i.e. measured condition data from machine or visual surveys). Ideally the model should use the most recent survey data for all lengths of the network and therefore these data are updated more frequently than other data sources, depending on the survey frequency completed (e.g. a monthly basis would not be unreasonable for machine surveys); and
 - c. Traffic: These data are for the traffic flows on the network. It is usually collected by automatic traffic counters embedded in the road surface or from overhead gantries, but it can also be obtained by manual count exercises. Traffic data are usually assigned to fixed points on a network and those traffic counts are applied across the whole network by assigning

the count locations to other locations of similar characteristics. Traffic flows were used in the model to calculate the cost of delays experienced by road users during maintenance and this cost was able to be included in the scheme prioritisation process, thereby allowing an agency to undertake analyses that prioritise maintenance on the basis of keeping user delays to a minimum.

2. Reference database: This contains values that act as defaults for lookup values used in model calculations. The reference data are primarily used to select default run parameter data selected through the model interface. The reference data are not usually updated more frequently than on an annual basis and some data fields (e.g. discount rates) may be updated only when associated high-level guidance documents are updated. The data types held in the reference data are default values for:

- Display names (e.g. full county names and not abbreviated names as stored in some database tables);
- Carriageway types;
- Surface types;
- Homogenisation correlation values, used to compare calculated homogenisation statistics against to determine if sections are suitably grouped for homogenisation;
- Deterioration rates for the condition parameters;
- Treatment parameters (e.g. road types where specific treatments are allowed, thickness, new surface type);
- Treatment triggers (i.e. the condition parameters that can trigger specific treatments if thresholds are exceeded);
- Maintenance thresholds;

- Unit costs (e.g. for the works);
- Working patterns (i.e. whether closures for maintenance are 24 hour, off-peak only or night-only);
- Closure types;
- User delay costs (depending on closure type, working pattern and traffic flow);
- Default data (i.e. data used to fill gaps where survey data are missing or used to reset condition parameters following a treatment); and
- Network class (i.e. whether a road is a primary or secondary road).

Reference data that was incorporated into the reference database later to handle the value parameters for the carbon and noise methodologies are:

- Unit costs for carbon and noise emissions;
- Carbon quantities used in maintenance processes (e.g. embedded in materials, from machinery to plane-off the old surface); and
- Noise change values (i.e. the change in noise when replacing one surface type with a new one of either the same or a different type).

The minimum data required to undertake an analysis in the base model is to have:

- Inventory data;
- One condition parameter;
- One defined treatment; and
- A reference database.

Traffic data are not required as a minimum but it will result in no user costs being calculated.

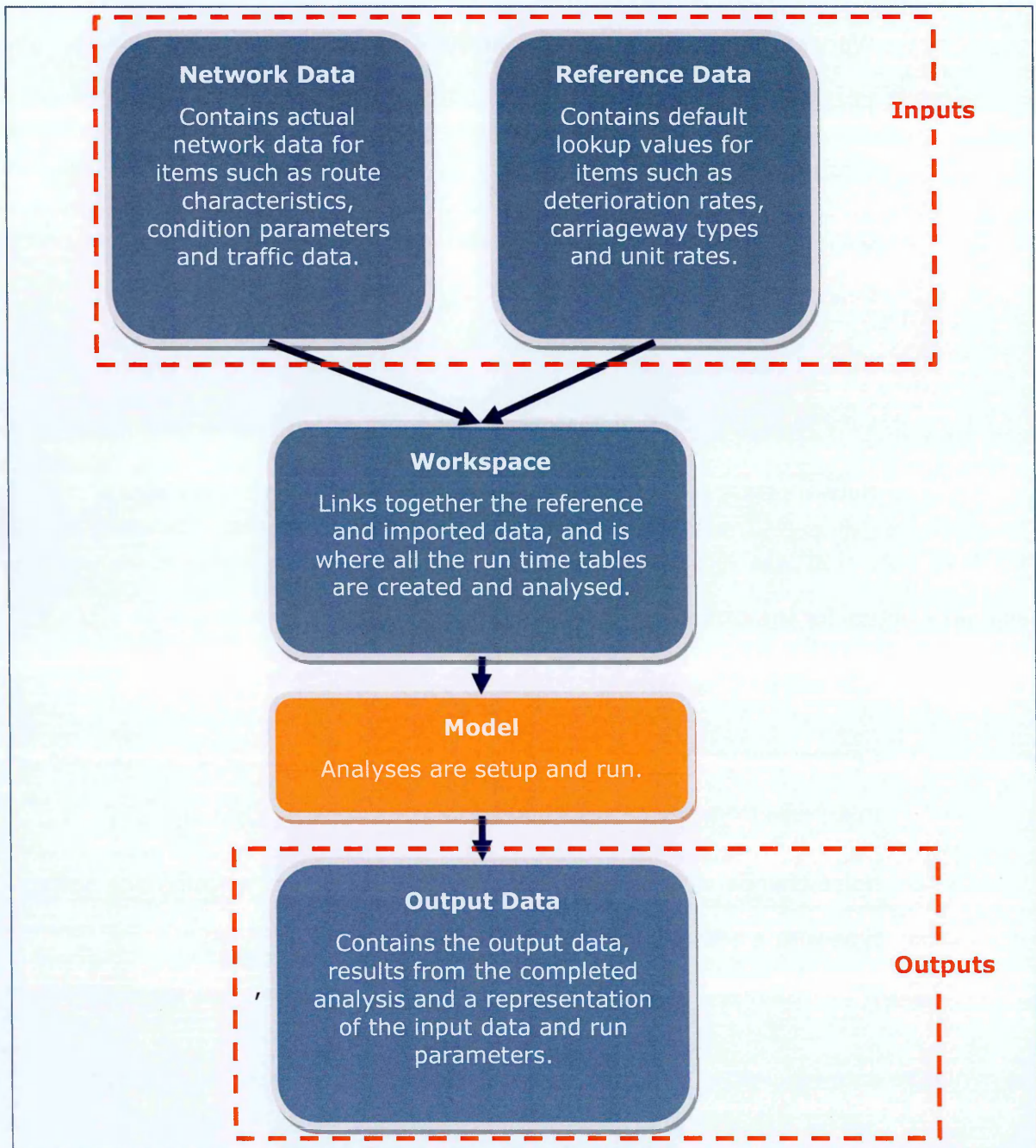


Figure 5-1: Model databases and their relationship in the model

At the point at which the network database has been created pre-processing of the data has already taken place from the data that are initially delivered. The pre-processing that takes place is:

- Defining a network: The routes on the network can be split based on different data fields. A single representation of the network and all the breakpoints is created during the pre-processing and these breakpoints are included when

aligning the data to a common network (see next bullet). The data fields used to create breakpoints along routes are changes in:

- Carriageway width;
 - County; and
 - Surface type.
- Aligning the data to a common network: Due to the data being gathered from different surveys it is not necessarily aligned to consistent reference lengths along the network. In the pre-processing all the survey data are aligned to consistent chainage intervals based on a value specified by the user importing the data (e.g. [0-10m, 10-20m, ...] or [0-100m, 100-200m, ...]); and
 - Selecting the latest condition records: The survey regime across the network is different for different data types, road types etc. Therefore the latest data for each condition parameter and each length of the network is unlikely to all be in the same year. In preparing a condition dataset the latest data for each condition parameter for each part of the network is imported into the network database (often there being a lack of historic data anyway, see section 5.2.1) along with the year in which it is collected. Holding the year of latest condition data (for each length) allows all data to be aged appropriately up to the start year of the analysis.

5.2 Model structure

The principal aim of the base model is that it allows comparison of maintenance appraisals across a selected network considering both the initial works and additional delay cost of each option and the future whole-life costs. The model uses data to allow maintenance strategies to be created and compared.

The structure of the modelling process is shown in Figure 5-2. The network database and reference database linked into the workspace are used as inputs into the first model

process, 'Data Setup'. This process allows the specific data for the particular model run to be grouped together into more efficient run-time tables (i.e. only including data records for the current network being analysed to make data sorting, analysis etc. quicker).

The model subsequently works through all the processes in turn in order to complete an analysis. The outputs from the model provide input to network management programmes that a road authority has to develop based on determining where the condition dictates that maintenance is required to deliver agreed objectives.

The processes 'Data Setup', 'Data Ageing' and 'Data Homogenisation' all occur in advance of the start of the first year of analysis and focus on data preparation. 'Data Setup' collates the specific network data needed for the run chosen (e.g. the correct sections, condition parameters etc.). 'Data Ageing' compensates for survey data from different years by ageing all data up to the start year of analysis. 'Data Homogenisation' groups lengths of statistically similar data together so that it can be analysed more efficiently and treated together, as an engineer would do.

The remaining processes occur as part of one of two loops within the model:

1. Programme period: The programme period represents the year(s) for which a maintenance strategy is to be developed. This is likely to be 1-4 years and will most often represent the period over which budgets are known or required. Within this loop the model takes each year of the programme period in turn, identifying all maintenance that could happen in the current year of the programme period. Each scheme in the current programme period year is analysed in turn to determine the whole-life costs (see treatment evaluation period);
2. Treatment evaluation period: All maintenance identified in a programme period year needs to be evaluated for its whole-life cost so that costs beyond the initial year (the cost in the programme period) can be included in decisions on whether

the scheme is viable. Each maintenance scheme is analysed for maintenance in year 1 (the current year of the programme period) and for all future maintenance needs within the treatment evaluation period, often set as 30 years within these types of analyses. The treatment evaluation period therefore allows the future costs and benefits of each scheme in the programme period to be determined.

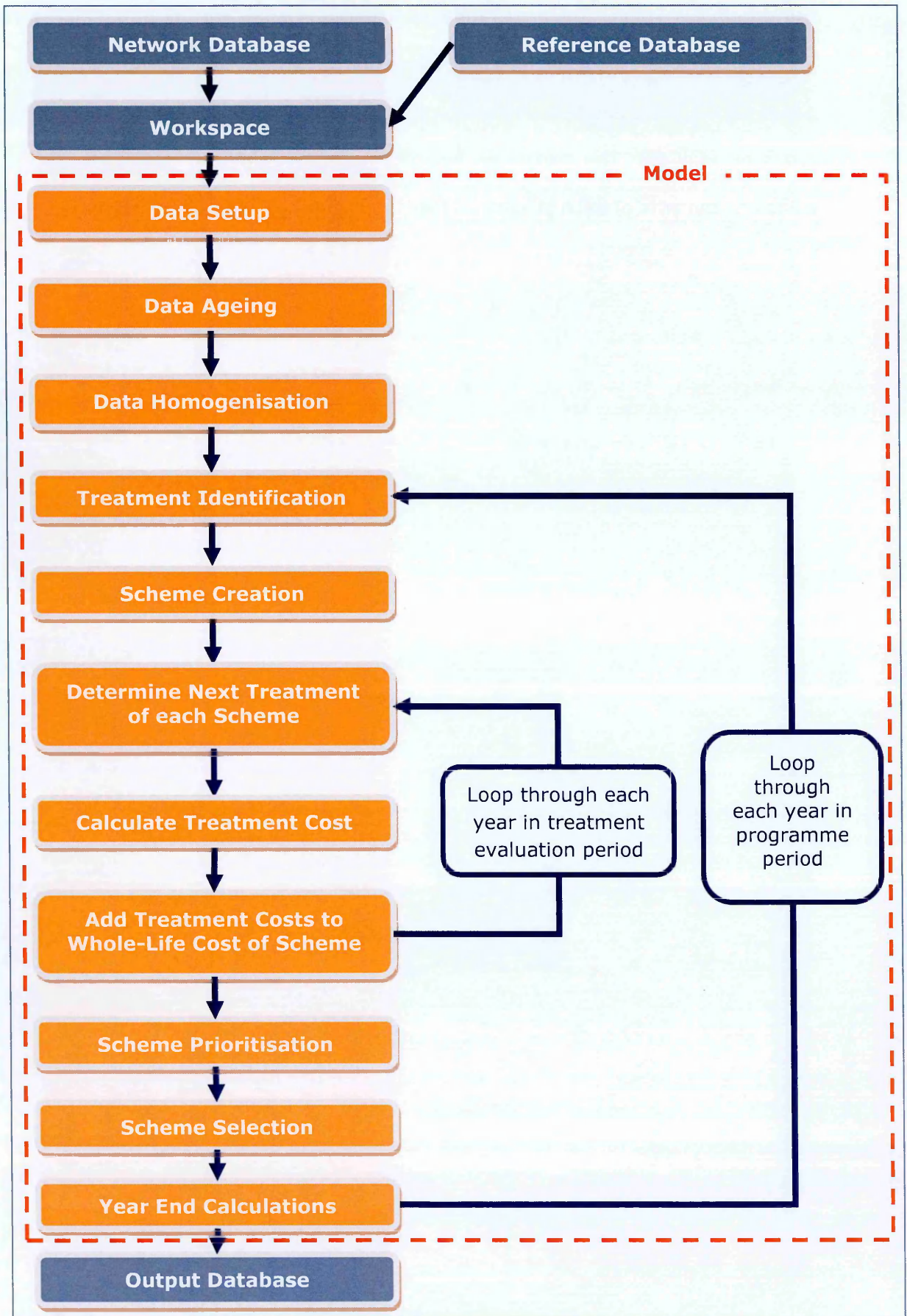


Figure 5-2: Modelling processes

The design of the model allows a user to interact with it using a user interface. The menu structure (and descriptions) for the user interface is:

- Database;
 - New;
 - Import (*Imports a new set of network data*);
 - Workspace (*Creates a new workspace from an existing Network and Reference database*)
 - Open (*Opens an existing workspace*);
 - Exit (*Exits the model*);
- Analysis;
 - New (*Creates a new analysis*);
 - Open (*Opens an existing analysis*);
 - Save As (*Saves an existing analysis with a new name*);
 - Configuration (*Configures the current analysis, including selecting run parameters, homogenisation, closure types etc.*);
- Setup (*The main menu item for setting up user defined datasets*);
 - Network Selection (*Allows a user to select a network*);
 - Deterioration (*Allows a user to select or amend a set of deterioration rates*);
 - Run Parameters (*Allows a user to select the years for an analysis and any constraints, e.g. budget*);
 - Intervention Thresholds (*Allows a user to set thresholds used by the condition parameters when triggering treatments*);
 - Unit Rates;

- Works (*Allows a user to set unit rates for the works costs for the analysis*);
- Carbon (*Allows a user to set unit rates for the carbon costs for the analysis*);
- Noise (*Allows a user to set unit rates for the noise costs for the analysis*);
- Committed Works (*Allows a user to enter any maintenance they specifically want the model to consider*);
- Run;
 - Start (*Starts an analysis*);
- Results;
 - Analysed Network (*Displays results for the network*);
 - Summary (*Displays summary results*);
 - Schemes (*Displays results for the selected schemes*); and
 - Condition (*Displays results for the network condition*).

5.2.1 Model approach

The base model has been developed as a deterministic tool that applies rules and algorithms to road network data to predict the future maintenance needs of a pavement network.

The choice of the deterministic approach drew upon both previous modelling experience and the results of the literature review and was chosen for two main reasons:

1. There was no existing network level model for use on the Irish network and therefore the existing engineering rules for the network could be more readily translated into the form required for use in a deterministic analysis; and

2. There was a lack of historic condition data for developing network specific trends and a lack of trends due to a limited quantity of data with three or more time-series points (see Appendix H for examples). Therefore deterioration rules needed to be used from other sources until Irish specific data allowed the derivation of suitable trends. This is much more manageable using a deterministic approach (as opposed to a probabilistic approach) and gives local engineers better vision of modelling rules, which is essential for a new model that needs to be embedded into an organisation. In the future, as more data becomes available, one enhancement to the model would be to use historic data for each individual section to determine trends at a section level.

5.3 Modelling processes

A detailed representation of the base model steps for the processes in Figure 5-2 can be found in each of the main sub-sections that follow in section 5.3.

5.3.1 Data setup

The base model was developed to allow for maximum flexibility at runtime by giving as much control to a user as possible (e.g. by allowing users to create their own treatments).

The data setup in the model relates firstly to the functionality given to the user in customising each analysis and secondly to specific run-time tables that are setup in the workspace when an analysis is started.

5.3.1.1 Analysis configuration

When setting up an analysis the base model was designed to store a set of variables that are used in two ways:

1. In advance of the run to determine the input data to use; and
2. During the run to determine the calculations and options that are carried out.

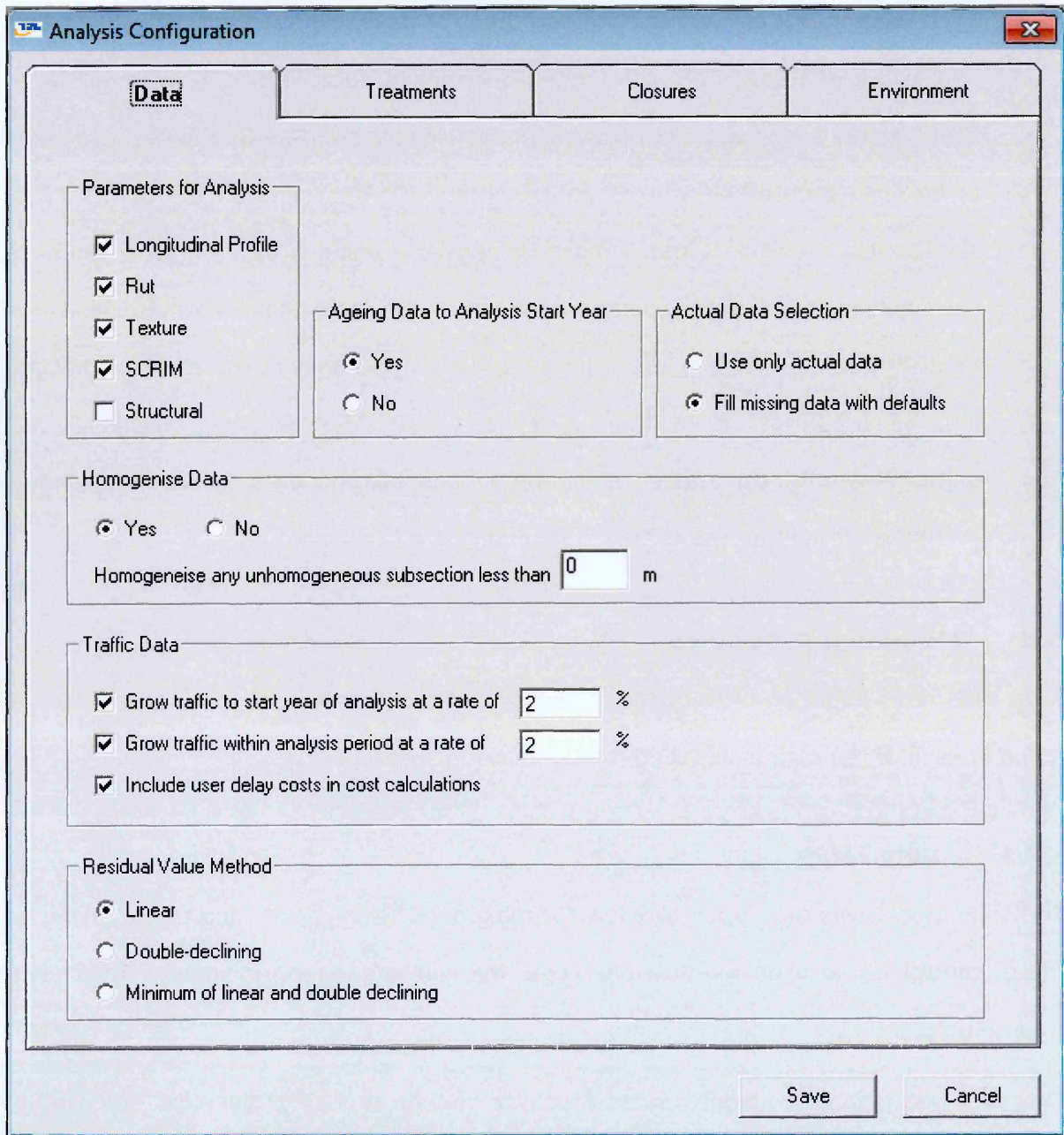


Figure 5-3: Analysis configuration screen: Data tab

The data that can be configured are:

- The condition parameters to include in the analysis;
- How to age the data;
- Whether to fill any data gaps with default values;
- Whether to homogenise the data;
- Traffic growth rates;

- Residual value method;
- The treatments to include in the analysis;
- Scheme creation constraints (e.g. minimum and maximum permitted scheme lengths, length of period following treatment during which no treatment is allowed on the same length); and
- Closures to apply for different road types and traffic levels.

Additional configuration parameters were added later to handle the methodologies for carbon and noise emissions from maintenance:

- Whether to include carbon and noise costs;
- Whether carbon and noise costs should be treated as agency costs (i.e. direct costs) or societal costs (i.e. indirect costs);
- Whether to include low carbon and noise options in the treatment alternatives;
- Whether to discount carbon and noise; and
- Whether to apply weightings to all the cost elements (works, delays, carbon and noise).

An exhaustive list of the descriptions and options for the analysis configuration and setup options can be found in the base model User Guide (Buckland, 2011b).

5.3.1.2 Network selection

A network definition can be chosen for analysis from the available data (see Figure 5-4).

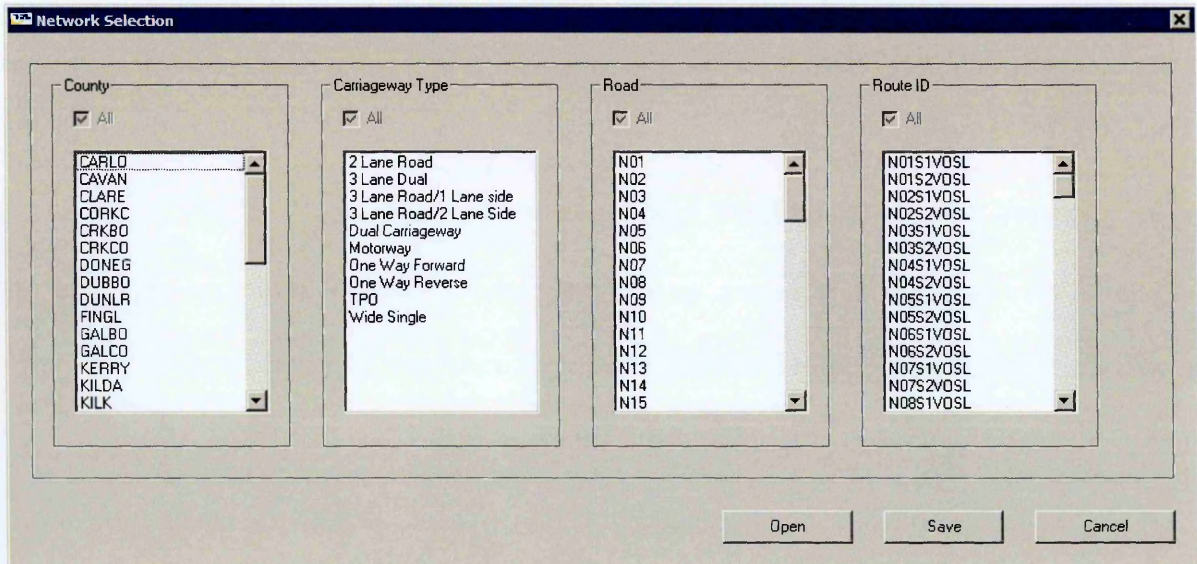


Figure 5-4: Network selection screen

The defined network can be the entire network or any smaller subset of the network. A specific subset of the network can be selected through a hierarchy of options:

- County;
- Carriageway Type;
- Road; or
- Route ID.

Although these were the parameters used to define the network in this study because the data was available, the categorisation of the network could make use of any data parameters that a road agency holds against their network. For example, the model could be used to store and hold data on strategic routes on the network, such as for TEN-T²⁵ routes. This type of data, such as strategic routes, could then be used in

²⁵ The TEN-T is the Trans-European Transport Network, a designated strategic network across Europe.

selecting networks for analysis, or potentially for a different type of prioritisation for those routes.

A network could be created from an individual section along a road (see 'Network 1', Figure 5-5) or it could be created from a collection of roads and/or sections (see 'Network 2', Figure 5-5).

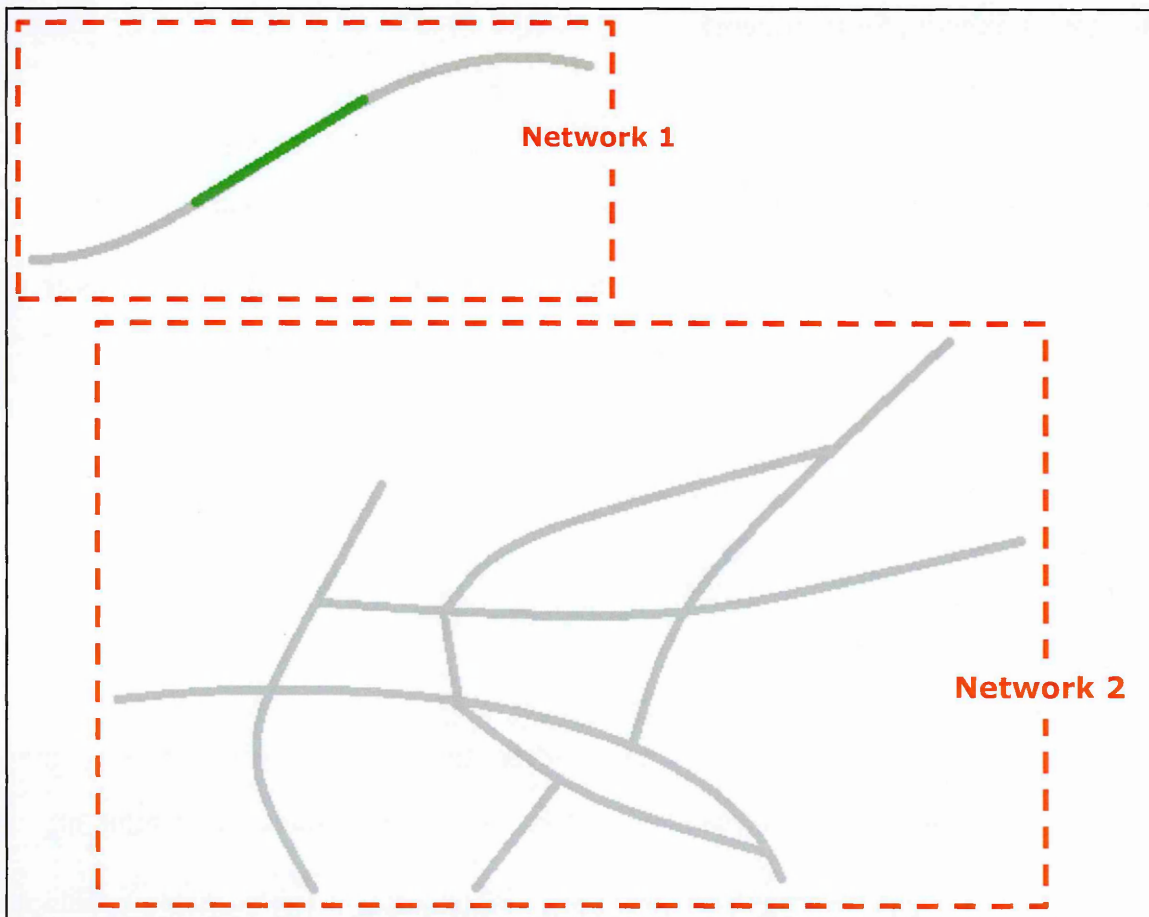


Figure 5-5: Example analysis networks

5.3.1.3 Condition parameter selection

Any model analysis must be configured to use at least one condition parameter from those available:

- Longitudinal Profile, a measure of the unevenness of the road surface;
- Rut depth, a measurement of the deformation of the upper pavement layers;
- Skid resistance, a measure of the friction and skid resistance of the pavement surface;

- Texture depth, a measure of the texture of the road surface that can be related to the skid resistance; and
- Structural, a measure of the structural strength of the road dependant on the data available.

The condition parameters selected during configuration are used in other modules of the model (e.g. as triggers for treatment).

5.3.1.4 Treatment selection

The base model requires each analysis to select at least one of the available treatments.

Default treatments included in the initial model for Ireland were based upon discussions with NRA engineers on the treatments currently used on the Irish network:

- Surface Dressing;
- Inlay;
- Overlay; and
- Patching.

Additionally the base model has been designed so that the user can add a custom treatment and include it in an analysis. Any custom treatment includes the creation of:

- Associated trigger mechanisms (from any combination of the available condition data) which allow the model to determine itself when and where the treatments should be applied; and
- Works effects (e.g. condition reset values following maintenance).

5.3.1.5 Missing Data

For the majority of road networks it is likely that there will be gaps in some of the available data (i.e. there will not be complete data coverage for the whole network). The model needs to have data for all lengths of the network it is analysing. The implication of

having gaps in the data are that if there is actual data for one condition parameter but a gap in the same location for another parameter (depending on the configuration of the analysis) it could result in that length of road being dropped from the analysis and therefore no use being made of the actual data for the one parameter where it exists.

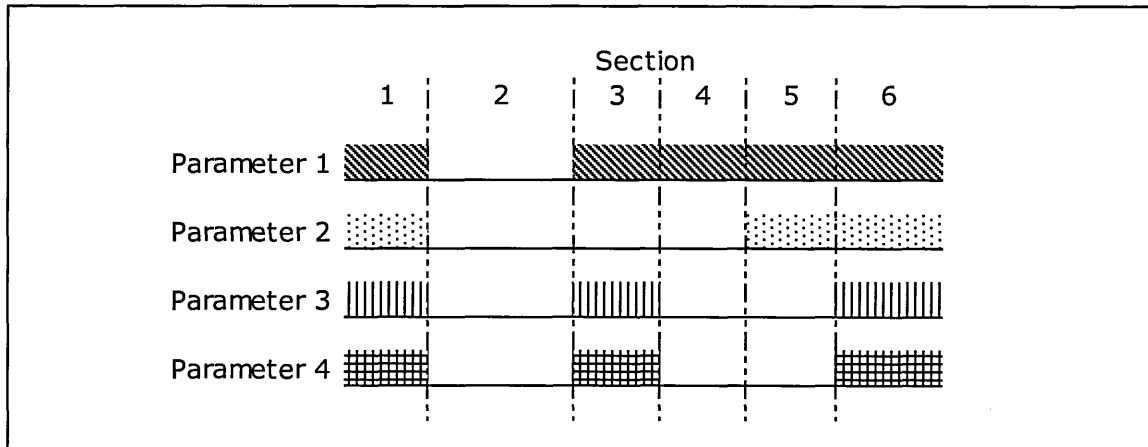


Figure 5-6: Missing Data Example

In the missing data example above (Figure 5-6) only sections 1 and 6 have complete data coverage for all parameters and if the user had not chosen to fill any gaps then they would be the only two sections used in the analysis. If that was the case then a lot of actual data would be lost from sections 3, 4 and 5. By filling in the gaps it allows all the actual data to be used from sections 3, 4 and 5 where it was provided. It should be noted that section 2 would always be dropped from any analysis because it does not have any actual data.

For the NRA network there were gaps for some lengths in the provided data for:

- Condition parameters; and
- Traffic data.

To address the missing data issues, rules were included in the model so that gaps can be filled and all actual data can be used in an analysis. The user can choose to fill any gaps in data with default values held in the reference database, configured through lookup tables. A separate method could be interpolating between surrounding data which

implies that the gaps are in the same condition as the known condition around it. Not one method is right but by filling the gaps with default values (which themselves will not trigger maintenance) then the model is only being allowed to select maintenance treatment using known data. This can also have the effect of improving survey regimes to make sure that data is available for a significant proportion of the network.

For the NRA network initial values were chosen so that any default value itself would not trigger a treatment intervention (if recommended deterioration rates are used). The default values recommended for condition parameters were:

- Longitudinal Profile: 0.1 IRI (International Roughness Index);
- Rut depth: -10 mm (with rut maintenance being triggered by positive rut values);
- SCRIM difference: 99; and
- Texture: 5 mm.

For traffic data the options for filling gaps were to set the AADT to the average value for the particular road type.

If during an analysis a treatment subsequently occurs on a record that has been populated with a default condition value, the missing data value will be reset according to the reset rule for the treatment.

5.3.1.6 Derived data

Containing lookup information in reference tables allows the owner of the model to manage changes in the future, promoting sustainability of the tool.

A number of the modelling rules or data (e.g. deterioration rates) are applied differently for different parts of the network and the lookup information for this is held in the reference database. For the Irish network this is based on knowing the:

- Network class: Whether the section is part of the primary or secondary network. This is derived from a lookup table in the reference database (tbl_Lookup_Network_Class²⁶) that uses the road number to determine the class.
- Carriageway type: Whether the section is a single-carriageway, dual-carriageway or motorway. This is determined from a lookup table in the reference database (tbl_Lookup_Cway_Type) which uses the fields ID, Description and Carriageway. Table I-1 (Appendix I) shows the lookup table customised for use on the Irish network.

5.3.1.7 Analysis run-time data setup

Figure 5-7 shows the data setup process undertaken during run-time at the start of an analysis. The process primarily clears all previous calculations from the workspace and gathers all the network data required for the current analysis into specific run-time tables. The run-time tables allow for calculations to be undertaken on the data and for records to be updated accordingly without changing the original data.

²⁶ If any definitions change in the future this table can be updated to reflect the change. At the time of development the N1 to N50 were classed as primary routes and the N51 to N87 as secondary routes.

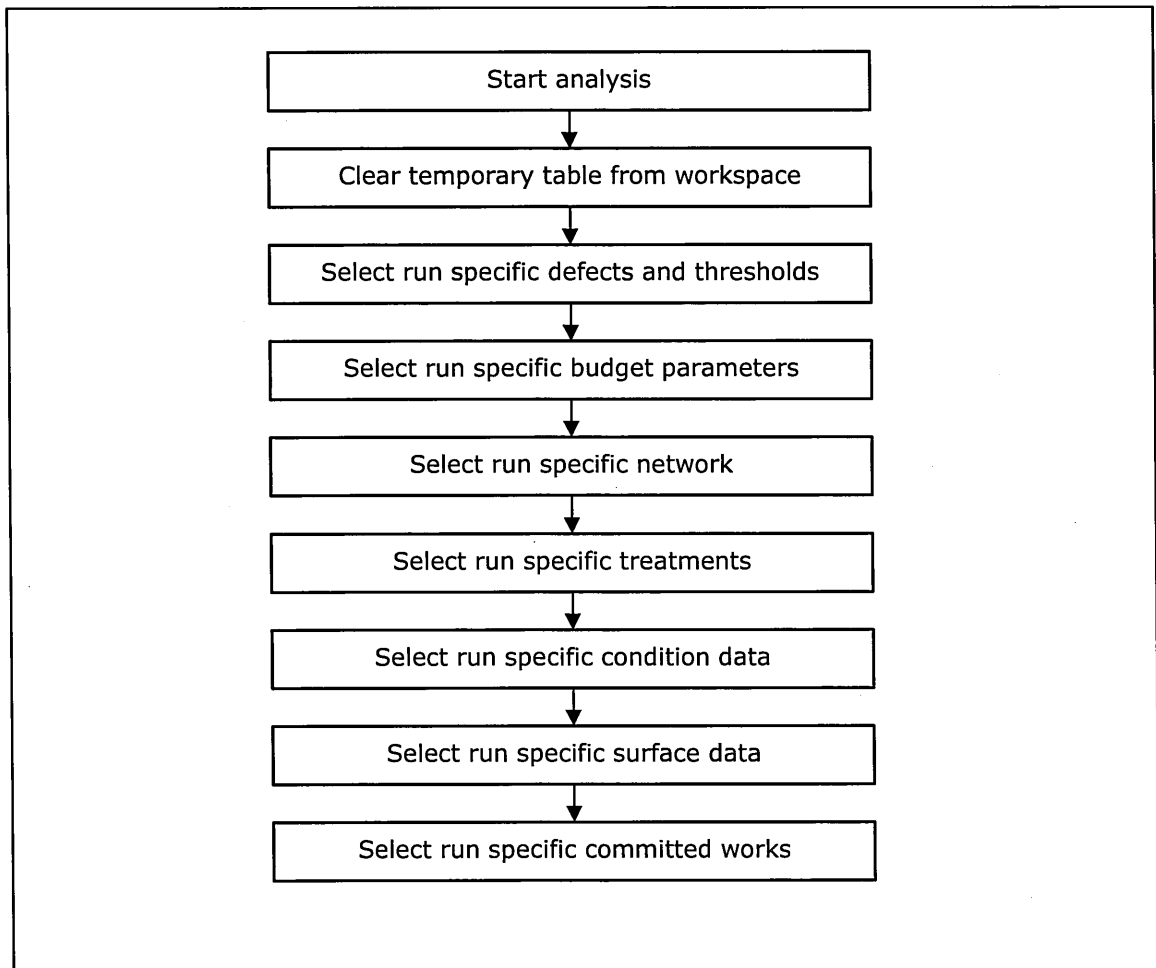


Figure 5-7: Run-time data setup flowchart

5.3.2 Condition projection

Condition projection rules are utilised within the base model in two main areas:

1. Condition data for the selected network from the time of collection is projected to the start year of analysis; and
2. All condition parameters used within the base model are aged up to the year of their treatment (if any). Following a treatment the appropriate condition parameters are reset and the data are aged again until the next treatment. This continues until the end of the analysis period.

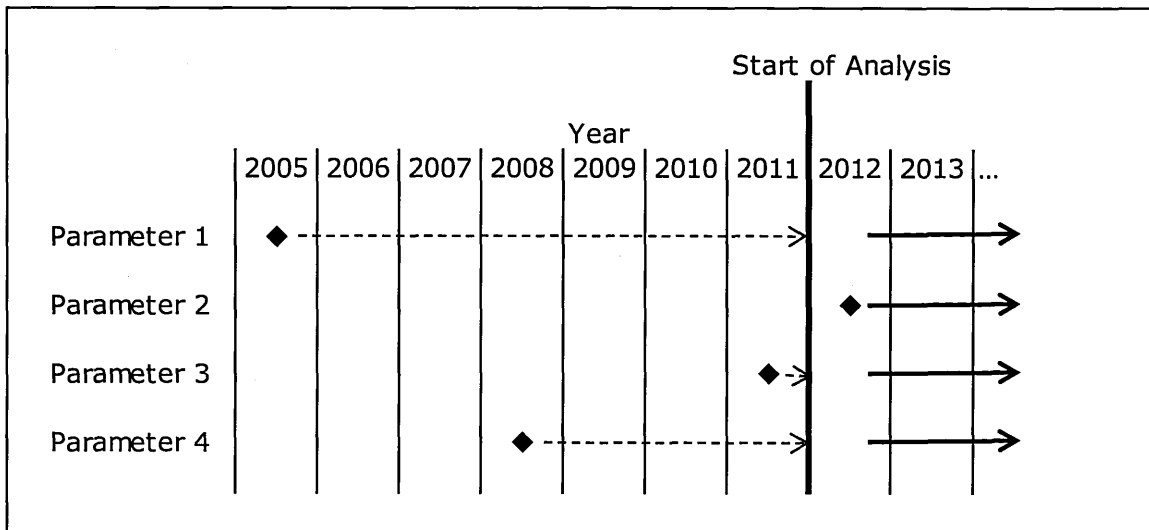


Figure 5-8: Data projection example

In the data projection example above (Figure 5-8) it can be seen that the survey year for data collection for each of the four parameters is different (marked by the diamond) and therefore different periods of projection (or deterioration) need to be applied to each data source to align them to the start of the analysis year, 2012 (marked by the dashed arrows). For parameter 1 the data needs deteriorating for a period of 7 years, and for parameters 3 and 4 it is 1 year and 4 years respectively. Data for parameter 2 was collected in the year of analysis and therefore no deterioration is required in advance of the start of the analysis.

Once all data has been deteriorated (aged) to the start year of the analysis (Figure 5-9) the deterioration periods within the analysis will be consistent for all parameters (marked by the black arrows).

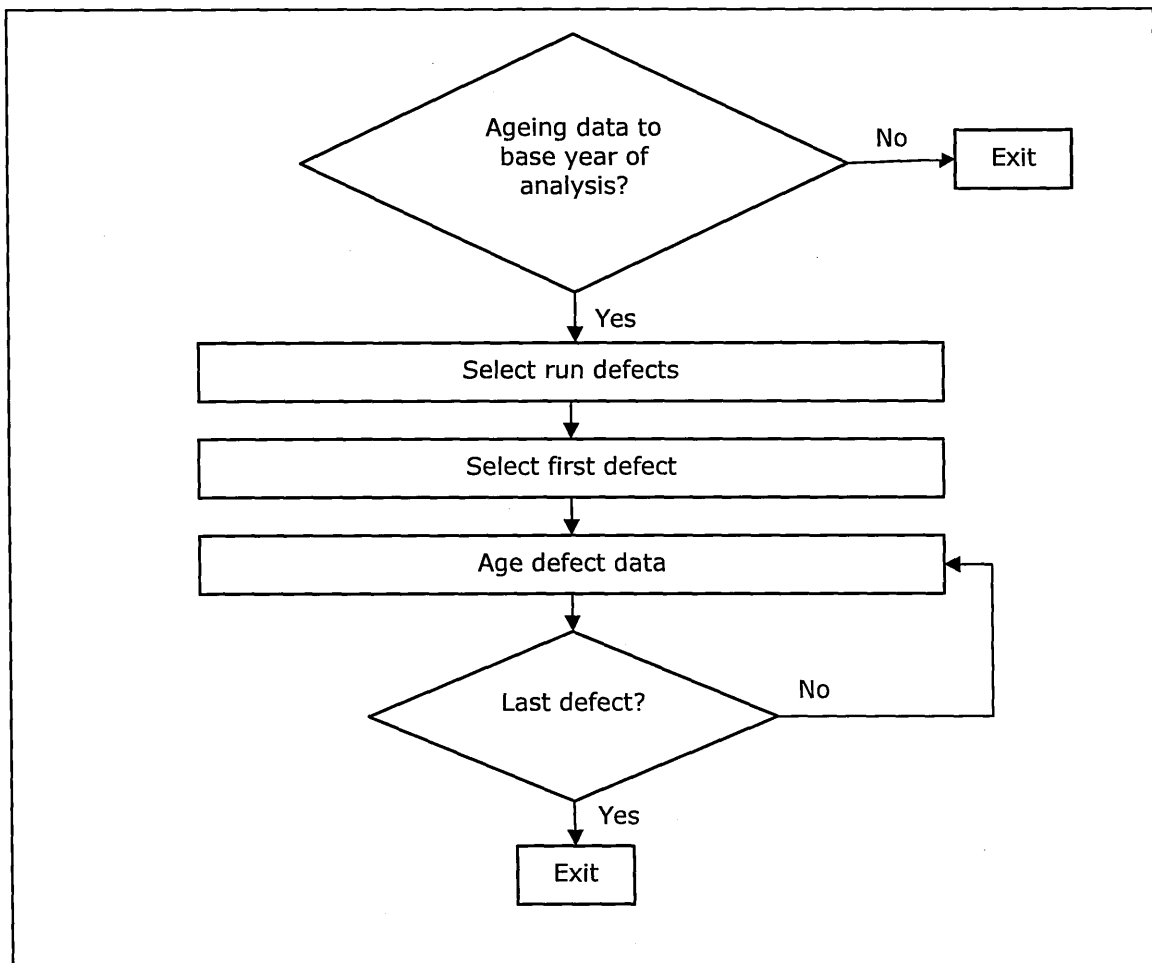


Figure 5-9: Data ageing flowchart

For all condition parameters the deterioration rates can be specified separately for the primary and secondary networks. For each network the rates can also be specified by the three carriageway types of single, dual and motorway.

The longitudinal profile, rut depth, sideways-force coefficient and texture data can be deteriorated in two ways, one of which must be chosen by the user during the configuration of the run:

- By a user specified amount per year; or
- By a user specified percentage increase per year.

The default deterioration method and rates setup in the reference database are shown in Table 5-1.

Table 5-1: Default deterioration mechanism and rates

Parameters	Deterioration Mechanism	Rate
Rut	Absolute	1mm/yr
Texture	Percentage	2%/yr
Longitudinal Profile	Percentage	2%/yr
SCRIM	Percentage	3%/yr

(source: authors research)

The rutting rates were chosen to align with default treatment lives when used with rutting maintenance thresholds and also to be in agreement with rates used in UK modelling work (author's own experience).

The rates for the other condition parameters were set as percentage deteriorations due to:

- The lack of absolute trends from the available condition data;
- To align with anecdotal evidence on the speed of the defect deterioration and the amount of maintenance it would likely trigger; and
- To not over predict maintenance in the programme period based on the starting condition values.

It should be noted that the model allows these rates to be varied for sensitivity analysis and a user of the model should tailor the rates for any specific data or factors on their network.

Rutting data can additionally be chosen to be deteriorated using a road type based relationship of the form:

$$Rutting_i = a - (b \times Rutting_{i-1}) - (c \times (Rutting_{i-1})^2) \quad (5.1)$$

where a , b and c are co-efficients for the rutting prediction and i is the year to predict. The default values for the carriageways are given in Table 5-2 (obtained from a study of road rutting trends on the English national network (Wright, 2005)).

Table 5-2: Default road type relationship coefficients

Road Type	a	b	c
Single Carriageway	0.1114	1.175	0.0015
Dual Carriageway	0.2235	1.175	0.0030
Motorway	0.2500	1.220	0.0030

(source: Wright, 2005)

If new data parameters are used in the model appropriate deterioration rules will need defining.

5.3.3 Homogenisation

In identifying maintenance needs an engineer would be unlikely to undertake interventions on very short sections (except in the case of patching) and would instead assess the smoothed condition over longer lengths.

To allow for this smoothing of the measured condition data within the model, a homogenisation process was incorporated. This process groups data that is statistically similar through the use of an algorithm and returns an appropriate average value for the whole of that grouped length. The homogenisation within this model was implemented such that each condition parameter is evaluated for homogeneity independently.

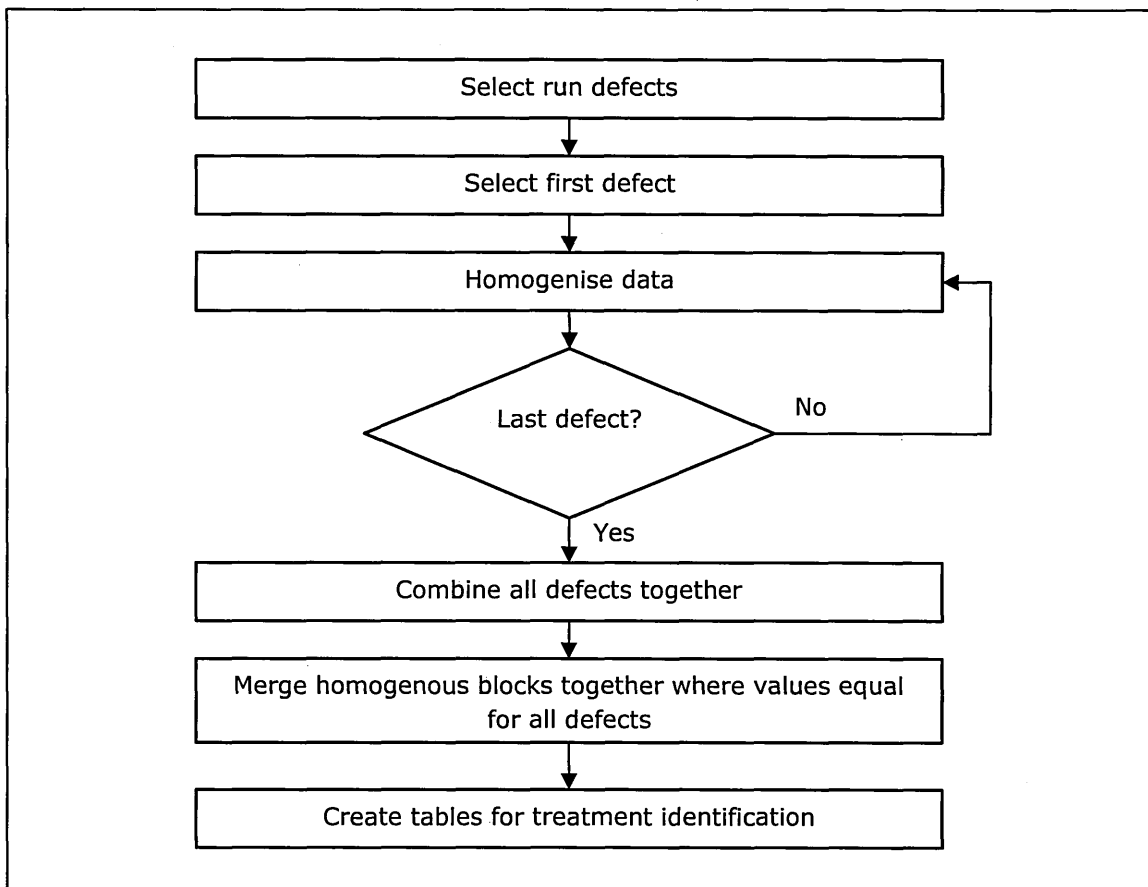


Figure 5-10: Homogenisation process

The homogenisation algorithm (marked as the 'Homogenise data' cell in Figure 5-10) was adapted from a method by Mensil-Adelee & Peybernard (1962) to homogenise statistically similar lengths of data for continuous deflection measurements. The same method was used in the development of the homogenisation algorithm in this model with the slight amendment that an additional variable was passed to the algorithm to prevent the lengths being split into lengths that were too short for maintenance treatment in practical terms. The algorithm in the model operates as follows:

- All individual road lengths are initially considered as potentially homogeneous lengths. If the user has chosen to homogenise across records where the surface construction changes (derived from the imported database) condition data for the entire length of each road will be the starting point for the algorithm. If the user has selected to not allow homogenisation across changes in construction,

condition data for each road will be segmented into groups which have the same construction.

- The average condition value $\bar{d} = \sum_{j=1}^{j=N} d_j / N$ is calculated for each length, where d_j is the j^{th} condition measure in the length and N is the number of condition measures in the length.

- Calculate the statistic $R = \sum_{j=1}^{j=N-1} (d_{j+1} - d_j)^2 / 2 \sum_{j=1}^{j=N} (d_j - \bar{d})^2$.

- If $N \leq 60$ the value of R is compared to given tabulated values. If the value falls within the bounds of the lookup value, the length is accepted as homogeneous and the value \bar{d} is assigned as the pavement condition of the entire length.

- If $N > 60$, calculate $U = \sqrt{\frac{N^2 - 1}{N - 2}} (1 - R)$. If $-1.282 < U < 1.282$ the length is accepted as a homogeneous length as above.

- If the length is not accepted as homogeneous the algorithm enters into an iterative process of splitting the subsection into two smaller parts and testing each for homogeneity. The location, i of N readings, at which a subsection is split is determined by maximising the statistic $G_i = \frac{N}{i(N-i)} \left\{ \sum_{j=1}^{j=i} l_j (d_j - \bar{d}) \right\}^2$ (l_j is the

length of the reading). If the length of the subsection is less than twice the homogeneity limit the mean condition value is assigned to the subsection.

- The iterative process continues with each new subsection being analysed independently and potentially split many more times until either all subsections are homogenised or any remaining subsections are shorter than the minimum allowed length (which is user-defined).

An example of homogenised data is shown in Figure 5-11.

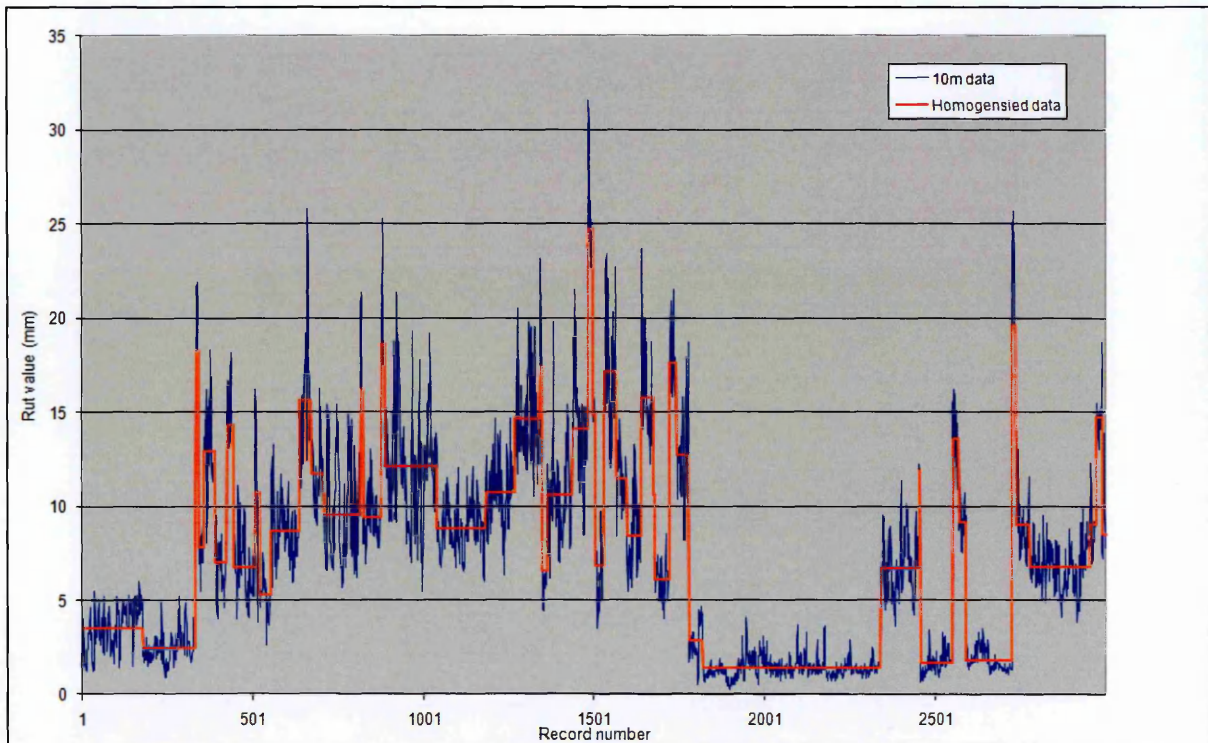


Figure 5-11: Example of homogenisation output compared to raw data

The base model allows a user to setup the homogenisation options at the time of configuring the run.

5.3.4 Treatment identification

The base model calculates when the next treatment is needed for each condition defect of every record by considering the current condition value, the threshold level and the rate of deterioration (Figure 5-12). Any lengths that require treatment in the current analysis year for one or more defects are selected for consideration as schemes. The whole-life costs of those schemes are calculated and the whole process is repeated for each year in which a maintenance programme is being derived.

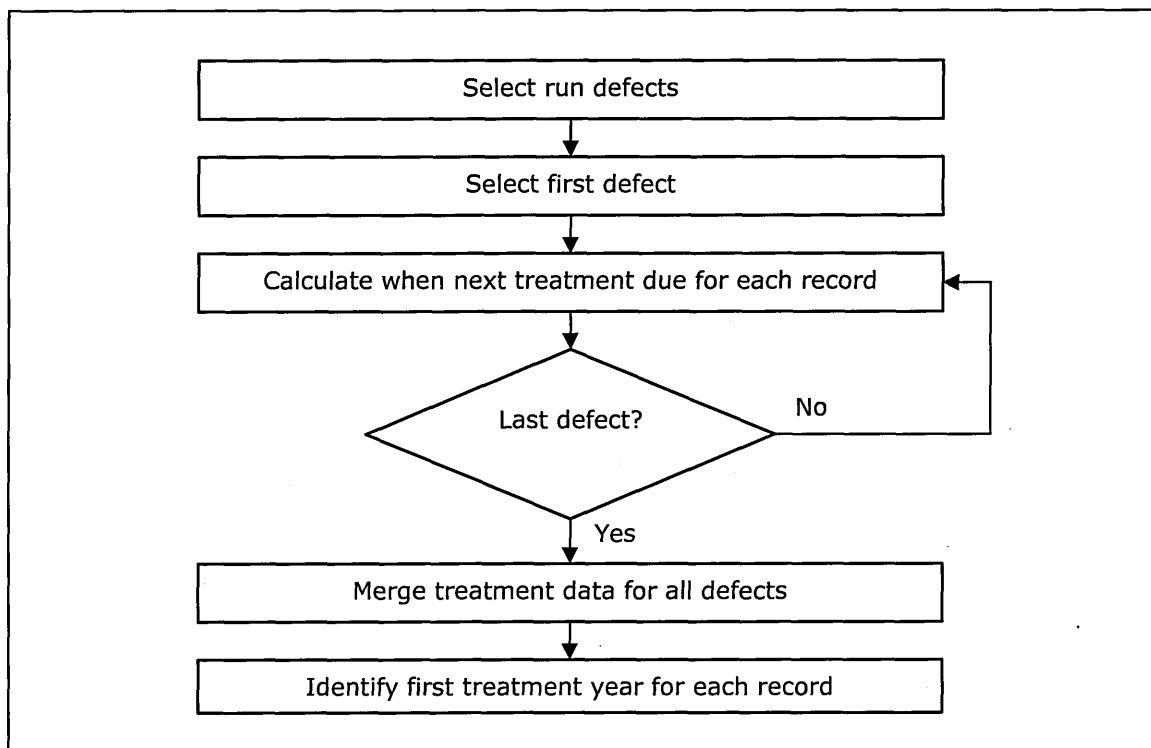


Figure 5-12: Treatment identification process

Two different analysis periods are used in the base model:

- Programme period: this is the number of years for which a maintenance programme will be determined (shown by the larger loop in Figure 5-2); and
- Treatment evaluation period: this is the length of the period over which whole-life scheme costs are calculated (shown by the smaller loop in Figure 5-2).

If the number of years in the programme period is greater than one, each year in the programme period acts as a base year in turn, and all maintenance identified in each base year is evaluated for a number of years beyond the base year, which is the treatment evaluation period (see Figure 5-13).

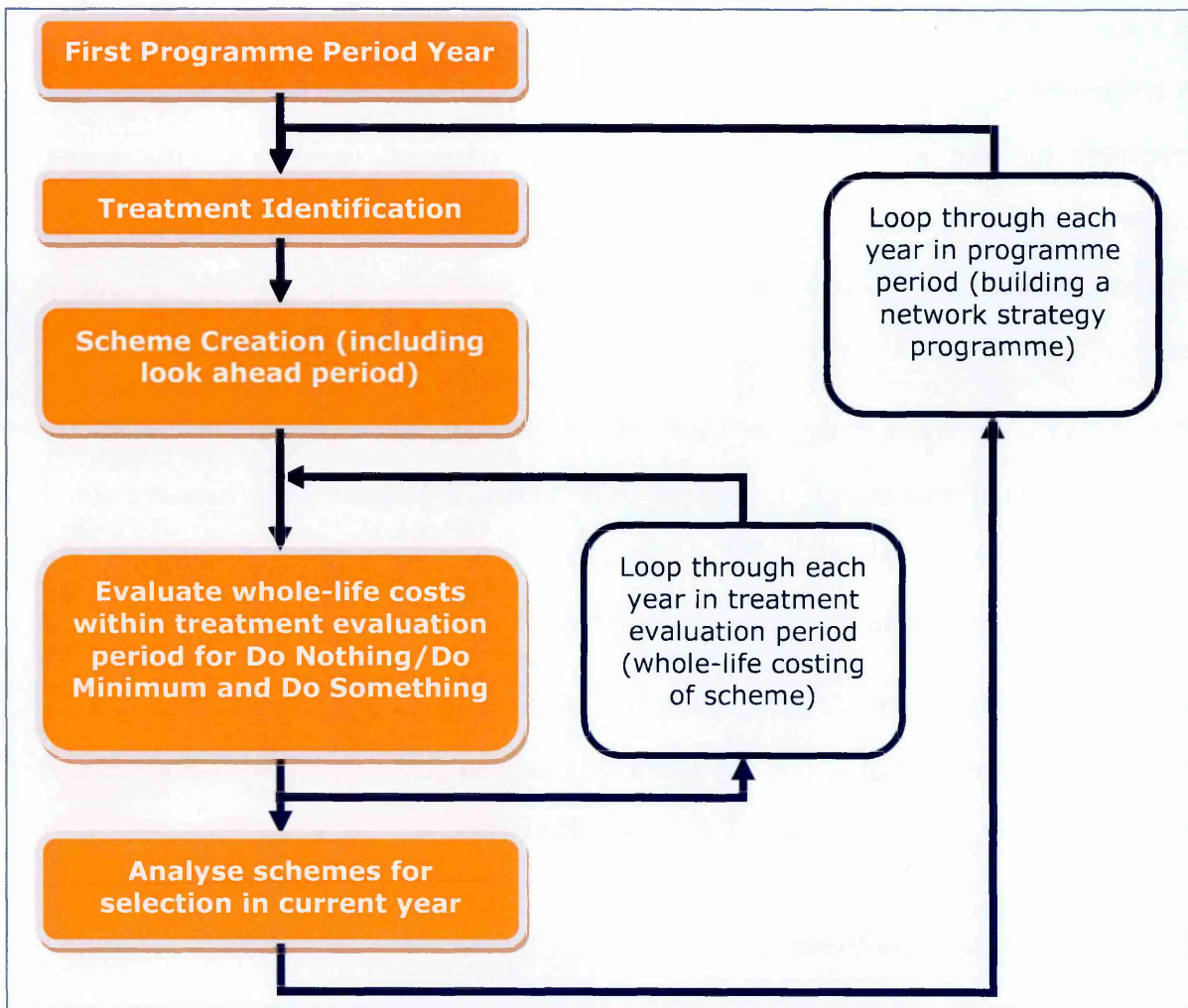


Figure 5-13: Treatment year's assessment loop

In addition, the base model has also been given a look ahead period in which the model can look ahead (in years) to see if it is worth bringing forward any interventions that are not above any current thresholds but would pass the thresholds during the look ahead period. The look ahead period aims to have the effect of avoiding having to do a further intervention in a few years at the same scheme location on the network (e.g. if a resurfacing has been identified now but a strengthening treatment is needed in 2 years, the strengthening treatment can be brought forward as long as the lookup ahead period is no less than 2 years). The default look ahead period was set to 2 years.

5.3.4.1 *Maintenance treatments*

A treatment is identified once a condition parameter passes the respective intervention threshold for that defect. The treatment that is triggered depends on the condition parameters and its value; this also determines whether it is a Do Minimum option (i.e. a maintenance option designed to treat only the defects required to keep the road at a minimum level of safety) or not.

It is possible for more than one treatment to be required and this can result in one treatment taking precedence. If multiple treatments are flagged, the treatment with the greatest hierarchical importance is undertaken. The hierarchy of the treatments can be managed through the analysis configuration form.

Some treatments may not be permitted on particular roads and if a length of road is in need of a treatment that is not permitted on that particular carriageway type, the next available treatment with a greater hierarchy will be chosen.

5.3.4.2 *Intervention levels*

Intervention levels can be defined by the user for all condition parameters when setting up the run. Treatments are considered when a value exceeds an intervention level.

When treatments are being identified there are two different threshold levels that are used. The first is the investigation level, which is the level at which it might be worth considering an intervention although it is not critical in terms of the condition. The second level is the Do Minimum level at which point it is essential that an intervention is undertaken in order to keep the road in a safe condition for use.

In the reference database for Ireland only rut depth and SCRIM difference²⁷ were given Do Minimum intervention thresholds (Table 5-3) although both thresholds can be specified for all parameters. A positive value implies the road surface offers adequate

²⁷ SCRIM difference is the difference between the measured skid resistance value and the intervention level.

skid resistance where as a negative value implies the road surface offers less than the recommended skid resistance, which can therefore trigger a maintenance intervention.

Table 5-3: Default thresholds

Parameter	Investigation Threshold	Do Minimum Threshold
Rut (mm)	16	20
Texture Depth (mm)	0.8	-
Longitudinal Profile (mm²)	7	-
SCRIM Difference	0	-0.05

(source: authors research)

The default values for the intervention levels are held in a lookup table in the reference database and the user can change these when configuring an analysis.

5.3.4.3 Treatment options

Two treatment options were included for analysis for each scheme in the base model developed. They were:

- Do Minimum (or Do Nothing); and
- Do Something.

For each year of the programme period a Do Something option and a Do Minimum (or Do Nothing) option are analysed for each identified treatment.

Do Minimum or Do Nothing option

The Do Minimum or Do Nothing option consists of the minimum treatment required to keep the condition of pavement length functional and safe for at least one year (i.e. if any lengths of condition are below the minimum acceptable safety level they will be treated to meet the safety requirements).

Do Something option

Treatments required in year 1 (the first year when the scheme is identified) are determined by comparing the condition value to the appropriate investigation threshold level for that measurement.

Within a scheme, some lengths may not have exceeded thresholds but may be close to the threshold (i.e. they will exceed the threshold within the user defined 'look ahead' period). Lengths that will exceed the given thresholds within the 'look ahead' period (i.e. future number of years) will also be considered for maintenance. This allows schemes to be built by joining up parts of the network both laterally and temporally.

The whole-life costs of the treatment options being considered are calculated by simulating future deterioration and generating a maintenance profile over the treatment evaluation period.

5.3.5 Scheme creation

Lengths of road that have exceeded the minimum intervention period²⁸ following the last treatment are considered for maintenance.

Schemes are created by grouping together contiguous lengths that need treatment using the following steps;

- Lengths that span either different counties or carriageway types are split accordingly;
- Committed works (see section 5.3.8) are included alongside any treatments identified by the model. If committed works overlap with a model scheme and the user has chosen not to allow the limits of the committed works to be extended the model identified schemes will be dropped. If the user has allowed the

²⁸ A period following a maintenance intervention within which no further maintenance is allowed on the same scheme.

committed works to be extended its limits will be extended to encompass any overlapping model generated schemes;

- These initial treatment lengths form the initial schemes;
- Any schemes that end within a user defined 'merge' length of another scheme are joined;
- If any scheme is less than the minimum scheme length it is dropped for consideration in the current year;
- If any scheme is greater than the maximum scheme length it is split into the required number of schemes to comply with the limits.

The complete scheme creation and option evaluation process is shown in Figure 5-14.

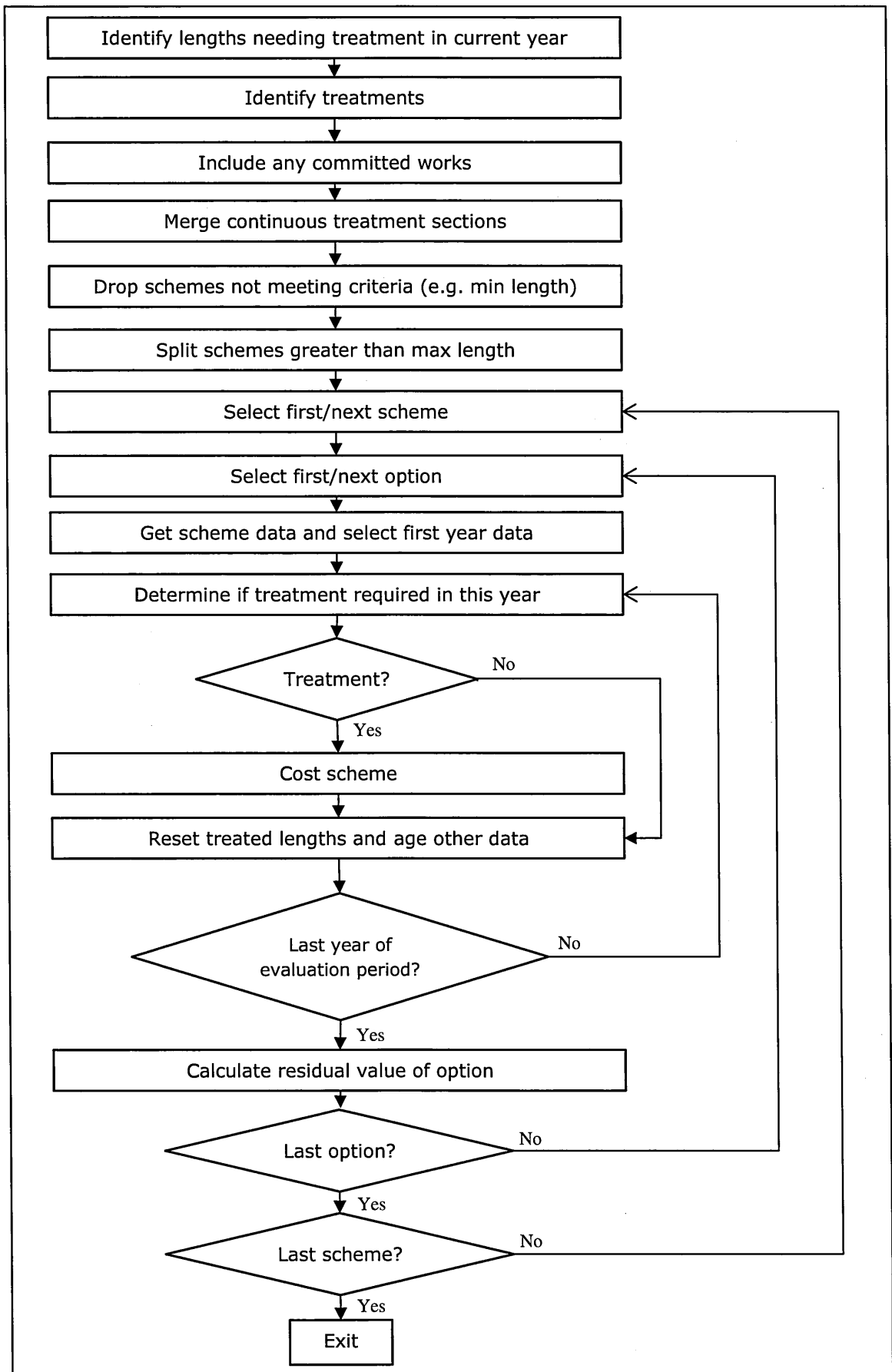


Figure 5-14: Complete scheme creation and option evaluation

5.3.6 Works and user delay costs

The area of pavement requiring treatment (by treatment type) is given by:

$$\text{Area} = (\text{Length requiring treatment}) \times (\text{Carriageway width})$$

All costs are calculated using the base year costs and all in-year costs during the analysis are the same (obtained from the reference database).

5.3.6.1 Works costs

Works costs and durations²⁹ use the units 'cost per square metre' and are dependent on the treatment and carriageway type. The unit rates and durations for treatments can be updated through the configuration screen.

The total works cost are calculated by multiplying the work costs per unit area by the area requiring treatment.

The duration of a treatment is calculated (in hours) by multiplying the duration per unit area by the area requiring treatment.

Representative values for the costs and durations obtained from NRA (Table 5-4) are held within the reference database.

²⁹ The duration of a treatment is the time taken to undertake the maintenance. The lookup unit rates are expressed as 'hours per square metre' (for each treatment type).

Table 5-4: Recommended unit cost rates for use in the base model

Treatment	Carriageway	Rate (€/m²)	Duration (hrs/m²)
Overlay	Motorway	44	0.0411
	Dual	44	0.0411
	Single	44	0.0411
Inlay	Motorway	25	0.0057
	Dual	25	0.0057
	Single	25	0.0057
Surface Dressing	Motorway	10	0.0027
	Dual	10	0.0027
	Single	10	0.0027
Patching	Motorway	40	0.0057
	Dual	40	0.0057
	Single	40	0.0057

(source: NRA discussions)

5.3.6.2 *User delay costs*

User delay costs represent the cost to road users of the additional delay experienced during maintenance. The user costs are calculated using lookup tables held in the reference database. The lookup tables were themselves created using QUADRO (Queues And Delays at Roadworks) a tool that is designed to determine the delays that will be experienced at roadwork sites (DMRB, 2006).

QUADRO analyses were completed for the road type setups listed in Table 5-5 and modelled for the following three different working patterns to replicate the different periods that maintenance could be carried out:

- 24 hour working;
- Off-peak working (start 10:00, finish 15:00); and
- Night working (start 22:00, finish 04:00).

Table 5-5: QUADRO data setup for modelled road types

Road Type ³⁰	Primary Lanes Open	Secondary Lanes Open	Permanent Speed Limit (km/h)	Closure Speed Limit (km/h)	Contra-flow	Narrow Lanes	Shuttle working	Site length (km)	Traffic flow Min (AADT)	Traffic flow max (AADT)	Traffic flow interval (AADT)	HGV %
D3M	3	3	113	80	Y	N	N	1	10,000	150,000	10,000	10
	2	3	113	80	N	N	N	1	10,000	150,000	10,000	10
D2M	2	2	113	80	Y	N	N	1	10,000	150,000	10,000	10
	1	2	113	80	N	N	N	1	10,000	150,000	10,000	10
D3AP	3	3	113	80	Y	N	N	1	10,000	150,000	10,000	5
	2	2	113	80	N	N	N	1	10,000	150,000	10,000	5
D2AP	2	2	113	80	Y	N	N	1	10,000	150,000	10,000	5
	1	2	113	80	N	N	N	1	10,000	150,000	10,000	5
S2AP	1	1	96	48	N	Y	N	1	10,000	100,000	10,000	5
	1	1	96	48	N	N	Y	1	10,000	100,000	10,000	5
	1	1	48	48	N	N	Y	1	10,000	100,000	10,000	5

(source: authors research)

³⁰ D3M = Dual 3-lane Motorway; D2M = Dual 2-lane Motorway; D3AP = Dual 3-lane All-Purpose; D2AP = Dual 2-lane All-Purpose; S2AP = Single carriageway


```

001 TITLE TABLE 18 TEST
006
010 2010 24 0.621 0.079 0.15 0.098 0.052
038 23 96 P 1998 1.036 0.973 1998 0.044 0.988 0.286 0.975 1.286 1.005
038 23 96 L 1998 1.036 0.973 1998 0.044 0.988 0.286 0.975 1.286 1.005
040
041 TABLE 18 TEST
042 2 LANE CONTRAFLOW FROM CHAPTER 8
043 24 HOURS CLOSURE
044 2010 1 100000
046 1 4 0 5 7.3 15 75 1.0 4.0 0.6 200 96
051 0.5 0.5 2.25 2.25
052 1 1 0 0 48 48 A B
053 7.5 7.5 0
054 85.7 366 78.6 1497 45.8
055 -2 -2 5 5
056 10 4

```

Figure 5-15: Example QUADRO input file

QUADRO requires a fixed format input file (see Figure 5-15) and outputs the delay both as a time element (average delay in seconds per vehicle) and a cost element (user time delay cost in pounds). The user time delay cost was required for use in the base model but it was output in 2002 prices. To be consistent with other cost bases planned for use in the whole-life value model (i.e. works, carbon and noise) the costs were required in 2010 prices (QUADRO had been run using 2010 as its base year but the costs are still output in 2002 prices).

The costs were updated using the following method:

1. The 2002 prices were uplifted to 2010 using RPI index values (2002 average RPI=176.2, 2010 average RPI=223.6³¹) such that the 2010 price discounted to 2002 = (QUADRO output price*2010 RPI)/2002 RPI;
2. The discounting to 2002 was reversed so that the costs were effectively 2010 prices, discounted to 2010, using a discount rate of 3.5% such that 2010 price discounted to 2010=2010 price discounted to 2002 * 1.035⁸. (Steps 1 & 2 are the QUADRO recommended method for uplifting costs in paragraph 3.5, Chapter 3, Part 1, of the QUADRO manual [DMRB, 2006].) ;
3. The 2010 prices were factored into hourly prices based on the number of hours the closure was operational for;
4. The hourly prices were factored into hourly prices per vehicle based on the modelled traffic flow of each output record; and
5. The hourly prices per vehicle (in £) were factored into Euros using an exchange rate of £1:€1.128³².

The final outcome of a cost per hour per vehicle (in Euros) for the closures and traffic levels specified in Table 5-5 were mapped to the Irish network as per Table 5-6.

³¹ Obtained from Office for National Statistics

³² They were converted to Euros using the historic exchange rate as of the 1st January 2010 (£1:Euro 1.128) from <http://www.xe.com/currencytables/?from=GBP&date=2010-01-01>

Table 5-6: QUADRO results mapped to Irish road types and closures

Irish road type	Closure	QUADRO mapping
2 Lane Road	Shuttle	S2AP 1 by 1 shuttle
3 Lane Dual	Contraflow	D3AP 3 by 3 Contraflow
3 Lane Dual	Lane closure	D3AP 2 by 2 Lane closure
3 Lane Motorway	Contraflow	D3M 3 by 3 Contraflow
3 Lane Motorway	Lane closure	D3M 3 by 3 Lane closure
3 Lane Road/1 Lane side	Lane closure	S2AP 1 by 1 Narrow Lanes
3 Lane Road/1 Lane side	Shuttle	S2AP 1 by 1 shuttle
3 Lane Road/2 Lane side	Lane closure	S2AP 1 by 1 Narrow Lanes
3 Lane Road/2 Lane side	Shuttle	S2AP 1 by 1 shuttle
6 Lane Road	Contraflow	D3M 3 by 3 Contraflow
6 Lane Road	Lane closure	D3M 3 by 3 Lane closure
Dual Carriageway	Contraflow	D2AP 2 by 2 Contraflow
Dual Carriageway	Lane closure	D2AP 1 by 2 Lane closure
Motorway	Contraflow	D2M 2 by 2 Contraflow
Motorway	Lane closure	D2M 1 by 2 Lane closure
One Way Forward	Shuttle	S2AP 1 by 1 shuttle
One Way Reverse	Shuttle	S2AP 1 by 1 shuttle
Reduced Single	Shuttle	S2AP 1 by 1 shuttle
Wide Single	Shuttle	S2AP 1 by 1 shuttle

(source: authors research)

Lookup values for the user delay costs are held in the reference database and use the unit 'cost per vehicle per duration hour' and are dependent on the carriageway type, closure type, traffic level and working pattern.

5.3.6.3 Closure Type

The options created within the base model for working pattern are shown in Table 5-7. The user can choose a default closure type for each treatment in the configuration screen.

Table 5-7: Closure types

Closure Type
Contraflow
Lane Closure
Shuttle Working

(source: authors research)

5.3.6.4 Working pattern

The options for working pattern are shown in Table 5-8. The user can choose a working pattern for low, medium and high traffic levels for each carriageway type in the configuration screen.

Table 5-8: Closure working patterns

Working Pattern
Night
Off-peak
All day (24hr)

(source: authors research)

5.3.6.5 Residual value

A calculation of the residual value is included in the base model. The residual value of a scheme is the remaining value at the end of the analysis period following any interventions carried out in the treatment evaluation period (Santos & Ferreira, 2013). Because the model has to stop at some point it allows consideration of the state of the network at the end of the analysis period, which is of further use if the user is unsure of what analysis period to set.

It is important in this type of model because it ensures that different options with different treatment profiles can be compared on an effectively equal basis. For example, without residual value included, if a maintenance intervention is undertaken in the last few years of the analysis period it would significantly affect the overall cost calculations without accounting for the fact that the road pavement would be in nearly new condition. In that situation because the pavement is in nearly new condition there is a lot of value remaining in the pavement and a future intervention would not be needed for many years.

In order to allow comparison between different treatment profiles calculated within the treatment evaluation period, the remaining value in the pavement at the end of the treatment evaluation period is subtracted from the total cost. This allows an equal comparison between a scheme that leaves the length in poor condition and a scheme that intervenes just before the end of the analysis but leaves the length in good condition.

Three options are available in the base model for calculating the residual value in the pavement, derived from common methods listed as depreciation mechanisms (Wikipedia, 2015) and based on the authors experience of using pavement management systems. These are based on knowing when the next treatment that lies beyond the end of the analysis period will occur:

1. Linear method: This method assumes that the cost of the last treatment intervention declines linearly until the next treatment is needed;
2. Double-declining method: This method is based on declining at a rate double the linear rate until the next treatment is needed (NB: this method may not fully depreciate the value of the pavement at the time of the next treatment); and
3. Minimum of linear and double-declining method: This method takes the minimum of the linear and double-declining method each year until the next treatment is needed.

Figure 5-16 shows an example of the three residual value methods, assuming a full reconstruction in year 0 (restoring full value back into the pavement) with a life of 20 years and no further interventions.

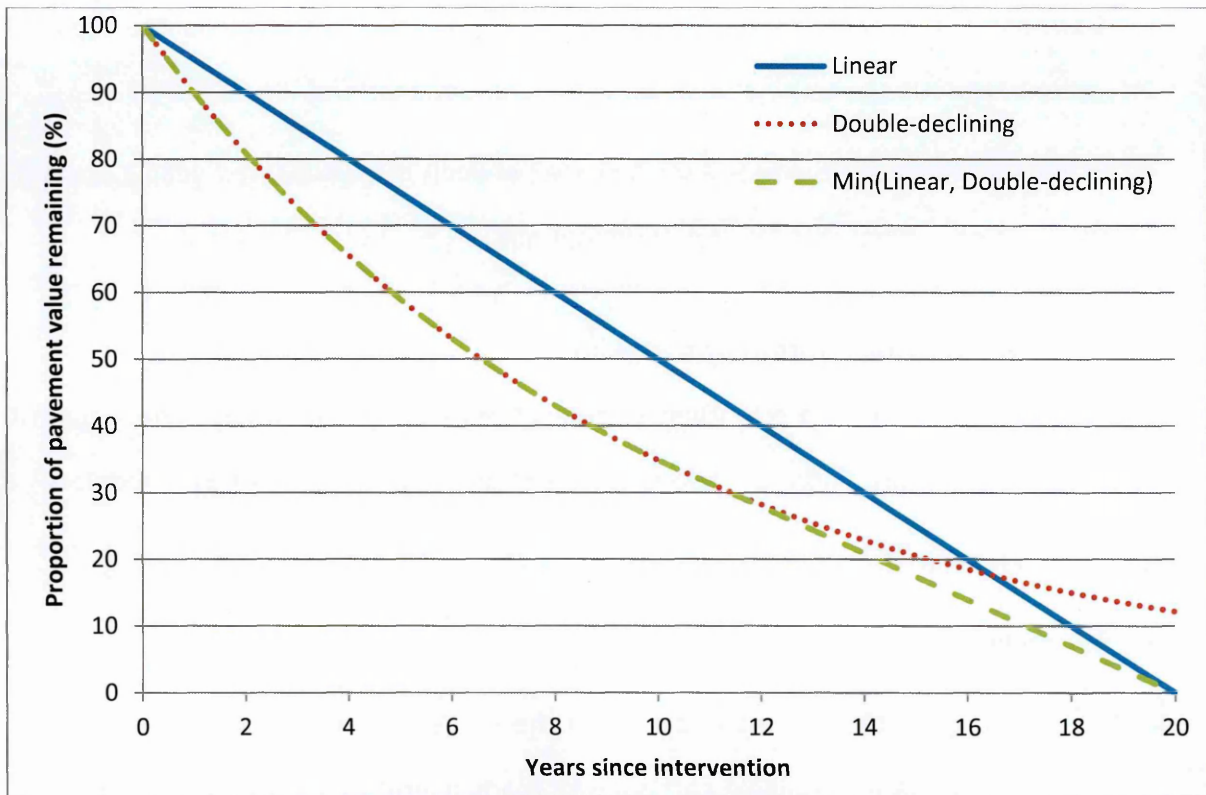


Figure 5-16: Residual value example

5.3.6.6 Discount rate

Discounting is the method that allows the maintenance interventions in different years to be compared equally by discounting their costs back to a base year. All future costs in the base model are discounted using the standard formula for discounting:

$$\text{Discounted Cost} = \frac{\text{Undiscounted Cost}_n}{\left(1 + \frac{\text{Discount rate for year } n}{100}\right)^n}$$

where n is the number of years elapsed since the base year of the analysis. The discount rate can be specified in the model when setting up the run parameters.

5.3.6.7 Total scheme costs

The total scheme costs are made up of:

$$\text{Total scheme cost} = \text{Works costs} + \text{User delay costs} - \text{Residual value}$$

5.3.6.8 Economic indicator and savings

All Do Something schemes have a savings and economic indicator calculated which are used in the prioritisation process. They are calculated using the following methods:

- Savings: The difference between the discounted total costs minus the residual value of the 'Do Something' and 'Do Minimum' options; and
- Economic Indicator: Savings / (Difference between the discounted year 1 costs of the 'Do Something' and 'Do Minimum' options).

5.3.7 Scheme prioritisation and selection

The maintenance schemes are prioritised to select the most appropriate schemes against any constraints for a run. There are two methods of prioritisation in the base model:

1. By budget; or
2. By condition.

Regardless of the prioritisation method chosen the model first determines if any of the schemes on opposite lanes of single carriageway roads overlap. The schemes are treated separately for costing purposes, savings and economic indicator calculations. However, if any of the schemes overlap with another by a proportion greater than a user specified value, and if one of the schemes is selected, the overlapping schemes will also be selected if constraints allow it (i.e. if there is enough budget).

5.3.7.1 Prioritisation by budget

The following method is used if prioritising by budget. For each year in the programme period:

- Determine the budget available for the current year;
- If there are any committed works that are to be carried out regardless of any budget constraint they are selected first and their total in-year cost is calculated;
- For any remaining schemes consider the Do Minimum options next;

- If the user has opted to carry out the Do Minimum options regardless of budget they are selected and their total cost is calculated and added to the previous committed works total to calculate the current in-year spend;
- If the user did not opt to carry out all Do Minimum options regardless of budget, order the Do Minimum options by their year 1 works cost and cycle through the options, selecting each one in turn until the budget is exceeded;
- If there is any remaining budget, order the remaining Do Something options by their economic indicator and year 1 works costs;
 - If the user chose to try and spend as much of the available budget as possible (i.e. they might have committed contracts with contractors), select the Do Something option only if the difference between the Do Something and Do Minimum year 1 cost does not exceed the budget. The associated Do Minimum option will be deselected;
 - If the user does not necessarily want to spend the available budget, select the Do Something option only if the difference between the Do Something and Do Minimum year 1 cost does not exceed the budget and the Do Something option represents an economic saving over the treatment evaluation period. The associated Do Minimum option will be deselected;
 - If there are any associated overlapping schemes consider those Do Something options next, before looping through the remaining Do Something options until the budget is exceeded.

This method is shown in Figure 5-17.

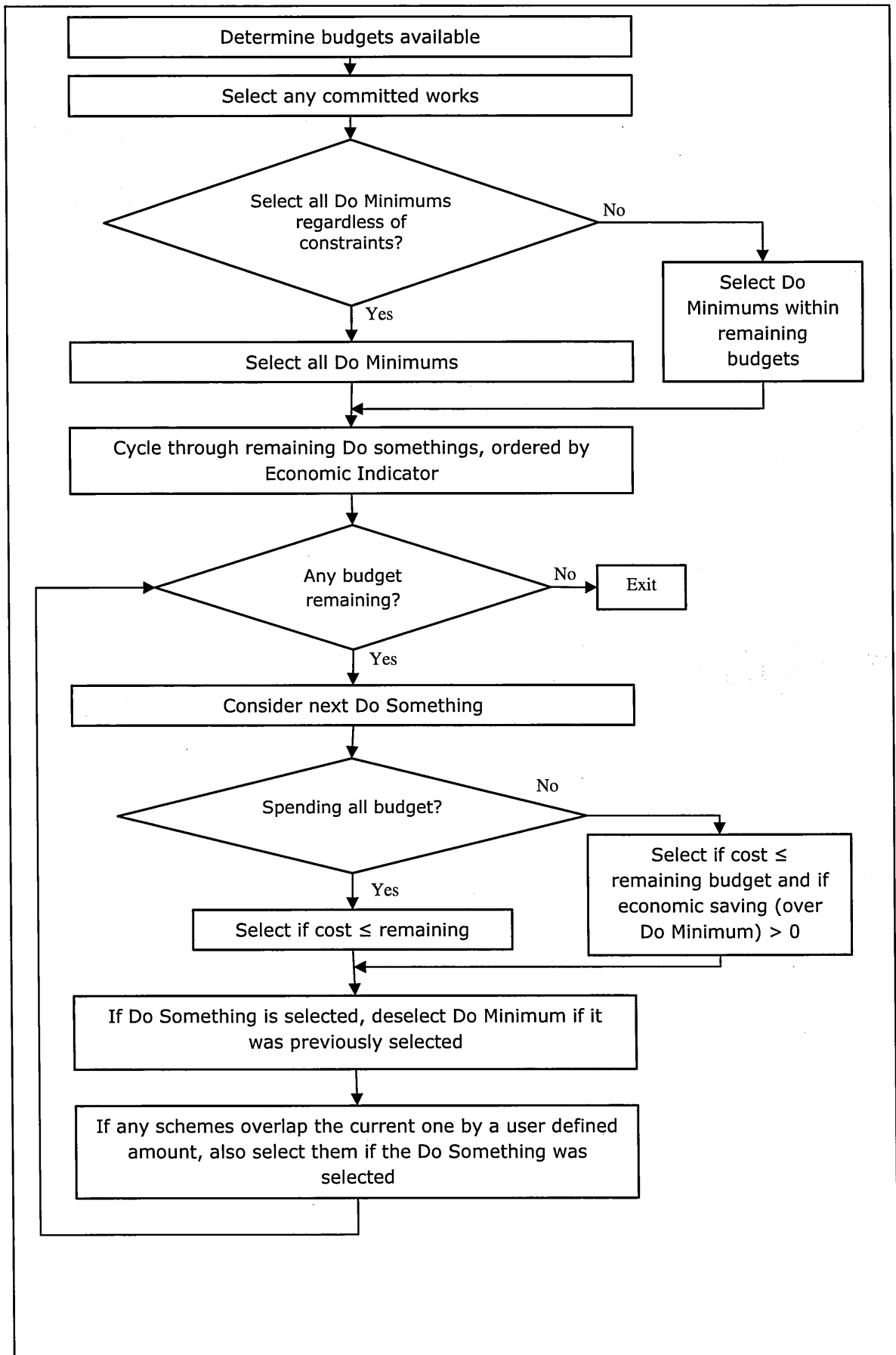


Figure 5-17: Prioritisation by budget process

5.3.7.2 *Prioritisation by condition*

During the run configuration the user can enter a target for the percentage of the network they will allow to be in poor condition for one or more of the defects being used in the analysis. The target can either be specified for the whole network or separate targets can be specified for each carriageway type. The user enters a target year in which they wish the target to be met.

The following method is used if prioritising by condition.

- Calculate the current poor condition percentage of the network for each defect, ordered by the importance of the defects from the treatment triggers and their treatment hierarchy;
 - If the target year is less than the current year, calculate the poor condition percentage for each defect for the current year so that it can be maintained against the target condition (i.e. if the target year has been exceeded the model tries to maintain the network in a steady state beyond the target year at a condition equal to the target condition). The improvement needed in the year is the difference between the current poor condition and the target poor condition percentage;
 - If the target year is greater than or equal to the current year calculate the poor condition for each defect that would exist in the target year if no treatments were performed. In order to meet the target in the target year it is assumed there will be equal improvements in all preceding years. Therefore the improvement needed in each year up to the target year is the difference between the current poor condition and the calculated poor condition in the target year, divided equally between the number of years from the current year to the target year;

- If there are any committed works that have been setup to be carried out, regardless of any constraints, they are selected first and their total in-year condition improvement calculated;
- If the user has opted to carry out the Do Minimum options regardless of any constraints they are selected and their total in-year condition improvement calculated and added to the previous committed works condition improvement to calculate the current in-year improvement;
- If there is any remaining improvement required all other schemes are considered in the order:
 - Do Minimum committed works – schemes are looped through and selected until the required condition improvement has been met;
 - Do Minimum non-committed works – schemes are looped through and selected until the required condition improvement has been met;
 - All remaining Do Something non-committed works;
 - If the Do Minimum option of the current Do Something scheme was not selected, select the current Do Something if a condition improvement is required;
 - If the Do Minimum option of the current Do Something scheme was selected, only select the current Do Something if:
 - The Do Minimum had a lower improvement for the defect and a condition improvement is still required; or
 - The Do Something improvement is equal to the Do Minimum improvement and the Do Something provides an economic saving;

- If any of the Do Something options are selected the Do Minimum option for the same scheme is deselected and the previous improvement is removed from the cumulative improvement total;
 - If any of these scheme options are selected the scheme is marked as being 'considered' so that it is not considered again for an improvement of any lower hierarchy defects;
- If there is any remaining improvement required after all the schemes have been considered, patching of short lengths is considered;
 - Patching can be considered for any lengths of the network that were not in schemes already considered (i.e. schemes not considered in the above and lengths not included in any schemes);
 - For any lengths available for patching, cycle through them in order of worst condition first and select the lengths until the required improvement is met;
 - All lengths that are patched are costed based on the area patched and the unit rate of patching.

This method is shown in Figure 5-18 and Figure 5-19.

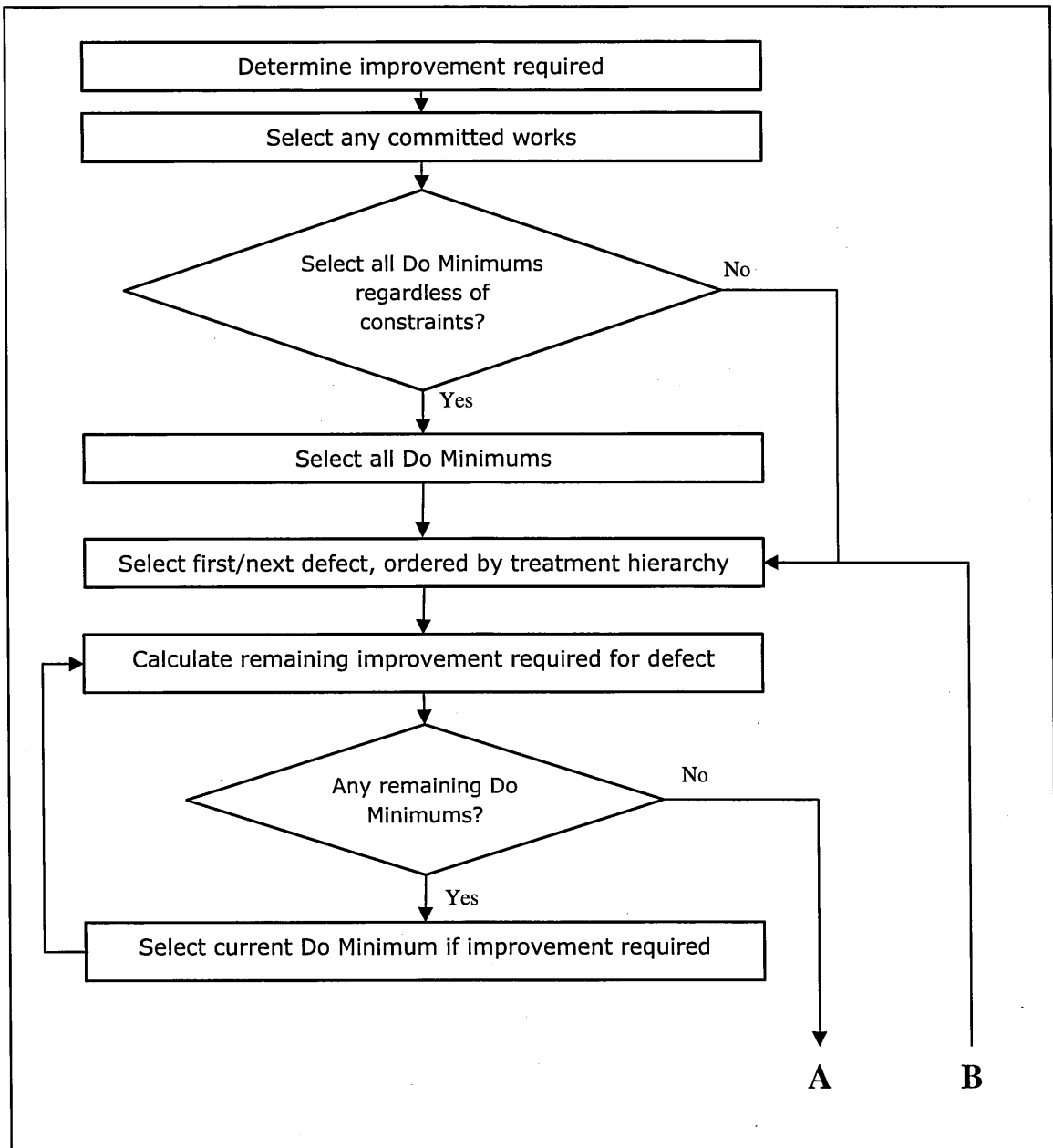


Figure 5-18: Prioritisation by condition process - Part 1

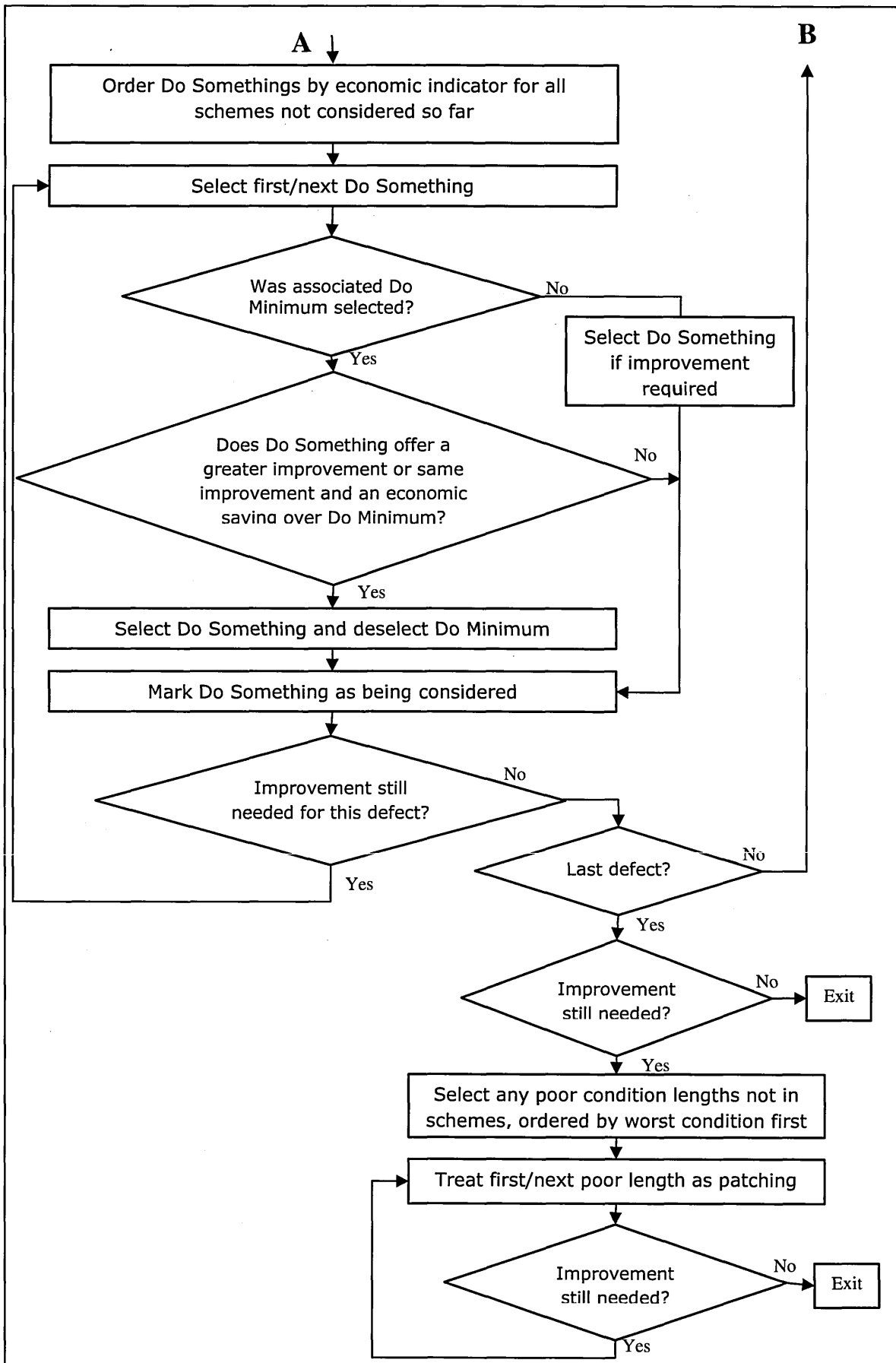


Figure 5-19: Prioritisation by condition process - Part 2

5.3.7.3 Treatment effects

The effect of performing a treatment on a scheme is that no further treatment will be considered on that length of road until a number of years equal to the minimum intervention period (except for patching, where the minimum intervention period does not apply).

5.3.7.4 Treatment resets

Following a treatment being selected one or more condition parameters may be reset. If a treatment is selected the defects that triggered that treatment will be reset, along with any other defect triggers for treatments of a lower hierarchy. The defect triggers can be amended in the configuration screen.

Separate reset values are specified for patching to reflect the lower standard of maintenance being applied and the fact that a future intervention is likely to be needed sooner than if a full treatment was applied.

The treatment reset values are held in the reference database (tbl_Lookup_Defaults) and shown in Table 5-9. They were chosen to give recommended expected treatment lives in combination with the default deterioration rates. Treatment values must be non-zero in order for all the deterioration relationships to function in the base model.

Table 5-9: Default treatment reset values

Defect	Standard Reset	Patching Reset
Longitudinal Profile	0.8	3
Rut	0.5	2.5
SCRIM	60	60
Texture	2	2

(source: authors research)

5.3.8 Committed works

The user has the option of entering committed works during the analysis period, in effect forcing the model to select schemes in particular locations. Committed works are entered if a scheme is already committed on a particular length of road. The schemes can be set to occur in a given year within the programme period. The 'User Guide' (Buckland, 2011b) provides details on entering committed works when setting up an analysis.

The following points apply to committed works:

- The user can specify whether to allow the length of the committed scheme to be extended if the model has identified any treatments that overlap; and
- For each committed scheme, the user can specify whether it should be carried out regardless of any budget or condition constraints. If so, the committed works scheme is selected in advance of any prioritisation and the remaining budget is reduced accordingly.

5.4 Testing

The modular design of the pavement maintenance base model meant that testing was completed for each module in turn. Each module had a recognised set of output fields that it was supposed to return (either within database tables or as variables within the code) and these were checked by providing the module with the required data inputs and checking that the module produced the required output fields. This meant the robustness of the base model could be checked by making sure that it functioned as it was specified.

Validation of the derived outputs from each module was obtained by comparing the outputs of the module with manual calculations using the same input data. This process allowed the location of any errors to be quickly highlighted within the appropriate module. For example, the data ageing module was checked by providing the module with a range of input data for each defect type and the module outputs of using that input

data were compared to the outputs of manually applying the data ageing rules (deterioration rules) to the input data.

Following development of the complete base model it was run with real data from the NRA network, the results of which are discussed as some of the case studies in chapter 7.

5.5 Summary

The base model was developed using methods and rules that were suitably generic so that the concept could theoretically be applied to different networks. IN this research the model was populated with default data examples for application on the Irish national network.

The base model successfully resulted in a modular tool into which the methodologies for the externalities of carbon and noise could attempt to be included.

Chapter 6 **Developing carbon and noise methodologies**

The whole-life cost model described in the previous chapter has been enhanced to become a broader, whole-life value model through the inclusion of assessments of carbon and noise. New methodologies have been developed to incorporate carbon and noise as value parameters in a network level pavement maintenance model such that they can be used alongside the costs of works and delays to users in the identification, assessment and prioritisation of road maintenance.

The methodologies incorporated into the base whole-life cost model address the goal of developing a network level pavement whole-life value model that includes carbon and noise impacts in maintenance assessments and prioritisation taking account of the views reflected in the stakeholder consultations.

This chapter documents the development of the new modelling methodologies for carbon and noise for integration into a network level pavement model and discussing how they can be included in the prioritisation of the identified maintenance, all of which forms the third research objective.

6.1 Treatments

In the base whole-life cost model each identified maintenance scheme is assessed by comparing two treatment options:

1. Do Minimum (or Do Nothing); and
2. Do Something.

Those option types were introduced in section 5.3.4.3 and tend to be common practice in road pavement scheme appraisals carried out by highway authorities. The difference between the options is designed to reflect engineering practice:

- Address only those defects that have safety implications (Do Minimum, or sometimes Do Nothing); or
- Undertake maintenance that is designed to meet more than the minimum safety thresholds, substantially improving the condition of the pavement (Do Something).

Any additional work above keeping the pavement at an acceptable safety level must be economically justifiable. This is especially important when the budgets are insufficient to allow the complete backlog of maintenance to be treated and therefore the prioritisation of schemes needs to be based on defined principles, such as economic prioritisation.

6.1.1 Treatment identification and reporting

Parameters used in the model fall into either one of, or both of the following categories:

- Driver of maintenance; or
- Reporting function of maintenance.

A parameter that is a driver of maintenance needs at least one defined attribute (or value) to set thresholds for maintenance, which can be linked to specific treatments that address the particular defect. Rutting and unevenness are examples of maintenance drivers.

A parameter that is a reporting function is used to calculate an effect of the selected treatment, which can also be used to prioritise the maintenance. Cost is an example of a reporting function used in the prioritisation process.

In developing methodologies for the externalities of carbon and noise the first step was to determine which category the new parameter belonged to because it had implications for how they are treated in the model.

In selecting treatments highway authorities have current guidelines for noise assessment and mitigation. Although these guidelines are primarily for new construction, the growth in noise mapping demonstrates the growing importance of the need to integrate noise

effects with other quantifiable parameters. During the stakeholder consultation, in the previous complete programme year (2011) one new construction scheme out of 22 was noted as having noise as the scheme driver. Currently this small sample represents just 5% of schemes being selected due to noise but other stakeholders also recognised noise was becoming more important. As both the extent of noise mapping and people’s awareness grows in the future, maintenance scheme appraisals are likely to include ‘noise’ as a parameter and therefore it should be a driver for maintenance.

Carbon on the other hand, as noted in the consultations is not a current driver of highway maintenance; it is not now and may not be a maintenance trigger for a long-time. Quite simply the very fact of doing a treatment would create additional carbon emissions that would otherwise not be encountered. Therefore, the potential role of carbon would realistically be a reporting function of the maintenance that is chosen, albeit a reporting function that can be used within prioritisation to inform decisions in the same way as the costs of works or delays are currently used.

Table 6-1: Maintenance drivers and reporting function status for ‘carbon’ and ‘noise’ impacts

	Driver	Reporting function
Carbon	x	✓
Noise	✓	✓

(source: authors research)

The assignment of drivers and reporting functions (see Table 6-1) is true within the boundary of this research. However, different modelling approaches could result in carbon being considered a driver. For example, if carbon from fuel was included which itself is an impact of the changing condition (unevenness) of the road surface then maintenance could be driven by the need to reduce vehicle emissions (i.e. improve the condition of the road surface) which under that approach could make carbon a driver.

6.1.2 Treatment options

A key aspect of incorporating 'carbon' and 'noise' into the modelling methodologies was identifying the potential questions and outputs a whole-life value model will be expected to address.

For example, a highway authority might be interested in developing a maintenance programme that minimises delays to road users or one that minimises cost. A natural extension of this for carbon and noise is to enable the model to examine the impacts on costs if the options with lowest carbon or lowest noise emissions were chosen when developing a maintenance programme.

Regardless of the parameters modelled, the Do Minimum option has to reflect maintaining the level of safety set out by standards. Neither carbon nor noise has a related safety standard to maintain and therefore the maintenance requirements and impacts on the identification of a Do Minimum option remain unchanged, although noise and carbon will be impacted as a reporting function of the Do Minimum.

Because noise is deemed to be a potential driver of maintenance, for Do Something options that means creating an additional Do Something option. As roads deteriorate noise levels can increase but if no condition defects would have led to a maintenance intervention and the noise is above a maintenance threshold, the noise Do Something treatment could potentially trigger maintenance.

The carbon being modelled is the embodied carbon within the maintenance materials and processes. When the road is being trafficked it does not influence the embodied carbon within the road materials. The Road Authority can only influence the embodied carbon at the time of maintenance. A specific low-carbon Do Something option was also identified to enable the investigation on network effects (e.g. condition, costs) if specific low-carbon materials are used.

Each required Do Something treatment is still triggered by engineering standards set by a highway authority but for each identified maintenance option there would be options that reflect:

- A standard approach;
- A low-carbon approach; and
- A low-noise approach.

To reflect differences that exist between the available Do Something options and their resulting treatment profiles (and consequent impacts on the network) attributes were associated with each option to model the expected differences in whole-life performance and outputs:

- Unit cost – each treatment having a different cost allows the whole-life cost of each treatment profile to be assessed and the works cost of the treatment to be balanced with other factors;
- Expected life – each treatment having a different expected life allows options to be modelled and investigated (e.g. is it better to have a higher initial cost treatment with long intervals between interventions or a lower initial cost with more frequent interventions);
- Carbon quantities – treatments with different materials will be associated with different quantities of embodied carbon, thereby allowing the modelling of different carbon profiles; and
- Noise reduction levels – different treatments resulting in different surface types and different associated noise reductions allow for different noise profiles to be modelled.

The different values associated with the attributes result in different treatment profiles being generated for the options, allowing the impacts from those profiles to be assessed.

The base model was enhanced to enable these additional Do Something options to be evaluated for each scheme appraisal and the complete list of options is shown in Table 6-2.

Table 6-2: Model treatment options

Treatment Option	Carbon	Noise
Do Minimum	-	-
Do Something₁	Standard	Standard
Do Something₂	Low	Standard
Do Something₃	Standard	Low
Do Something₄	Low	Low

(source: authors research)

6.2 Incorporating carbon

Two elements required for incorporating the consideration of embodied carbon emissions of maintenance options in the model are:

- Developing a reporting mechanism so that the carbon footprint for each maintenance option is included in the costing calculations (e.g. carbon quantity, carbon cost); and
- Defining a specific low-carbon maintenance option to be considered in the model for each of the default treatment types.

6.2.1 Developing a carbon reporting mechanism

Key to including carbon emissions from maintenance in a road pavement maintenance model is reliable estimates of the embodied carbon within each treatment. Data is required to calculate how much carbon is linked to a particular maintenance regime, which can be converted into a cost using carbon prices. The method used to calculate the carbon quantities for particular products needs to be robust and based on recognised standards and accepted protocols.

The tool used in this research to determine the embodied carbon for the treatments was the asphalt Pavement Embodied Carbon Tool (asPECT). The tool takes account of the CO₂e (carbon dioxide equivalent) impact of building or maintaining a road, following the requirements laid out in BSI PAS 2050:2008 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).

For use in the model the embodied carbon quantities were determined in two stages for the pavement maintenance:

1. Planing – the energy required to plane, remove and dispose the existing material;
and
2. Laying – the embodied carbon in the new material and the energy to transport it, lay and compact it.

The carbon quantity for each maintenance intervention is a sum of the embodied carbon for the two stages.

The methodology proposed in this research is enabled by lookup tables of the amount of embodied carbon associated with each treatment option. The lookup tables of carbon quantities are used to calculate the total embodied carbon quantities by multiplying the amount of carbon per unit area with the area of maintenance. To further understand the importance of the inputs to the creation of the lookup tables their sensitivity was investigated using asPECT.

The inputs to each stage are:

1. Planing:
 - a. Depth of material being removed;
 - b. Distance of transporting waste.
2. Laying
 - a. Binder content;

- b. The inclusion (or not) of polymer modified binders;
- c. Amount of recycled asphalt;
- d. Heating and mixing energy used at the plant;
- e. Distance of transporting material.

Reductions in the embodied carbon due to recycling are considered within asPECT by rules that take account of the:

- Use of recycled material which reduces the requirement for virgin material; and
- Future recyclability of the material being produced.

6.2.1.1 *Sensitivity of carbon inputs*

Depth of material being removed

The carbon emissions from the planing of existing material are not influenced by the existing material type. The data inputs which do have an influence on the outputs are the planer width and the depth of material being removed. The planer width is assumed to be fixed at 2.2m, representing the widest planer considered in asPECT and the size of machinery that is commonly used on larger maintenance schemes on a national network. The outputs from asPECT for the permitted range of planing depths are shown in Appendix J.

Figure 6-1 shows the quantities of carbon (in kg CO₂e/t) for the range of planing depths. The relative inefficiency of the planer (in emissions per tonne) for removing only the upper layers of material can clearly be seen, although it is more consistent at the standard planing depths undertaken.

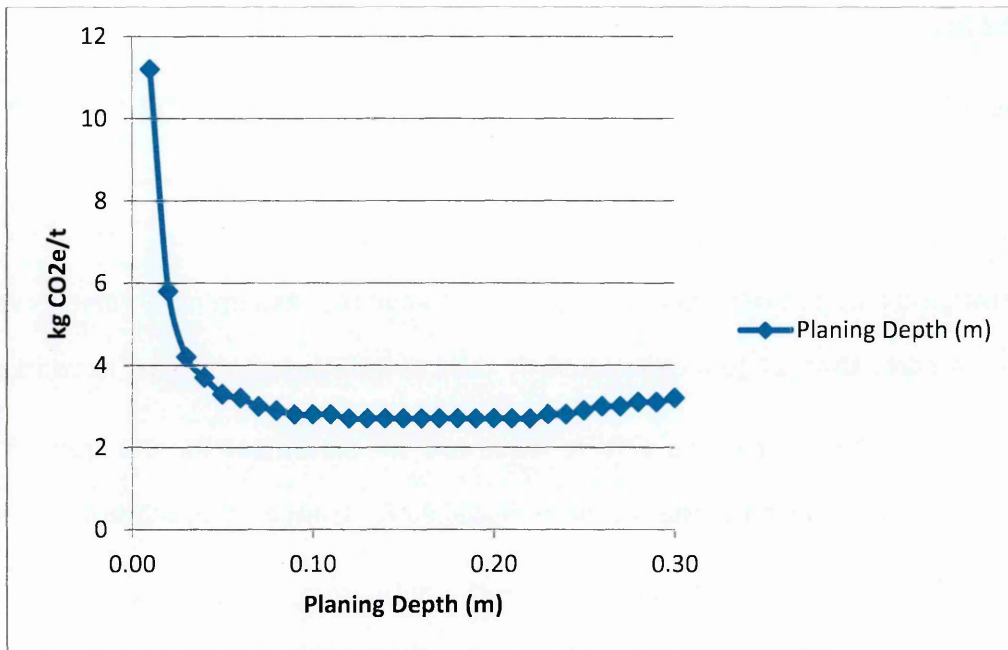


Figure 6-1: Carbon emissions (kg CO₂e/t)

Figure 6-2 shows the outputs normalised by the depth of material removed per square metre of road surface (assuming an asphalt density of 2.3 t/m³). When expressed in this way, an almost linear increase in emissions with increasing depth is seen across all depths as the planer is required to remove greater quantities of material per unit area.

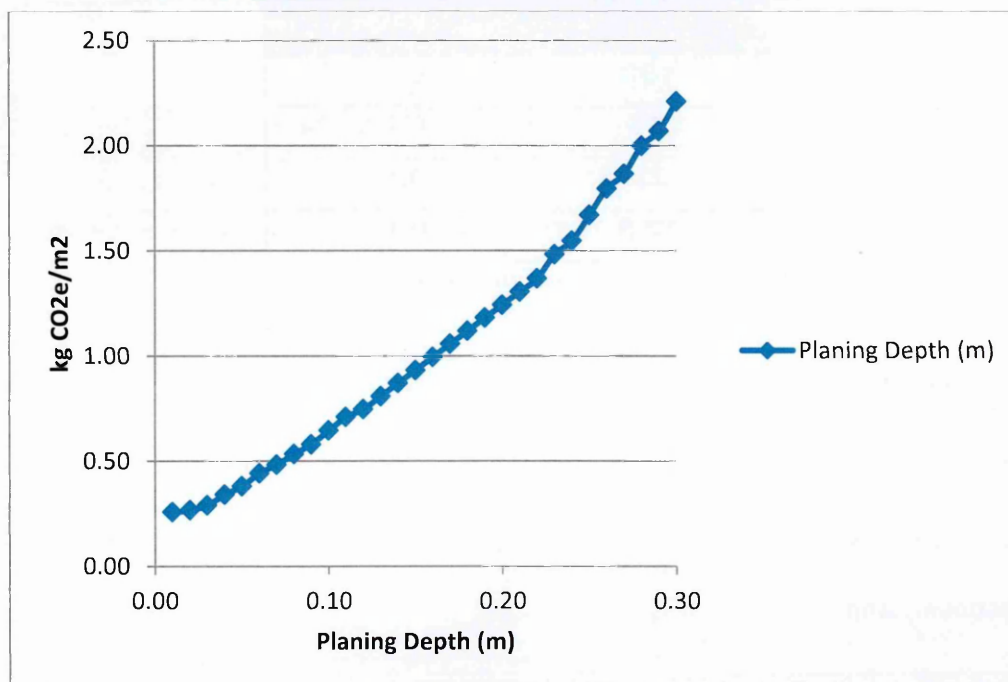


Figure 6-2: Carbon emissions (kg CO₂e/m²) assuming asphalt density of 2.3 t/m³

Transport distance

An additional source of associated carbon emissions comes from the planned material transported off-site (assumed to be back to the plant for processing) and the new material transported to site (from the processing plant). The emissions from transportation using different vehicle loads were calculated, assuming a vehicle type of a rigid truck greater than 17 tonnes as used by road authorities on national networks.

Along with the vehicle type, the vehicle loads are the key input for the transportation emissions and the following scenarios were modelled for transporting material off-site:

- 100% vehicle load³³: Full loads on both the outward and return journeys;
- 50% vehicle load: Full load on one journey, empty load on the other;
- 25% vehicle load: Half-load on one journey, empty load on the other; and
- 12.5% vehicle load: Quarter-load on one journey, empty load on the other.

Table 6-3: Transport utilisation carbon emissions per km calculated using asPECT

Utilisation (%)	Carbon (kg CO_{2e}/t per km)
100	0.07
50	0.12
25	0.14
12.5	0.15

(source: authors research)

For implementation within the methodology it was assumed that:

- During the process of removing the waste, no material is brought to site;
- During the process of bringing material to site, no waste material is removed for disposal; and

³³ The vehicle load refers to the total utilisation over a return journey

- The size and volume of the maintenance schemes for modelling on a national network will permit the majority of truck loads to operate full loads either to or from site.

The 50% vehicle loading was therefore chosen to be used, which aligned with the normal assumptions made for material delivery, being a full load on delivery and empty on the return (Huang et al., 2009).

The data to calculate the actual distance material is transported is not available for a strategic model but it could be an enhancement to a project level tool that makes use of a GIS. Therefore a general default value of 39.1km was used, representing a generic average distance of transport from plant to site in the UK (Mineral Products Association, 2011).

Binder content

Binder content can vary between products and asPECT was used to determine the embodied carbon for a mixture that uses two different binder proportions representing the envelope of recommended ranges (PD 6691, 2010).

Table 6-4: Sensitivity of binder content amounts using asPECT

Binder content (%)	Recycled content (%)	Polymer modified binder included?	Carbon (kg CO_{2e}/t)
4.5	0	N	57.24
6.5	0	N	59.83

(source: authors research)

Due to the limited variation in the embodied carbon between the recommended ranges of binder content (PD 6691, 2010) one binder content has been assumed for the modelling per Do Something option. Additionally, in a strategic network level tool it is not feasible to model where on the network mixtures of different binder proportions

would be used. This type of decision would be made more locally in consultation with contractors and therefore more relevant at the stage of detailed scheme design.

In creating a default data set the low-carbon Do Something option was set to reflect the low end of the recommended range, whilst the standard carbon Do Something option was set to reflect the high end value of the permitted range. This still allows strategic benefits of different treatment options to be compared against one another and provides an impact of the effect of different options on the total carbon outputs.

Polymer modified binders

Sensitivity analysis showed that the inclusion (or not) of polymer modified binders has a greater impact than binder content on the resulting embodied carbon (calculated using the mid-point of permitted binder content ranges).

Table 6-5: Sensitivity of the inclusion of polymer modified binder using asPECT

Binder content (%)	Recycled content (%)	Polymer modified binder included?	Carbon (kg CO _{2e} /t)
5.5	0	Y	68.37
5.5	0	N	58.47

(source: authors research)

To model the four Do Something options, inclusion or not of polymer modified binders have been used to reflect differences between those options (i.e. included in the standard mixture but excluded from the low-carbon treatment). The purpose of this was to reflect the different treatment mixtures that are used on the network, which would further help to identify the levels of embodied carbon when adopting different maintenance programmes.

Recycled asphalt content

The amount of recycled content within mixtures was investigated for surfacing and base materials. Up to 10% of recycled material can be used in surface courses (DMRB, 2004b; World Highways, 2011) and up to 50% for base materials. However for base materials usage generally peaks at 10-20% for road applications, with the higher percentages usually found in non-highway pavement applications such as car parks or driveways (World Highways, 2011).

Table 6-6: Sensitivity to the impact of recycled content (of thin surfacing material) on embodied carbon

Recycled content (%)	Carbon (kg CO_{2e}/t)
0	68.37
5	67.72
10	67.07

(source: authors research)

Table 6-7: Sensitivity to the impact of recycled content (of base material) on embodied carbon

Recycled content (%)	Carbon (kg CO_{2e}/t)
0	57.24
10	56.38
20	55.52
30	54.66
40	53.90
50	52.94

(source: authors research)

Recycled content does impact upon the total embodied carbon, although to a lesser extent than for the inclusion of polymer modified binders.

However, there is a lack of data on the recycled content used by Irish highway authorities. The tables show an environmental incentive to recycle (which could be reflected in treatment options for modelling) but anecdotal evidence appears to indicate that the level of recycling is very low (if any).

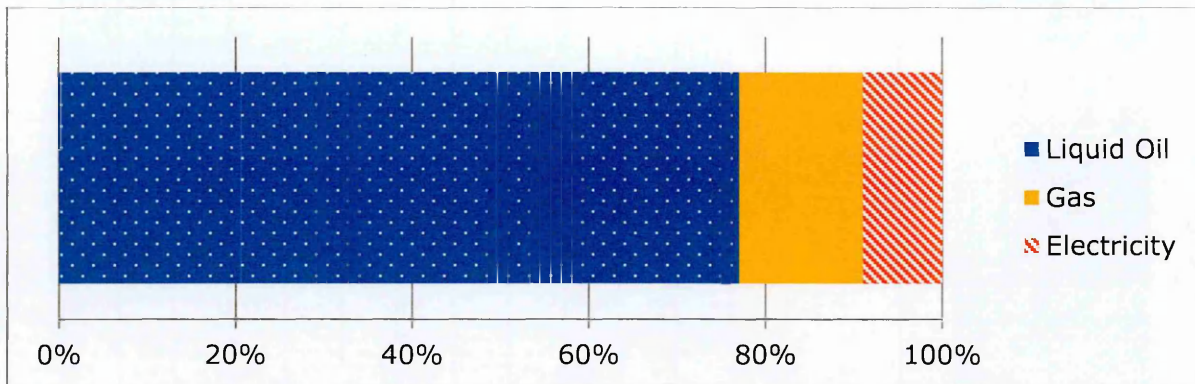
In creating a default data set for modelling, recycled content is a further element that can be used to differentiate between the low and standard carbon maintenance options. Although the difference in embodied carbon between the recycled amount of 0% and 10% for a surfacing is low (<2%) a value of 0% for the recycled content was proposed for standard carbon options and 10% for low-carbon options.

Similarly for the base material, the small difference in embodied carbon between 0% and 10% recycled material (10% being assumed as a maximum due to low recycling in Ireland) means that little difference is experienced in the output results. However, to allow the model to more fully investigate the carbon impact of different options, as with the surfacing material, the base material was set at 0% recycled content for the standard carbon option and 10% for the low-carbon option.

Plant energy

Although the plant energy can have an impact on the outputs from asPECT (e.g. changing from a fuel oil plant to a gas plant can reduce the embodied carbon by around 20%) the predominant fuel type used is liquid fuel, or fuel oil (Figure 6-3). It was therefore assumed that liquid oil would be the assumed fuel type in the methodology and associated calculations.

Figure 6-3: Energy use in asphalt plants (source: Carbon Trust, 2010)



6.2.1.2 Embodied carbon quantities

The base whole-life cost model was created with four default treatment types which represent the treatments that are currently used by the NRA on the Irish network:

- Patching;
- Surfacing;
- Inlay; and
- Overlay.

For each of those options the treatment could have either a 'standard' or 'low' configuration for carbon and noise thereby generating four potential Do Something options for each treatment, in addition to the Do Minimum (see Table 6-2).

The assumptions used to derive the quantities of embodied carbon for each of those treatment options were selected to be representative of mixtures that would be specified for maintenance and are shown in Table 6-8. A user can specify any local treatments or mixes in their version of the model and enter the associated carbon quantity to be used into the model.

Using the listed assumptions, the quantities of embodied carbon for each treatment option was calculated using asPECT with the resulting carbon quantities shown in Table 6-9.

Table 6-8: Materials assumptions made for treatment options

Treatment	Do Something		Surface Type	Planing depth (mm)	Surface binder content (%)	Surface treatment thickness (mm)	Base binder content (%)	Base treatment thickness (mm)	Polymer modified binder included?	Recycled content (%)	Transport distance (km)
	Carbon	Noise									
Patching	Std	Std	SMA	45	7.6	45	-	-	Y	0	39.1
Patching	Std	Low	SMA	45	7.6	45	-	-	Y	0	39.1
Patching	Low	Std	SMA	45	5	45	-	-	N	10	39.1
Patching	Low	Low	SMA	45	5	45	-	-	N	10	39.1
Surfacing	Std	Std	Surface Dressing	-	11.64	-	-	-	Y	0	39.1
Surfacing	Std	Low	SMA	30	7.6	30	-	-	Y	0	39.1
Surfacing	Low	Std	Surface Dressing	-	9.42	-	-	-	N	10	39.1
Surfacing	Low	Low	SMA	30	5	30	-	-	N	10	39.1
Inlay	Std	Std	SMA	70	7.6	30	8	40	Y	0	39.1
Inlay	Std	Low	Porous Asphalt	60	7	60	-	-	Y	0	39.1
Inlay	Low	Std	SMA	70	5	30	3	40	N	10	39.1
Inlay	Low	Low	Porous Asphalt	60	3	60	-	-	N	10	39.1
Overlay	Std	Std	SMA	80	7.6	35	8	75	Y	0	39.1
Overlay	Std	Low	Porous Asphalt	80	7	60	8	50	Y	0	39.1
Overlay	Low	Std	SMA	80	5	35	3	75	N	10	39.1
Overlay	Low	Low	Porous Asphalt	80	3	60	3	50	N	10	39.1

(source: authors research)

Table 6-9: Resulting embodied carbon quantities from asPECT

Treatment	Carbon	Noise	Surface Type	Carbon quantity (kg CO_{2e}/t)
Patching	Std	Std	SMA	74.9
Patching	Std	Low	SMA	74.9
Patching	Low	Std	SMA	57.1
Patching	Low	Low	SMA	57.1
Surfacing	Std	Std	Surface Dressing	52.9
Surfacing	Std	Low	SMA	74.9
Surfacing	Low	Std	Surface Dressing	31.9
Surfacing	Low	Low	SMA	57.1
Inlay	Std	Std	SMA	75.5
Inlay	Std	Low	Porous Asphalt	72.9
Inlay	Low	Std	SMA	55.7
Inlay	Low	Low	Porous Asphalt	59.5
Overlay	Std	Std	SMA	75.6
Overlay	Std	Low	Porous Asphalt	74.3
Overlay	Low	Std	SMA	55.4
Overlay	Low	Low	Porous Asphalt	57.3

(source: authors research)

6.2.1.3 Carbon pricing

Carbon pricing was discussed in chapter 3 and the different sources of prices were introduced (e.g. NRA, DECC) with the choice of source depending on the type of appraisal being undertaken and its location, accepting noticeable differences between the pricing structures (Figure 3-2).

Prices from both NRA and DECC are included in the model to calculate the carbon cost of a treatment. The costs are held in lookup tables in the model reference database, and the user can select the cost source for use in the analysis through the model interface (e.g. NRA, Non-traded DECC-Central). A table of the available costs is included in Appendix K.

Traded prices are for use where emissions are generated in the traded sector (i.e. those which are covered by the EU Emission Trading System (ETS)) and therefore are not relevant to emissions for the transport sector. However, the carbon prices for the traded sector are also included alongside the NRA and DECC non-traded prices to enlarge the scope of potential sensitivity analyses using the model. The reason for this inclusion is that the price of carbon in the European markets has fallen significantly in 2013 and is not expected to recover quickly (Financial Times, 2013). The traded prices (which are lower than the non-traded prices up to 2030, especially in the early years) therefore allow for lower carbon prices to be modelled to understand the impacts if prices are subjected to significantly lower revisions in the near-future.

6.2.1.4 Carbon methodology implementation in the model

Removal of existing material

The total calculated embodied carbon for the planing activity is summed from the emissions for excavating the existing material and the emissions for transporting the waste material off-site, for either processing or disposal (Appendix J).

The methodology for determining the total embodied carbon emissions (in kg CO₂e) for the removal of existing material (for the total treatment area) is implemented as:

	$Carbon_{Removal} = (CO_{2e_{depth}} \times density \times depth \times area)$	(6.1)
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where: CO_{2e_{depth}} = embodied carbon per tonne for removal and waste transport for given depth (kg CO₂e / t)

density = density of asphalt (2.3 t/m³)

depth = depth of planing (m)

area = area of material being removed (m²)

Laying new material

The methodology implemented for determining the total embodied carbon emissions for laying new materials (for the total treatment area) is described in the following steps:

1. Determine the treatment being applied (i.e. a surfacing, standard carbon, standard noise) and the associated carbon quantity (kg CO₂e/t);
2. Multiply the carbon quantity (from step 1) by the density of asphalt (2.3 t/m³) to generate the carbon quantity per unit volume of the treatment (kg CO₂e/m³);
3. Multiply the carbon quantity per unit volume (from step 2) by the treatment thickness to generate the carbon quantity per unit area for that treatment option (kg CO₂e/m²); and
4. Multiply the carbon quantity per unit area of treatment (from step 3) by the treatment area to calculate the total embodied carbon for the newly laid material of the maintenance option (in kg CO₂e).

This methodology was implemented as:

	$Carbon_{Laying} = (CO_2e_{material} \times density \times thick \times area)$	(6.2)
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where: CO₂e_{material} = embodied carbon per tonne for selected treatment material (kg CO₂e / t)

density = density of asphalt (2.3 t/m³)

thick = thickness of treatment of planing (m)

area = area of material being laid (m²)

Pricing the total carbon

Following the calculation of the carbon quantities for removal and laying of pavement layers for each intervention they are priced as follows:

1. Sum the carbon generated from the removal of the existing material and the carbon generated in the laying of the new material to determine the total carbon quantity for the maintenance intervention;
2. Multiply the total carbon quantity by the user chosen price of carbon ('Low', 'Central' or 'High' from the lookup table in the model (recommended values are the 'Central' non-traded estimates). If carbon prices not on the list are required to be modelled they have to be added to the lookup table in the reference database;
3. Apply discount rates to the carbon prices over the period of the analysis to calculate the carbon NPV for all maintenance interventions. The standard Treasury Green Book values are used as defaults for the carbon discount rate although users can specify their own discount rates if required (which can be separate to the works costs discount rate);
4. Include the discounted carbon cost in cost calculations as specified by the user during the run configuration (i.e. whether carbon costs should be treated as an agency or user cost).

6.2.2 *Creating a specific low-carbon maintenance option*

As shown in Table 6-8 each treatment type has four Do Something options, two of which are designed to have a low-carbon element, the other two represent standard carbon outputs. Providing the increased number of options in modelling the impacts of carbon for the same treatment, allows a greater depth of investigation to be performed.

However, the different environmental characteristics of the options need to be linked with a representation of how the performance of each option is affected by any change in its characteristics (e.g. how does a change in binder content affect the life of the treatment option).

Within the model the performance and life of any treatment is modelled by the deterioration rules applied to the condition parameters. Any subsequent treatment

needs are determined when the condition parameters cross their respective thresholds for treatment. In order for the different carbon characteristics of the model to be linked with different pavement performance and durability, the deterioration rates need to be varied accordingly. To deal with this a deterioration factor has been included for each treatment option and applied to the deterioration rates.

Different factors can impact upon the durability and performance of asphalt mixes (e.g. air void content, asphalt temperature, binders, addition of PMB³⁴). Comparing these with the data inputs using asPECT to generate the embodied carbon dataset (Table 6-8) showed that binder content is the main factor common to both.

Increased levels of binder content can lead to increased durability (Nicholls et al., 2010). In order to replicate this behaviour the low-carbon alternatives (i.e. those with lower binder content) were factored to deteriorate at a faster rate. Anecdotally, durability varies between mixtures and binder content and there is some thought that higher binder contents can lead to deformation due to the reduced stiffness. In this dataset, the low-carbon alternatives (with the lower binder contents) were set to deteriorate at a rate 10% greater than the 'standard' options.

6.3 Incorporating noise

In the context of roads, at low speeds (e.g. below 30mph) the vehicle and engine are the dominant source of noise compared to moderate and high speeds (e.g. above 30 mph) where the interaction between the tyre and road surface dominates (Sandberg, 2001). Higher speeds are more common on a national network where a greater proportion of the network has higher speed limits compared with local networks and therefore the road surface type and its interaction with tyres is important because it contributes significantly to the overall noise. Therefore, the new surface type chosen during maintenance can have a noticeable bearing on the

³⁴ Polymer modified binders

resultant noise and hence why it is included in a model for a national road agency. When this is coupled with deterioration, which can lead to increased potholing, fretting etc., the noise will increase further. If an agency can take control of mitigating some of the pavement noise at the time of planning then it will lead to additional benefits for road users.

Noise has been discussed to be both a potential driver of maintenance and a reporting function of the maintenance chosen for implementation. In addition to the noise impacts of laying new material, there is a third aspect specific to incorporating noise; noise can act as a trigger mechanism for maintenance.

The three aspects relevant for developing a methodology to include noise impacts in scheme appraisal are therefore:

1. A reporting mechanism to enable noise benefits for each maintenance option to be calculated (e.g. change in people affected, cost);
2. Data to enable a specific low-noise maintenance option to be modelled for each treatment type; and
3. Rules so that noise can trigger maintenance interventions.

In order to address those aspects this chapter discusses the development of the methodology under the following headings:

1. Available data;
2. Derived data; and
3. Calculating benefits and costs.

6.3.1 Available data

6.3.1.1 Noise maps

Level of data

An early step in developing a methodology for modelling noise impacts of different maintenance treatments was identifying the noise data available to populate a suitable dataset for use in the modelling. A generic process to create such a dataset has been developed and it can be applied by other road authorities who have compiled noise maps. Other noise data may be available (e.g. CPX or SPB measurements) although it is only likely to be for scheme specific locations and not at a network level due to the cost and time required to collect that data. However, if more detailed sources of data for noise become available over time a road authority could make use of it when creating their input data.

The European Noise Directive (END) (Directive 2002/49/EC, 2002) has required highway authorities of EU member states to map noise corridors on their road networks that meet a set of criteria. The first phase of the directive required noise to be mapped for trunk, motorway and classified roads having more than 6 million vehicle passages per year (by 31st March 2007). The second phase widened the criteria so that the same road classifications having more than 3 million vehicle passages per year were required to be mapped (by 31st March 2012).

The noise map for county Kilkenny, Ireland (Figure 6-4) shows the level of outputs from the latest phase of noise mapping undertaken in Ireland.

The map shows the national and regional road network for the county and the lengths of the roads mapped are shown by the coloured shading on the maps. All data from the mapping is aggregated at a county level and displays, within set noise bands, the:

1. Approximate number of people affected;
2. Approximate area affected; and

3. Approximate number of dwellings affected.

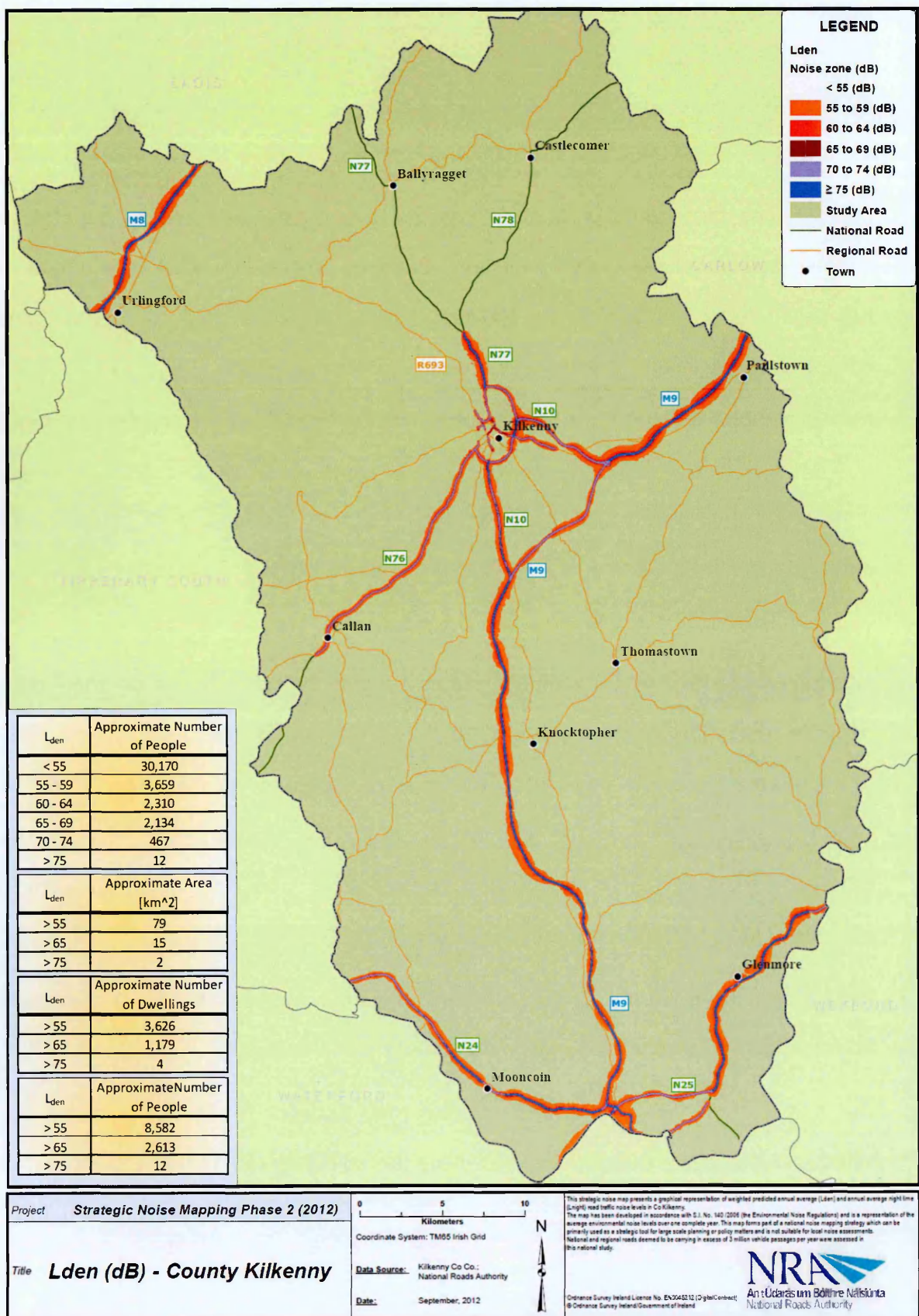


Figure 6-4: Phase 2 noise mapping for county Kilkenny, Ireland (source: NRA)

Required data

The data underlying the noise maps is not sufficient for modelling noise as a condition parameter at network level. Firstly, the noise maps do not provide noise records for each county in its entirety. This is due to the mapping criteria of the directive.

Secondly, the maps and associated data do not provide specific locational records of the limits of the noise mapping and this information is required to link the noise records to specific sections of the road network.

Thirdly, the number of people and households affected is not held for specific chainages but aggregated at a county level. Although the maps show how the noise zones change with distance from the road by the changing shape of the colours overlaid on the mapped roads (albeit crudely), the numerical data are not presented at that level. Whilst not essential for the analyses, this level of data would allow different maintenance schemes along the same road to use different levels of noise in the calculation of noise costs, rather than using an aggregate county-level average.

When modelling noise impacts to compare alternative options at a project level, more detailed data on the noise levels experienced along the entire length of the scheme would be required. This could include noise level data at regular chainage intervals, how it varies along the length, as well as information on the number of residents and properties affected. Understandably that level of information is not currently available for the whole network because it is both costly and time consuming to collect and analyse it.

Considering all of the above the noise mapping data in Figure 6-4 still represented the best current source of noise data for the Irish road network. It is consistent with outputs from END across Europe. That therefore extends the potential benefits of the developed methodology for use by other road authorities.

The apparent problems in using the noise mapping data as it is available, and the potential mitigations are described in Table 6-10.

Table 6-10: Problems and mitigation of available noise mapping data

Problem	Description	Mitigation
Data is not available for the whole network	A significant proportion of the network remained unmapped because the END only required noise mapping in phase 2 for roads that carried more than 3 million vehicle passages per year.	For the road lengths that have not been included in phase 2, noise benefits cannot be calculated for maintenance schemes. However, the areas currently mapped should represent the areas where road noise has the greatest impact. If there are future phases of noise mapping then any new data can be added to the network coverage as it becomes available.
Some roads are only partially mapped within a county	The END requirements mean that a road may only be partially mapped in a county and the length of the mapped section to which the noise data applied is not available.	The length of each national road in each county is obtained by interrogating the base Irish data used for this model. The mapped proportion of each road is assumed from the noise maps in order to estimate mapped length of each road. These lengths are summed for each county so that the county level data

Problem	Description	Mitigation
		could be converted into 'per km' values (e.g. households in each noise band).
<p>The mapping includes some regional roads</p>	<p>Regional roads are not the responsibility of the NRA and are not included in the network in the pavement maintenance model. However, the aggregated noise data was presented for all roads in each county and therefore included some of the regional roads for some counties.</p>	<p>No information was available from the NRA on the length of regional versus national roads that had been mapped in any county.</p> <p>An assumption is made as to the national and regional split of data and that proportion is used to factor the aggregated data to estimate values for 'national only' roads.</p>
<p>Data is aggregated to a county level</p>	<p>Data is not available for individual roads in any county. Therefore all roads in a county had to be given the same derived average noise levels from the aggregate county</p>	<p>Until more detailed noise data are available on a chainage basis, or for individual roads, the modelled noise metric (e.g. number of affected properties per km) will be uniformly applied to all roads in a county.</p> <p>If more granular data becomes available the noise condition data can be updated.</p>

Problem	Description	Mitigation
	data.	

(source: authors research)

Creating the mapped noise dataset

The data presented on the noise maps for L_{den}^{35} and L_{night}^{36} noise classifications are:

- Number of people within zone of influence of noise bands, in 5 dB bands from <55, 55-59, 60-64, 65-69, 70-74 and >75;
- Area (km²), in 10 dB bands from >55, >65 and >75;
- Number of dwellings, in 10 dB bands from >55, >65 and >75; and
- Number of people, in 10 dB bands from >55, >65 and >75.

The most relevant dataset is the number of dwellings because this aligns with recommended practices for costing road noise, such as WebTAG unit 3.3.2 (DfT, 2012c). However, the noise mapping inputs presented this data measure in only three 10 dB bands as opposed to the 5 dB bands for the population data.

Additional data were obtained from the NRA on the number of dwellings in 5 dB bands, derived from more accurate data of façade level noise. This resulted in data for the number of dwellings within the zone of influence of noise levels in 5 dB bands being available in the following format:

- L_{den} 55-59 dB;
- L_{den} 60-64 dB;
- L_{den} 65-69 dB;

³⁵ L_{den} (Day Evening Night Sound Level) is the average sound in a 24 hour period, weighted with a penalty of 5 dB added for the evening hours or 19:00-23:00, and a penalty of 10 dB added for the night hours 23:00-07:00 to account for extra annoyance in those period.

³⁶ L_{night} is the equivalent continuous noise level over the night hours 23:00-07:00. It is not weighted and is often used during sleep disturbance assessments.

- L_{den} 70-74 dB; and
- $L_{den} > 75$ dB.

A base noise dataset was created from these data for each county (Appendix L).

Deriving a noise metric for modelling

Using the generated mapped noise dataset, a noise value that normalised the noise data in each county on a 'per km' basis was derived. This allows consistent rules to be applied across the network, whilst picking up differences in the county level data. It also allows for more detailed data to be applied to specific roads where it becomes available. The process consists of the following steps:

1. For each national road in each county derive the route length (km) from the base Irish data;
2. By looking at each county noise map assess:
 - a. The proportion of the length of each national road mapped (%);
 - b. The proportion of the total mapped national roads compared to regional roads (%);
3. Sum the total mapped length of national roads (using 1 and 2a) to provide a county level mapped national road length (km);
4. Use the noise dwelling dataset to determine (in each 5 dB band) the:
 - a. Number of dwellings affected on the national roads (using 2b);
 - b. The number of dwellings per km affected on the national roads (using 3 and 4a);
5. For each county, apply the 'number of dwellings per km' to all the mapped national roads, and tabulate those values in a chainage format for use by the model as input noise data.

An example of this process is demonstrated for county Killkenny in 0.

6.3.1.2 *Noise costs*

Monetising noise allows for the noise nuisance or benefits as a result of maintenance to be costed and included in an economic analysis. NRA does not have any published noise costs for use in their transport appraisals for the change experienced by each dwelling. However, WebTAG unit 3.3.2 (DfT, 2012c) contains recommended values for the change in noise in 1 dB bands for transport related noise (Appendix N).

To derive values for household noise change in the required 5 dB bands, the 1 dB change values were summed to generate lower and upper values for the respective halves of each 5 dB band. These half-band values were summed assuming that the noise was equally distributed in each 5 dB band (i.e. to get the cost of a change from one 5 dB band to another the value from the upper half-band of one 5 dB band was summed with the lower half-band value of the next 5 dB band. For example, to calculate the monetary value per households of a change from 50-55 dB to 45-50 dB band, the upper half band value from the 45-50 dB band (£54.7 per household) was summed with the lower half-band value from the 50-55 dB band (£76.9 per household) (see Appendix N for source values)).

Table 6-11 of noise costs for the 5 dB bands has been derived using the method described.

Table 6-11: Noise costs

Noise Change in the interval, dB _{Leq} ³⁷		Value of a change in 5dB band, £ per household per dB per annum	Value of a change in 5dB band, € ³⁸ per household per dB per annum
<45	45-50	34.21	38.59
45-50	50-55	131.65	148.51
50-55	55-60	217.15	244.95
55-60	60-65	302.78	341.53
60-65	65-70	388.34	438.05
65-70	70-75	473.77	534.42
70-75	75+	594.46 ³⁹	670.55

(source: adapted from WebTAG unit 3.3.2 (DfT, 2012c))

The costs for the change in noise in Euros per household are used as the lookup noise cost data in the reference tables in the model.

6.3.2 Derived data

6.3.2.1 Noise change values

The shape of noise progression

To enable the calculation of the change in noise from the road surface following a maintenance treatment, values for the noise change (in dB) from one surface to another (old to new as a result of maintenance) were required. Without a representation of the noise levels associated with different surfaces, noise benefits would only be a function of the dwelling data without any consideration of the treatment applied.

³⁷ Equivalent Continuous Noise Level

³⁸ The WebTAG prices were expressed in 2010 prices. The conversion to Euros used the historic exchange rate as of the 1st January 2010 (£1:Euro 1.128) from <http://www.xe.com/currencytables/?from=GBP&date=2010-01-01>

³⁹ The value for a change between the 70-75 and 75+ dB bands was derived by averaging the change from the 70-75 to the 75-80 band and the 75-80 to the 80+ band.

Different pavement surfaces contain different aggregates that result in different noise emissions when interacting with tyres. As the surfaces deteriorate and there is an increase in defects such as fretting and potholes, the road macrotexture⁴⁰ and megatexture⁴¹ increase which are closely related to noise (Sandberg and Ejsmont, 2002) and therefore the noise generated from the surface also increases. The noise generated at moderate and higher speeds experienced on a national network is primarily influenced by road surface and vehicle tyre interactions. As this is a road maintenance model aimed at supporting a highway authority it concentrates only on the element of noise from surfaces because a road authority cannot control vehicle tyre choice and neither are surfaces controlled by vehicle tyre choice. The methodology is required to reflect the noise differences that are experienced when changing surfaces and how this might be different for surfaces of different ages, for example, a new porous asphalt compared to an older surface dressing.

The review of noise literature (e.g. FEHRL, 2006) has shown:

1. There is a difference in noise levels resulting from different surface types;
and
2. There is a difference in noise levels between the same surface type at different periods in its life.

To emphasise the second point, a newly laid surface of the same type as the older surface being replaced would generate noise benefits at least in the short-term. However, the long-term benefits of changing one surface for another of the same type may decrease as the surface deteriorates with time. For example, in the case of a new surface of the same type there may be an immediate noise reduction⁴², although the largest benefit will come from a change from a noisier surface to a

⁴⁰ Wavelengths of 0.5mm up to 50mm

⁴¹ Wavelengths of 50mm up to 500mm

⁴² A new surface dressing may result in an increase in noise for a few weeks as the chips bed-in, but over a period of the first year the road would be expected to generate less noise due to the removal of surface defects

quieter one. However, any immediate reduction from a new surface of the same type might be diminished after a couple of years, at which point the surface is no different in noise characteristics to the older surface. If the noise benefits are going to level out, or plateau, the length of time for this transition is required.

This leads to the creation of two different noise change measures for the model:

1. An initial noise change immediately after the surface has changed; and
2. A constant noise change that can be expected following the initial bedding-in period.

These measures combine to produce the average lifetime noise change, adapting an approach by Veisten & Akhtar (2011) that investigated the difference in the initial noise change compared to the average lifetime noise change.

This concept of an initial noise change plateauing out in later years applies a representative relationship onto the concept being modelled. An alternative is a more traditional s-shaped curve, whereby there is a period of little change, followed by an initiation event at which point there is rapid change which then begins to steady. Both options are similar in effect but a plateauing curve might have a very short or non-existent initial period of limited change.

There was limited data available for analysing these trends but some appropriate measurements were documented by FEHRL (2006) for the maximum sound level recorded and two examples of these are reproduced in Figure 6-5 and Figure 6-6.

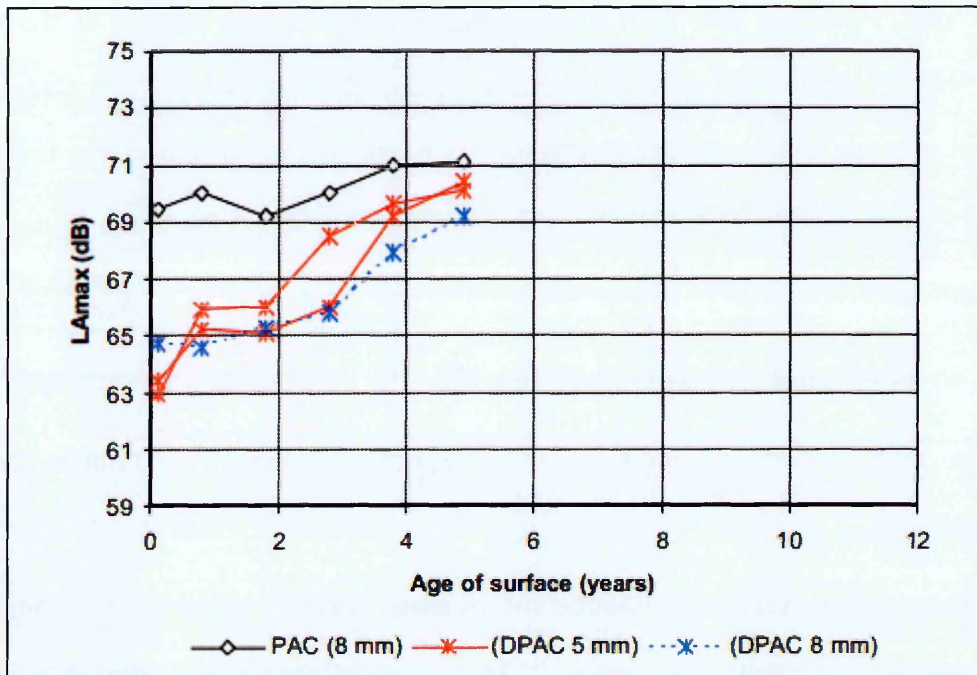


Figure 6-5: Example of noise level increase over 5 years of measurement for porous asphalt (PAC) and double layer porous asphalt (DPAC) surfaces. (The example above is from FEHRL (2006) and the data was for light vehicles at a reference speed of 50 km/h).

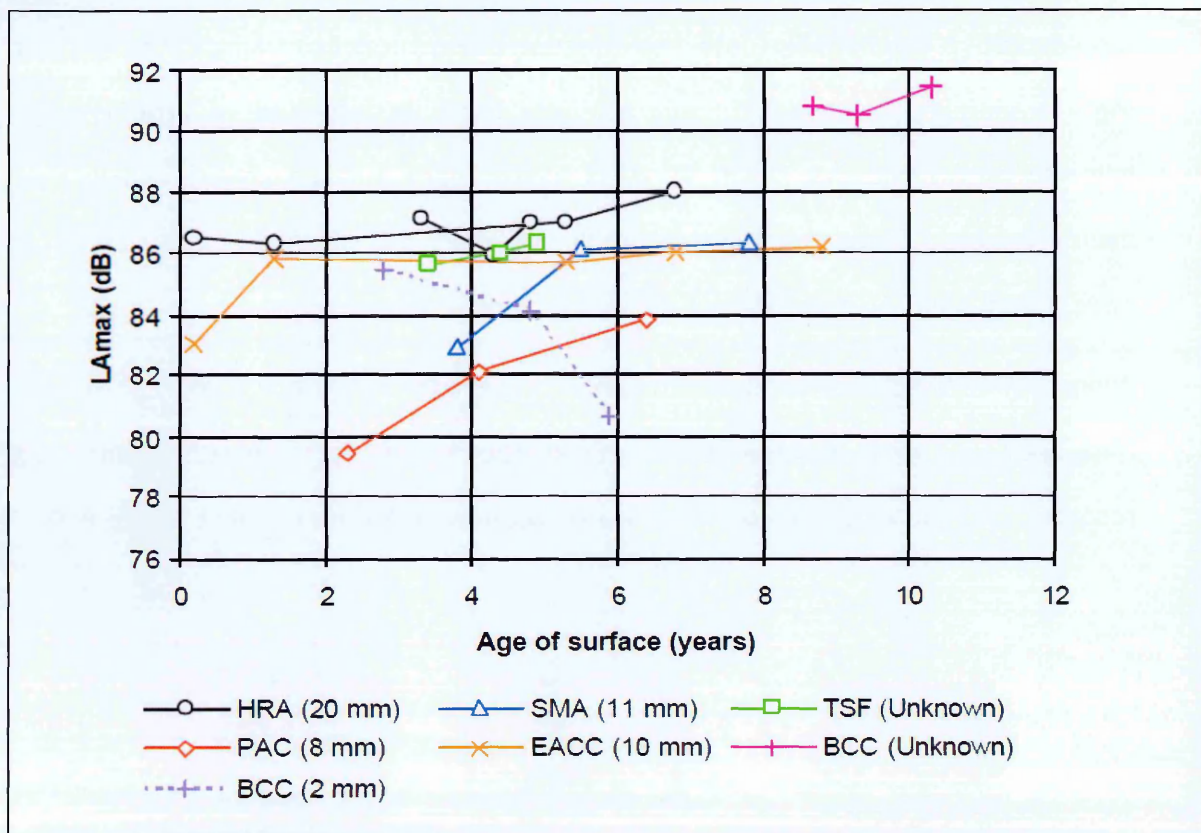


Figure 6-6: Example of how noise data has been shown to demonstrate an initial noise change, followed by a plateauing some years later, for hot rolled asphalt (HRA), porous asphalt (PAC), brushed cement concrete (BCC), stone mastic asphalt (SMA), emulsified asphalt cement concrete (EACC) and thin surfacings (TSF). (The example above is from FEHRL (2006) and the data was for medium heavy vehicles at a reference speed of 85 km/h).

The increase (or deterioration) of noise over time can be generally seen in the two graphs, with a few exceptions. An initial rapid increase in noise can also be seen to plateau in some of those examples (e.g. SMA and EACC in Figure 6-6) with others showing signs of beginning to plateau (e.g. DPAC 5mm and DPAC 8mm in Figure 6-5). If noise follows standard deterioration curves (as with other pavement parameters) we would expect these relationships to be present. Although the FEHRL data is limited, noise is anecdotally and theoretically expected to behave as per the examples of SMA and EACC in Figure 6-6 (i.e. the noise level deteriorates from an initial value over an initial period of years, before becoming steady).

In representing this, the methodology allows the following rules to be applied for noise:

- Following a maintenance intervention, an initial noise reduction is applied to the new surface from the year of maintenance;
- The initial noise reduction deteriorates linearly to a 'constant change' value, over a period equal to the 'time to constant change'; and
- Once the number of years since maintenance is greater than or equal to the 'time to constant change' the 'constant change' value is applied until any further maintenance intervention is triggered, at which point the process is repeated, with the new input data dependent on the old and new surface types.

An example application of this approach is shown in Appendix O. Although this concept has been documented (e.g. FEHRL, 2006) the limited amount of data is often project specific. Nevertheless, in order to build a dataset for the model and to present realistic case studies noise change data was required for all surfaces identified in the NRA construction records. A dataset was therefore built for this purpose which is described in the following sections. The creation of the dataset also demonstrates how road authorities could build their own, network specific data.

Noise change due to condition

Silence (2006), a three-year project co-funded by the European Commission, attempted to classify the level of noise change that is expected following a surface change. The report described how noise can change for pavement types of different conditions (based on typical Danish experience) with the maximum noise change as high as 9dB.

Table 6-12 shows the noise data the report presented for the differences in noise levels for surfaces in different conditions (assuming a base surface of a good asphalt concrete). There was no empirical basis for this data however; the values were suggested for what might be experienced in an urban environment.

Table 6-12: Noise data for different pavement types and conditions

Pavement type	Condition		
	Good	Acceptable	Unacceptable
HRA	+3 dB	+4 dB	+5 dB
Surface dressing (SD)	+1 dB	+2 dB	+3 dB
Asphalt Concrete (AC)	0 dB	+1 dB	+2 dB
Thin surfacing (TS)	-2 dB	-1 dB	0 dB
Porous Asphalt (PA)	-4 dB	-3 dB	-1 dB

(source: Silence, 2006)

Although the values were not scientifically measured, the layout of the data collection presented the beginnings of an approach for creating the dataset. Although a pavement surface is not always in an unacceptable condition when maintenance is triggered (e.g. for structural reasons) it should always result in a good condition afterwards. Similarly, pavement surfaces might not be performing in an unacceptable noise band prior to maintenance due to other condition parameters deteriorating first (i.e. rutting or skid resistance).

To investigate the potential of the data source for this research the noise data was reorganised as part of this research to represent the initial noise change

experienced when changing from one surface type to another, also aligning with surfaces used on the Irish network (Table 6-13). It was assumed that the majority of maintenance interventions begin with the surface in an unacceptable condition.

Table 6-13: Representation of noise change between surface types

Old surface (unacceptable)	New Surface (good)				
	HRA	SD	AC	TS	PA
HRA		-4 dB	-5 dB	-7 dB	-9 dB
SD	0 dB		-3 dB	-5 dB	-7 dB
AC	+1 dB	-1 dB		-4 dB	-6 dB
TS	+3 dB	+1 dB	0 dB		-4 dB
PA	+4 dB	+2 dB	+1 dB	-1 dB	

(source: adapted from Silence, 2006)

However, the data in the revised table only allows for the derivation of an initial change, rather than a constant change value.

Average lifetime noise change

In a 2006 report on implementing low-noise surfaces FEHRL collated data from member states that measured the change that could be experienced by different surfaces over an average lifetime. Using the same format as Table 6-12 and Table 6-13, values for the 'noise change over an average lifetime' were collated from the FEHRL (2006) report.

Table 6-14: Ranges of average lifetime noise reductions

Old surface	New Surface				
	HRA	SD	AC	TS	PA
HRA		+1 dB	-3 to -4 dB	-2 to -4 dB	-6 to -8 dB
SD	-1 dB		-4 to -5 dB	-3 to -5 dB	-7 to -9 dB
AC	+3 to +4 dB	+4 to +5 dB		0 to +1 dB	-3 to -4 dB
TS	+2 to +4 dB	+3 to +5 dB	-1 to 0 dB		-4 dB
PA	+6 to +8 dB	+7 to +9 dB	+3 to +4 dB	+4 dB	

(source: adapted from FEHRL, 2006)

There are some significant differences between Table 6-13 and Table 6-14, mainly because the former is representing the initial change compared to the latter which represents an average lifetime change. There are also differences in the provenance of the data. Using data that is measured appropriately (Table 6-14) as opposed to taking very localised, non-scientifically measured data helps build credibility in the outputs generated, especially for a non-localised, network level tool.

From the ranges in Table 6-14 a single noise change was extracted for this research by selecting the most conservative limit of each range (Table 6-15), except where this would lead to a value of 0 being used (i.e. the value closest to 0, but not 0). The conservative value from the ranges was chosen so as to limit any over-estimation of noise change benefits.

Table 6-15: Lifetime noise reduction estimated from non-zero conservative ranges in Table 6-14

Old surface	New Surface				
	HRA	SD	AC	TS	PA
HRA		+1 dB	-3 dB	-2 dB	-6 dB
SD	-1 dB		-4 dB	-3 dB	-7 dB
AC	+3 dB	+4 dB		+1 dB	-3 dB
TS	+2 dB	+3 dB	-1 dB		-4 dB
PA	+6 dB	+7 dB	+3 dB	+4 dB	

(source: authors research adapted from FEHRL, 2006)

However, the data presented in Table 6-15 does not include an initial change and a constant change, only an average lifetime change. Both an initial change value and a constant change value are required if the methodology developed was going to reflect the pavement noise behaviour as discussed previously. The time taken for the initial noise value to reach the constant noise change value effectively acts as a degradation factor for the new noise surface, with the assumption that when the constant noise change value is reached there is then no further degradation of the

noise. This method was chosen because it would replicate the noise behaviour better as opposed to applying a single average noise change value.

Initial noise reduction

Veisten & Akhtar (2011) undertook a study investigating road noise measures in Norway, which used realistic noise reductions for low-noise pavements for both the initial reduction and the average noise reduction over the pavement lifetime. Covering a range of surfaces (thin surfacing, stone mastic asphalt and porous asphalt) the ratio of the initial reduction to the lifetime reduction averaged 1.3:1 (i.e. the initial reduction was 1.3 times greater than the average lifetime reduction).

This factor was applied to the average lifetime noise reduction values in Table 6-15 to produce estimated values for the initial noise reduction (Table 6-16). It was also assumed that any maintenance that results in a newly laid surface of the same surface type would lead to an initial noise reduction of -1 dB to represent an improved road surface of the same type offering an initial small improvement in noise.

Table 6-16: Derived initial noise reduction

Old surface	New Surface				
	HRA	SD	AC	TS	PA
HRA	-1 dB	+1.3 dB	-3.9 dB	-2.6 dB	-7.8 dB
SD	-1.3 dB	-1 dB	-5.2 dB	-3.9 dB	-9.1 dB
AC	+3.9 dB	+5.2 dB	-1 dB	+1.3 dB	-3.9 dB
TS	+2.6 dB	+3.9 dB	-1.3 dB	-1 dB	-5.2 dB
PA	+7.8 dB	+9.1 dB	+3.9 dB	+5.2 dB	-1 dB

(source: authors research)

Constant noise reduction

For the methodology proposed in this research the initial noise reductions needed to be paired with a 'constant change value' which is reached after a set number of years for each surface type (reflecting the behaviour in Figure 6-6). In addition, for

each new surface type a value was required for the number of years it took to get to the constant change value after the maintenance.

Using the information from FEHRL (2006) relating different surfaces to effects of different vehicles and speeds (e.g. as in Figure 6-5 and Figure 6-6, but for a greater range of vehicles and speeds) the number of years until the noise level (or change) plateaued for each surface was estimated (Table 6-17).

Table 6-17: Number of years after maintenance that constant noise value is achieved

Surface	Years to constant noise level
HRA	3
SD	2
AC	4
TS	5
PA	6

(source: authors research and adapted from FEHRL, 2006)

An iterative process was created and used to derive the constant noise change values as described:

1. Apply the initial noise reduction (Table 6-16) in year 1, declining linearly to x , where x is the constant change value that begins after the 'years to constant change' is reached (Table 6-17);
2. Apply the constant change value x for the remainder of the average pavement lifetime (from Nicholls et al, 2010). This noise reduction value will be applied until the model identifies and selects a future maintenance scheme on the section;
3. Average the yearly noise reduction obtained over the life of each pavement;
4. Apply a factor to the average lifetime noise change (Table 6-15) to estimate the constant change values for the same pavement surfaces;

5. Using both the initial change profiles and the constant change noise profiles, assess how the average noise reduction calculated compares with the lifetime averages reported in Table 6-14;
6. Repeat the process until the factor applied in stage 4 leads to noise values being produced that align with the total average lifetime noise changes (in stage 5).

This process resulted in a factor of 1.2 being applied to all noise levels from Table 6-15, and assumed that for a maintenance option that replaced one surface with the same surface, following an initial reduction of -1 dB, the constant change would be 0 dB (i.e. after a period of y years, there would be no difference in noise between surfaces of the same type regardless of age).

This resulted in noise change levels being derived for use in the 'constant noise change' period (Table 6-18).

Table 6-18: Constant noise change values

Old surface	New Surface				
	HRA	SD	AC	TS	PA
HRA	0 dB	+0.8 dB	-2.5 dB	-1.7 dB	-5.0 dB
SD	-0.8 dB	0 dB	-3.3 dB	-2.5 dB	-5.8 dB
AC	+2.5 dB	+3.3 dB	0 dB	+0.8 dB	-2.5 dB
TS	+1.7 dB	+2.5 dB	-0.8 dB	0 dB	-3.3 dB
PA	+5.0 dB	+5.8 dB	+2.5 dB	+3.3 dB	0 dB

(source: authors research)

Developed noise change dataset

Using all of the above sources and approaches, a noise dataset was developed for modelling the performance of noise in the model by using a combination of the:

- Initial noise change values;
- Constant noise change values; and

- Number of years following maintenance when constant noise change is reached.

Table 6-19 displays the noise data used in the model database.

Table 6-19: Noise data used in the model database

Old surface	New surface	Initial noise change (dB)	Constant noise change (dB)	Time to constant change (yrs)
HRA	HRA	-1	0	3
SD	HRA	-1.3	-0.8	3
AC	HRA	+3.9	+2.5	3
TS	HRA	+2.6	+1.7	3
PA	HRA	+7.8	+5	3
HRA	SD	+1.3	+0.8	2
SD	SD	-1	0	2
AC	SD	+5.2	+3.3	2
TS	SD	+3.9	+2.5	2
PA	SD	+9.1	+5.8	2
HRA	AC	-3.9	-2.5	4
SD	AC	-5.2	-3.3	4
AC	AC	-1	0	4
TS	AC	-1.3	-0.8	4
PA	AC	+3.9	+2.5	4
HRA	TS	-2.6	-1.7	5
SD	TS	-3.9	-2.5	5
AC	TS	+1.3	+0.8	5
TS	TS	-1	0	5
PA	TS	+5.2	+3.3	5
HRA	PA	-7.8	-5	6
SD	PA	-9.1	-5.8	6
AC	PA	-3.9	-2.5	6
TS	PA	-5.2	-3.3	6
PA	PA	-1	0	6

(source: authors research)

6.3.2.2 *Developing trigger rules*

Unlike the parameter of carbon, noise levels might be a trigger for treatment. For example, a road might exceed a set threshold for noise but otherwise be in good condition. This would not require a treatment to correct any pavement condition defects but it could require maintenance to lower the noise levels of the road. This could be either through non-surface noise mitigation measures (e.g. barrier), a new surface or a combination of the two.

In the model, noise data needs to be capable of triggering a noise-only maintenance treatment. Any rules for noise-only maintenance have to work independently of the condition of the network. The difficulty with setting up triggers for noise is that there are no standard metrics or values used by road authorities. In many instances 'noise' appears to trigger maintenance on particular lengths only when the highway authority receives complaints from the public about the noise levels. Some road authorities have recommended limits for noise or 15 year design goals (e.g. NRA, Ireland) which if exceeded could be argued that a Do Minimum approach should be adopted to mitigate the noise getting any worse.

However, that approach uses data on the absolute level of noise in an area that does not align with the noise data mapped at a network level (number of dwellings or people affected). It would be relevant at a scheme level approach but not as a trigger for maintenance at a strategic level simply because road authorities do not have that data at that level of detail for their network.

In order to align with both the metrics collected under the EU Noise Directive and the WebTAG guidance on costing it is proposed to use a measure around the number of affected dwellings. This allows noise treatments to be generated when the numbers of dwellings over a set noise level exceeds a threshold.

Analysis of the noise data set showed that approximately 50% of counties did not have any dwellings that experienced noise above 75 dB, but all counties had some dwellings that experienced noise in the 70-75 dB band. Therefore, the parameter chosen to trigger noise is the number of dwellings per km experiencing noise above

70 dB. This meant that all counties can theoretically be included in analyses to trigger noise treatments. However, it has been noted by the World Health Organisation (2011) that noise levels lower than this can cause adverse health impacts and so a road authority may wish to tailor this trigger value to suit their own policies and recommendations.

A noticeable difference in noise (and tolerance by residents) is expected between urban and rural locations and therefore different thresholds can be set for city and county local authority networks (see Figure 6-7).

This noise trigger rule is incorporated into the model along with all other maintenance triggers. Any section of the road network that does not trigger maintenance due to surface condition defects can potentially trigger a noise treatment if it has noise data that is above the noise threshold.

Maintenance Thresholds		
	Investigation Level	Do Minimum
Longitudinal Profile	7	<input type="checkbox"/>
Rutting (mm)	16	<input checked="" type="checkbox"/>
Texture (mm)	0.8	<input type="checkbox"/>
SCRIM	0	<input checked="" type="checkbox"/>
Structural	5	<input type="checkbox"/>
Noise (dwellings > 70 dB per km)		
City	15	<input checked="" type="checkbox"/>
County	5	<input checked="" type="checkbox"/>

Treatment Reset Values	
Longitudinal Profile	0.8
Rutting (mm)	0.5
Texture (mm)	2
SCRIM	0
Structural	99

Buttons: Open, Save, Cancel

Figure 6-7: Example of noise thresholds incorporated alongside pavement condition thresholds

6.3.3 Calculating benefits

6.3.3.1 Noise methodology implementation in the model

The noise methodology is used to calculate the benefits or costs of 'noise' for each maintenance option, regardless of why the scheme was triggered.

The modelling methodology implemented in the model to quantify and cost the noise changes over a treatment profile is documented in this section. It should be

noted that noise costs or benefits could be generated in any year of the treatment profile, not just the year(s) in which maintenance occurs. This is because noise profiles can vary in the years following a maintenance intervention. To truly account for the noise costs or benefits, noise levels need calculating for each year of the entire treatment evaluation period.

1. Determine the number of dwellings in each 5 dB band using the noise input data set (dwellings per km);
2. If the noise level is being deteriorated, deteriorate the noise level for each year until the first maintenance intervention;
3. For each intervention:
 - a. Determine the initial noise change, constant noise change and years until constant noise change values using the old and new pavement surfaces for this intervention;
 - b. Determine the number of dwellings that existed in each 5 dB band in the year prior to the maintenance intervention. This is used as the reference dwellings in the calculations for this maintenance intervention;
 - c. For each year in the treatment evaluation period:
 - i. Determine the in-year noise change based on either:
 1. If the year is less than the number of years until a constant change: linearly decrease the initial noise change to the constant noise change; or
 2. If the year is equal to or greater than the years until a constant change: apply the constant noise change;
 - ii. Using the reference dwellings and assuming that the dwellings are distributed evenly within each 5 dB band, calculate the

- change in the number of dwellings in each 5 dB band using the in-year noise change;
- iii. Apply the change in the number of dwellings in each 5 dB band to the reference dwellings to calculate the number of dwellings in each band at the end of the current year;
 - iv. For each noise band, calculate the costs or benefits by multiplying the change in the number of dwellings by the value of moving between the respective bands;
 - v. Sum the noise costs or benefits across each 5 dB band to calculate a total in-year cost or benefit;
4. Repeat step 3 for each new maintenance intervention within the treatment evaluation period;
 5. Apply discount rates to the noise costs through all years of the analysis to calculate the noise NPV. The user can specify a noise specific discount rate, although it is recommended that the standard Treasury Green Book values are used;
 6. Include the discounted noise cost in cost calculations as specified in the run configuration (i.e. whether noise costs should be treated as an agency or user cost).

An example of the noise implementation methodology is given in Appendix P.

6.3.3.2 Creating specific low-noise maintenance option

As shown in Table 6-8 each treatment type has four Do Something options, two of which have a low-noise element, the other two having standard noise. In the same manner as with carbon, this allows the model to investigate how the impacts from the Do Something treatment changes when there is a shift in the environmental characteristics of the scheme.

The data used to build the noise dataset and the noise change characteristics between different surfaces came from a variety of sources, but notably European funded projects that look at the effects across a wide range of data and surfaces. Even with the different noise characteristics derived, an additional measure is required in the model to reflect deterioration characteristics of these surfaces. For example, it has been generally accepted that a low-noise porous asphalt surface will have a shorter life than a thin surfacing (i.e. the benefits of the improved noise performance of porous asphalt are to be balanced by the higher cost of more frequent interventions). Because the condition parameters each have a single deterioration relationship applied there needs to be a deterioration factor that can be applied to different surface types to vary the rate of the deterioration by surface type also.

As with carbon, a noise deterioration factor is applied to the user specified condition deterioration rates, to reflect the change in performance (durability and life) that is expected for different noise surface types.

The shorter life experienced by the low-noise surfaces is documented by Nicholls et al. (2010) in which typical service lives of different pavements are compared. The expected life data for the selected surfaces used within this model is shown in Table 6-20.

Table 6-20: Expected life data

Surface Type	Expected Life (yrs)
Thin Surfacing (SMA)	10-16
Porous Asphalt	7-10
Surface Dressing	3-8

(source: Nicholls et al., 2010)

In order to replicate the difference in expected lives, a noise deterioration factor was set to enhance the normal rate of deterioration and mirror the results from Nicholls et al. (see Table 6-21), assuming a base surface of Thin Surfacing.

Table 6-21: Deterioration uplift factors to reflect changes in performance between standard- and low-noise surfaces

Surface Type	Deterioration Factor
Thin Surfacing (SMA)	1
Porous Asphalt	1.5
Surface Dressing	2

(source: authors research)

This set the low-noise surfaces to deteriorate at a rate 1.5 times greater than the standard noise options (SMA) making the model capable of assessing the benefits of a low-noise surface against more frequent interventions. The model is therefore able to provide an assessment of how different whole-life value scenarios compare and what the impacts are for a network.

6.4 Linking all methodologies to stakeholder opinion

One of the key outputs from the consultations was how different groups of stakeholders can place different emphasis on what were termed the 'core cost elements', namely:

- Works costs;
- Delays to road users;
- Embodied carbon; and
- Noise surface impacts from maintenance.

This was brought out of the consultations through individual discussions and exercises (e.g. the pairwise comparison exercise in the focus groups).

Therefore, as well as giving a user of the model the ability to exclude the carbon and noise methodologies in order to compare with the 'standard' model approach, a modelling opportunity was developed whereby a user could also apply weightings to the different cost elements to investigate placing different priorities on the

calculated costs and benefits and allowing their contribution to the overall economic calculations to test the sensitivity of the costs.

This ensures that the discussions around demonstrating different benefits and the weighting exercises from the consultations can be built upon to have direct influence in how the model operates.

The model is developed to calculate the costs for each element but if the user chooses, those costs are weighted so that economic indicators, and subsequently prioritisation, are based on a weighted representation of the costs⁴³.

6.5 Summary

This chapter has documented the methodologies that have been created for modelling the impacts of carbon and noise from maintenance. The novelty in both the carbon and noise methods is from the ability to model the carbon quantities and costs and the noise costs alongside the other cost elements within the same analysis and include all costs together when prioritising and building a maintenance programme. Additionally, the carbon methodology presents opportunities for applying a carbon cap to a strategic maintenance programme. The noise methodology uses noise mapping data and noise surface change data together in a new approach making best use of current data for including noise impacts from maintenance in the prioritisation so some of the novelty also comes from the creation and use of new datasets.

As well as developing the methodologies themselves, an equal challenge was in creating realistic datasets for use in the model representing the best of the current data and knowledge available. This was a challenge because the methodologies (particularly for noise) pushed the current application of ideas into new areas of

⁴³ If the user chooses to use weighted costs in the model and there is a budget constraint setup for the run, the unweighted scheme costs are used to determine how much work can actually be undertaken against the given budget cap; but the priority of those schemes is based on their weighted economic calculations.

modelling and therefore there was not a straightforward 'off-the-shelf' dataset to use. Over the coming years it is hoped that the data available will grow as noise mapping becomes even more prevalent, especially with regards to getting a greater level of detail for noise mapping for individual lengths of a road, including how many properties are affected by those specific individual lengths.

In incorporating both methodologies into the existing model the modular design facilitated their inclusion in the base whole-life cost model. The resulting whole-life value model was subsequently transformed and the abilities of this model are demonstrated in the case studies in the following chapter.

Chapter 7 Model application to the Irish national network

This chapter describes the application of the pavement whole-life value model to the Irish national network using data specific to Ireland. The case studies reported in this chapter have been developed to demonstrate the use of the model (including impacts of alternative maintenance options with different levels of carbon and noise emissions) to develop pavement network maintenance strategies. This addresses the fourth key research objective of demonstrating the use of the developed methodologies through case studies and showing the capabilities of the whole-life value model.

The main objective of these case studies is to show the capabilities of this whole-life value model alongside the role and impact that environmental externalities can play in the development of a maintenance strategy. In order to achieve this two completely different types of networks were chosen to form the basis of the case studies, one being a route with good data coverage and the other being a regional network with limited data coverage.

7.1 Data

The case studies have been built up using data specific to the Irish national network. The reference data used in the model (e.g. unit rates, carbon quantities, noise costs) are all designed for use on the Irish network, as documented in the previous chapters.

The condition data was obtained from NRA in May 2013 and included data collected in surveys carried out in 2011 and 2012 for the parameters SCRIM, Longitudinal profile, rut depth and texture depth. This data covers the whole of the NRA network and the most recent values from the surveys have been used to represent the

network. Noise data was included from the noise datasets developed as part of this research.

The network definition (e.g. routes, lengths) and inventory information (e.g. carriageway width, surface type) had not changed from an earlier dataset provided at the beginning of the research and that data was therefore used as the source for all non-condition data:

- Route ID's;
- Route lengths and chainages;
- Counties;
- Carriageway type;
- Carriageway widths; and
- Surface Type.

In addition, the traffic data previously provided remained as the most current traffic dataset and was therefore retained for use in these case studies.

The model has an 'import data' process which is used to check, validate and collate all the data from the various separate condition and inventory surveys and data sources. The import process results in the road authority data being represented in the format required for this model. All of the imported data, both for condition and inventory, is held in the imported database of the model. The import process was checked to validate that it performed as expected and all data was transformed into the required model format using the most recent condition value for each chainage record.

7.2 Model capabilities

As a reminder from the previous two chapters, the main modelling processes describing how the model operates and its capabilities are summarised in this sub-section:

- The model allows users to set-up an analysis for any subset of the network (e.g. whole network, region or a route);
- Analyses can be configured (e.g. condition parameters, treatments) and run parameters (e.g. intervention thresholds, budgets) can be customised for each analysis;
- Data from different sources are aligned to common chainage intervals (for comparison of the different data sources and surveys);
- The model operates using two different time periods for analysis:
 - Programme period: the number of years for which a maintenance programme is being developed;
 - Treatment evaluation period: a longer evaluation period over which each identified treatment and option in the programme period is assessed to understand when future interventions are required (i.e. determining the whole-life implications for each identified treatment);
- For each year in the programme period the model:
 - Identifies pavement lengths requiring treatment (e.g. where the condition has exceeded treatment thresholds);
 - Simulates the future deterioration of these lengths; and
 - Determines the forward treatment profile over the selected treatment evaluation period.
- The identified treatment lengths can be short, depending on the coarseness or otherwise of the network and condition data. Very short lengths are not efficient to treat and so the model requires all identified treatment lengths to be built into potential schemes, using criteria such as allowing treatment lengths to merge if they are within a specified distance of each other;

- Schemes are created by appropriately joining up the lengths needing treatment. This may mean some lengths remain untreated until they are long enough to be schemes themselves or merge with other schemes;
- At the end of each year in the programme period the schemes can be compared using both their initial year costs and their whole-life costs. These comparisons, and related economic calculations, are used to create a prioritised scheme list;
- The prioritised list of schemes is used to decide which schemes get selected based on any constraints imposed on the analysis (e.g. treating certain road types first, or working under budget caps);
- The effects for any selected schemes (i.e. resetting condition data to a good condition) and ageing of any data not treated in schemes is undertaken in the workspace before the analysis moves onto the next year in the programme period;
- The output from the analysis is a database of:
 - Projected condition data;
 - Identified lengths for treatments and the treatments;
 - Selected schemes;
 - Treatment effects; and
 - Cost (of works, user delays, carbon and noise).

7.3 Comparison of modelling scenarios

The whole-life value model can be used to analyse different outputs with scenarios by using different combinations of parameters in order to represent different options for the maintenance that could be undertaken. The impacts that are analysed in the final whole-life value model are:

- Works;

- Maintenance delays to users;
- Embodied carbon of the maintenance (i.e. machinery, transport & materials); and
- Noise (from the road surface).

All impacts are commonly expressed in cost terms and are calculated over the lifetime of both the programme period and treatment evaluation period and present an opportunity to combine and evaluate the different costs and benefits together to more widely assess the economic impact of different treatment options in developing a maintenance strategy or programme.

As discussed in the literature review, maintenance has previously been prioritised on a worse-first basis, therefore giving little or no consideration to the longer-term implications of any maintenance undertaken. As knowledge and modelling developed it was realised that diverting funds to roads before they deteriorate fully can lead to better overall results because it results in more holding treatments being able to be carried out than if the same money was spent on more expensive reconstructions for the roads that were in poor condition. Although, this can change depending on the network and data being analysed, whole-life costing was a method to demonstrate the resultant impacts of this longer term, more cost effective vision.

This model adopts a new approach and considers more than just the traditional costs, providing a practical methodology to include assessments of the impacts of wider externalities alongside the costs of the works and delays to users.

By selecting different cost parameters it gives a different emphasis to the analysis being undertaken and varying the analysis configuration in this manner effectively allows different highway authority policies to be investigated (see Table 7-1). Building up a picture of the impacts and sensitivities from the different scenarios, or policies, provides significant support (and justification) for the maintenance strategy decision making.

Table 7-1: Cost parameters and links to example policies

Cost Parameter	Example policies
Works	<ol style="list-style-type: none"> 1. Undertaking the maintenance intended to maintain the network at a minimum safety level. 2. Developing a programme of works under a constrained budget.
Delays	<ol style="list-style-type: none"> 1. Minimise (the cost of) disruption to road users from maintenance.
Carbon	<ol style="list-style-type: none"> 1. Reducing the amount of embodied carbon used in maintenance activities (i.e. materials, transport, machinery) to achieve emission targets.
Noise	<ol style="list-style-type: none"> 1. Ensuring a certain proportion of the network has a low-noise surface. 2. Reducing the noise experienced on key routes or locations. 3. Making sure noise levels do not increase across the network.

(source: authors research)

Analyses that use a combination of works and delay costs are the types of analyses that most road authorities currently use when modelling networks. The representation of delay costs in an analysis shows that the lowest whole-life cost schemes are derived from a combination of the actual treatment and the disruption experienced by road users.

When other cost parameters are introduced into the analysis (such as carbon and noise) it allows for extended policies to be investigated and their impact assessed. A road authority has a primary requirement to keep their network in a safe condition but they might want to know what the additional cost would be if they also addressed any noise issues alongside the safety-based maintenance. Those are the types of questions that this model can be used to explore through analysis of different scenarios.

In addition to testing wider environmental policies within the pavement model, future potential policies or road authority and government objectives can be trialled to see any likely effects that they may have on the management of the network in advance of deciding when and where they should be implemented.

A network for analysis can vary from a whole network, a region, road or individual lengths. A region might be used to analyse the budgetary impacts on government delineated areas or a single road might be used to model a strategic route, for example a road between two key ports or planning infrastructure investment and maintenance on a key route for a one-off event such as an Olympics or World Cup. The reasons for the analysis will also influence the programme period chosen. For example, an analysis of a government area would likely be over multiple years to align with funding cycles compared with a single strategic route analysis which would likely have a shorter term strategy to address more immediate concerns, such as only a single year.

7.4 Developing a maintenance strategy for a route

The first case study is based on using different scenarios to investigate alternative maintenance programmes for a single road, the N4. The N4 runs from Dublin in the east to Sligo in the west (see Figure 7-1 and Figure 7-2) and is the longest national primary route at approximately 207 km. The standard of the road varies significantly along its length and includes a tolled motorway section near Dublin and

single-carriageway sections either side of Longford, almost halfway along the route (see Table 7-2).

This was picked for the first case study primarily because of the length of the route and the diversity of data along the route; there is a mix of road types along the length of the N4 as well as good data coverage and variation in the data (for example, traffic flows and condition). This provides the opportunity to demonstrate not only the capabilities of the model but also the application of the model to a strategic route on the network.

The variation associated with this strategic corridor is further reflected in the inventory and condition data in the following figures:

- Figure 7-3: a representation of the change in counties along the route, aligned with the condition data graphs;
- Figure 7-4: a graph showing the traffic levels along the N4 (two-way AADT);
- Figure 7-5: a graph showing the measured rut depth in mm (in blue) and the homogenised data used in the analysis (in red) as a result of the model homogenisation routine;
- Figure 7-6: a graph showing the measured longitudinal profile variance (in blue) and the homogenised data used in the analysis (in red);
- Figure 7-7: a graph showing the measured texture depth (in blue) and the homogenised data used in the analysis (in red);
- Figure 7-8: a graph showing the difference between the SCRIM measurement and the investigation level (in blue) and the homogenised data used in the analysis (in red);
- Figure 7-9: a graph showing the mapped number of dwellings exceeding 70 dB (in blue) and the homogenised data used in the analysis (in red). NB: the blue line cannot be seen in the image due to the homogenised data being exactly the same as the raw data and the red line is on top.

It can be noted in Figure 7-7 and Figure 7-8 that the texture and SCRIM homogenisation output appears less homogenised than for the other condition parameters. The reason for this is due to the greater variability of the measured condition data for both texture and SCRIM respectively. When applying the same homogenisation module, the resultant lengths are much shorter and have greater variability, reflecting the characteristics of the source data.

It should also be noted that in all condition data graphs (Figure 7-5 to Figure 7-8) the red homogenised line tends to zero at approximately 200km due to no actual measured data beyond that point for the rest of the road, and therefore no data is available to homogenised against. In the actual running of the model, those data values are not permitted to drive any maintenance treatments.





Figure 7-1: N4 location in Ireland (source: Google Maps, 2015a)

169.823	191.932	Kilda	Motorway
191.932	192.336	Kilda	Dual
192.336	197.971	South Dublin	Dual
197.971	201.704	South Dublin	Dual
201.704	207.337	Dublin	Dual

(source: NRA data)

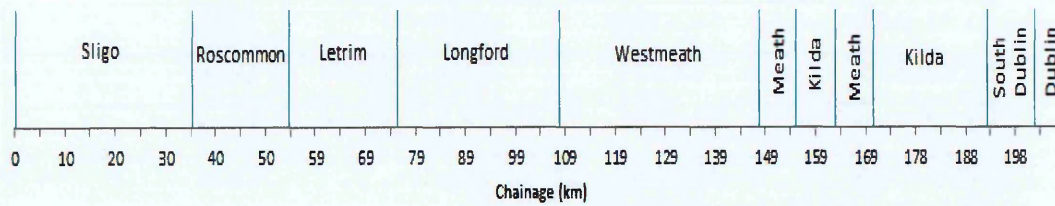


Figure 7-3: Counties along the route of the N4 (aligned with Figure 7-4 to Figure 7-9)

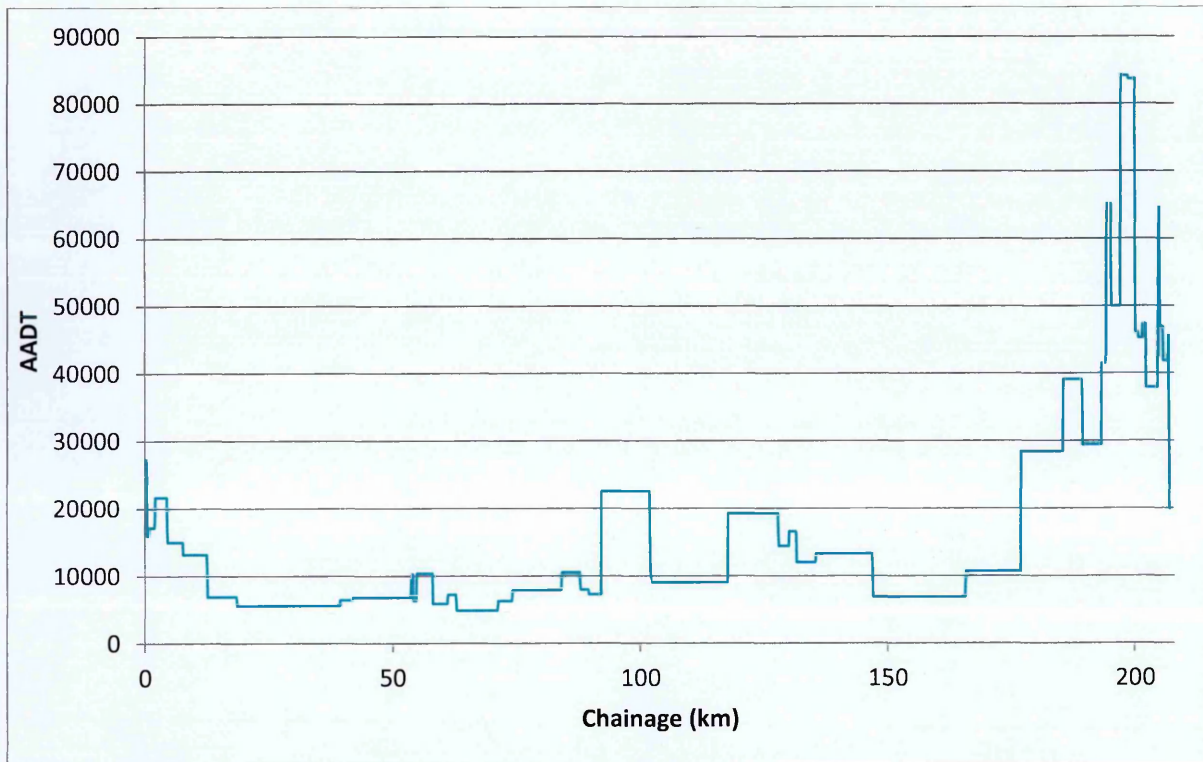


Figure 7-4: N4 traffic (all charts start with Sligo at 0 km chainage)

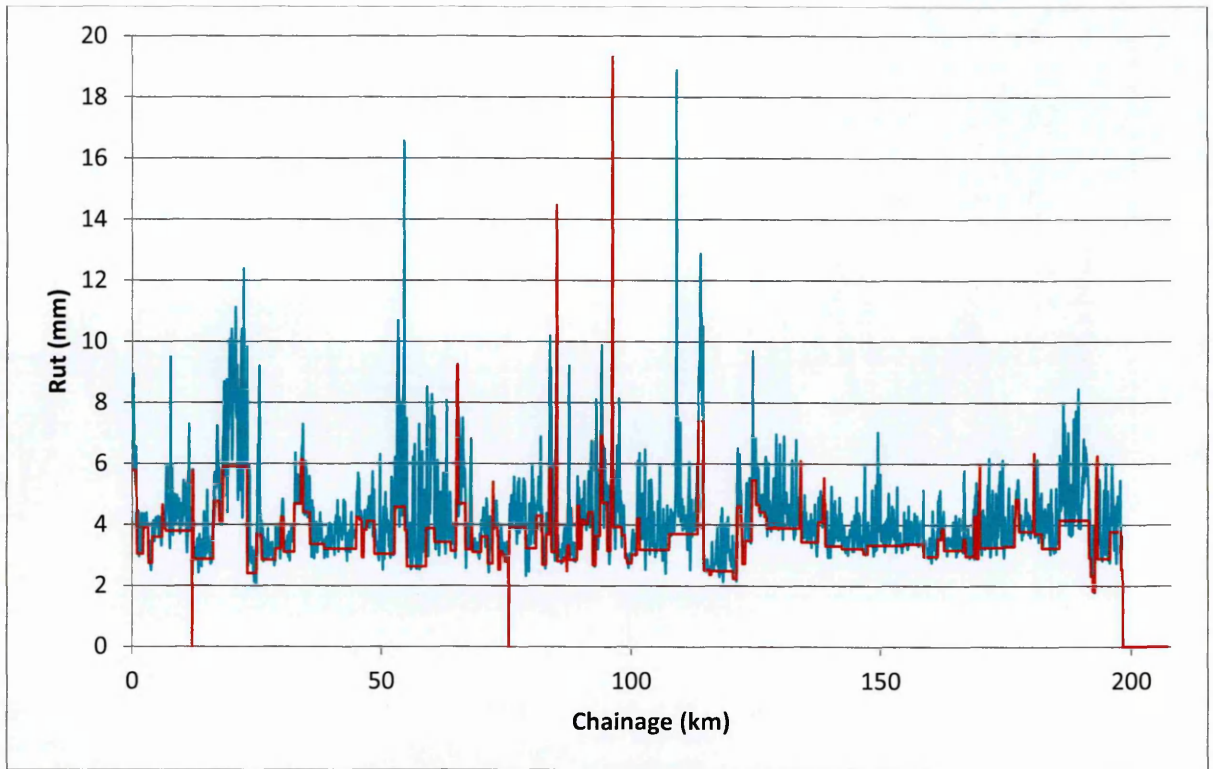


Figure 7-5: N4 rut depth (for the condition parameters, the blue line represents the individual data records, whilst the red line represents the homogenised data)

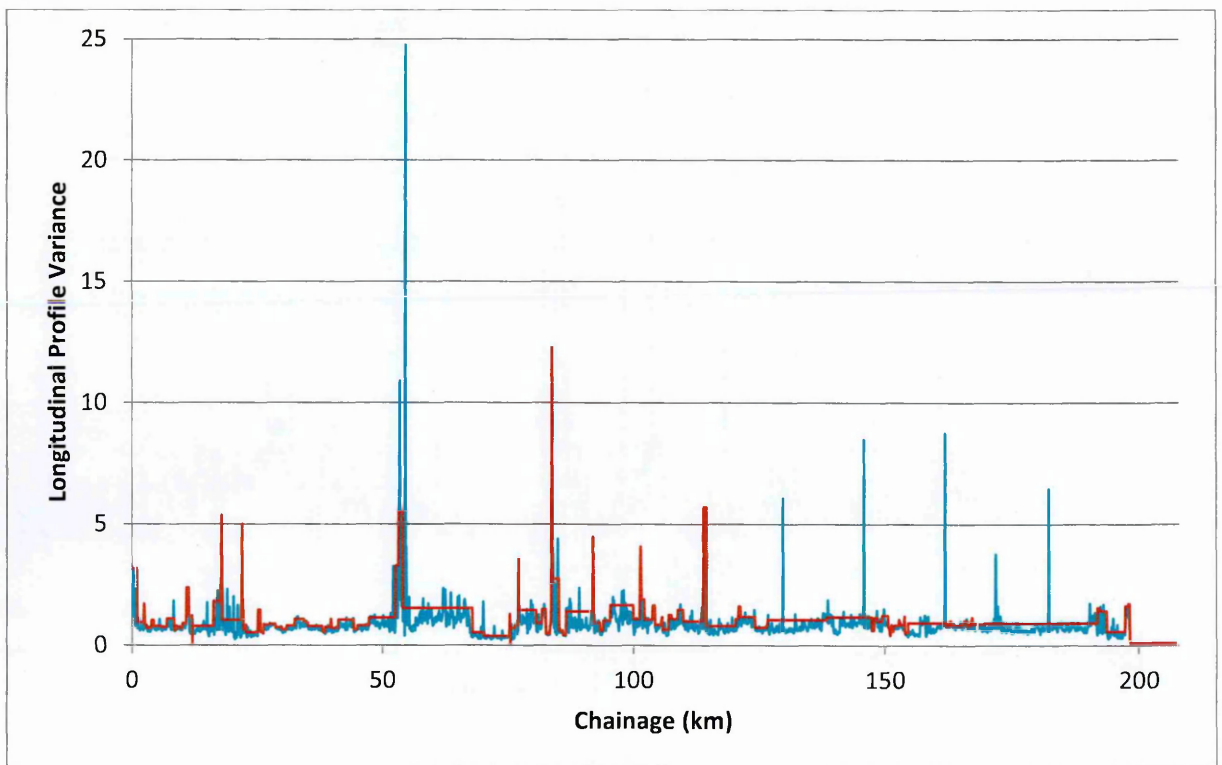


Figure 7-6: N4 longitudinal profile variance

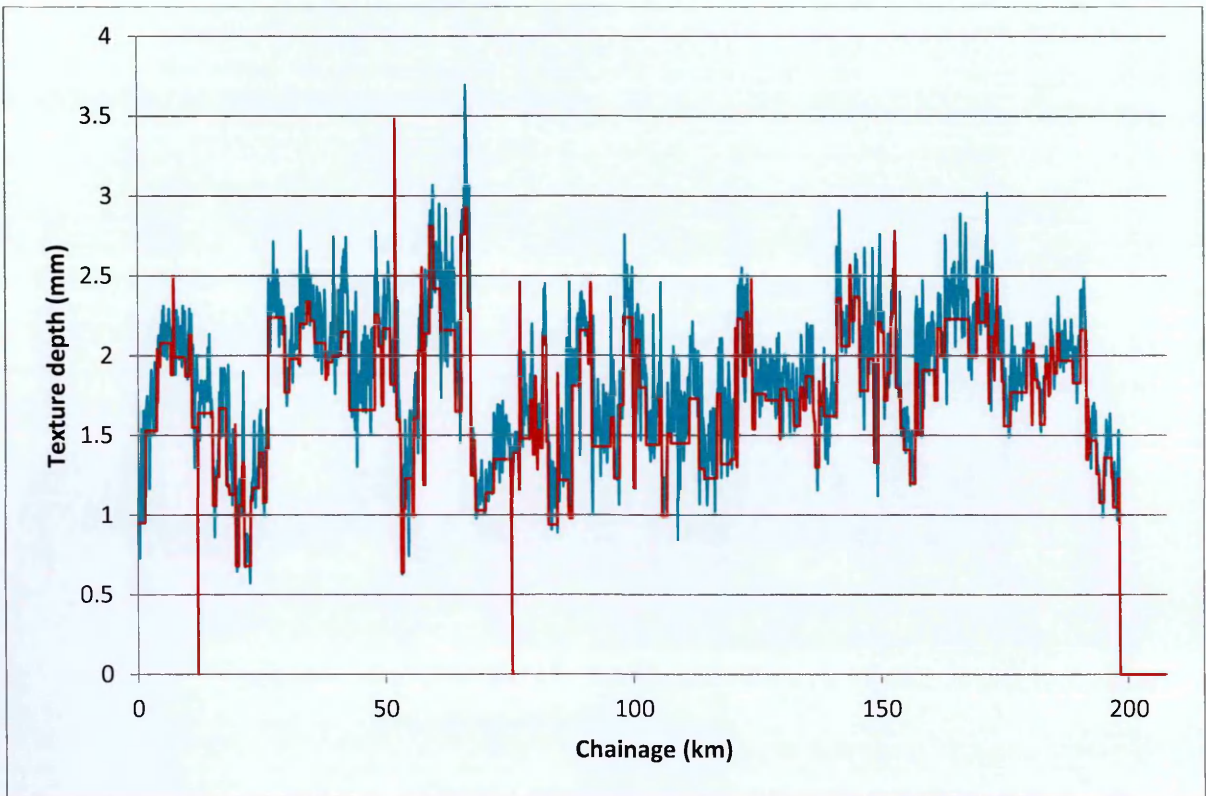


Figure 7-7: N4 texture

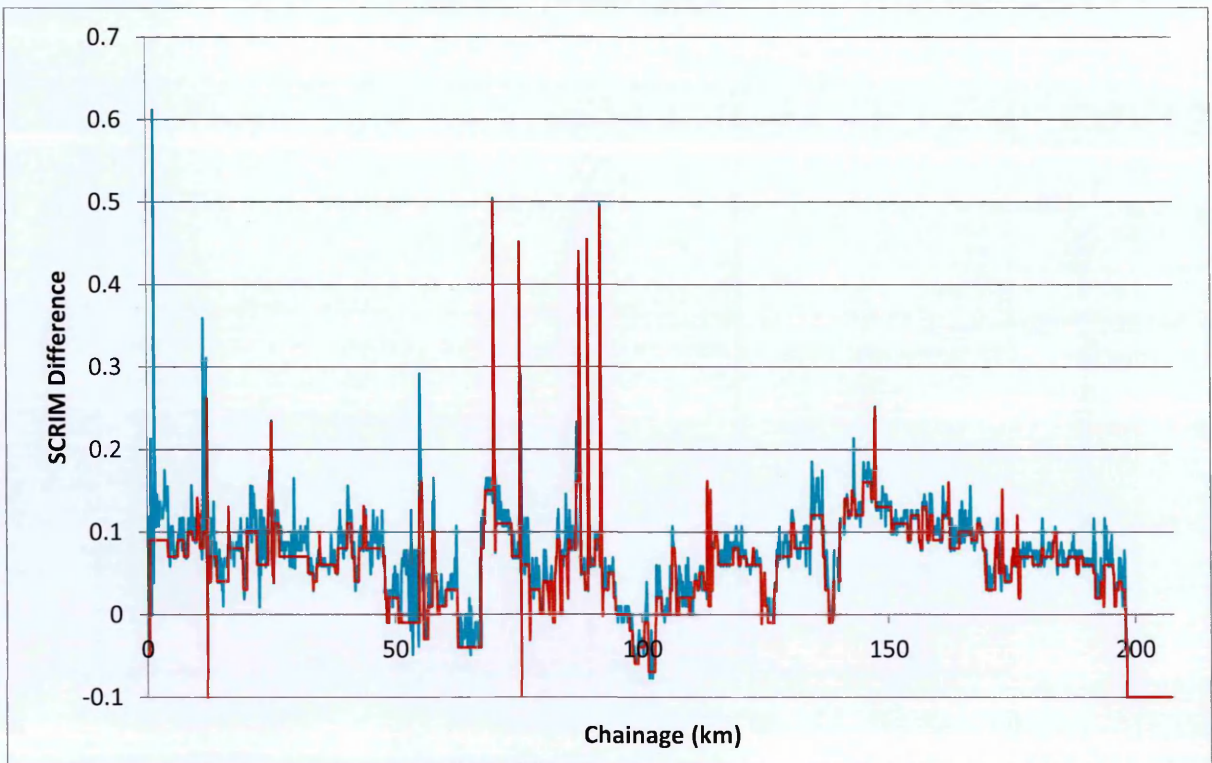


Figure 7-8: N4 SCRIM

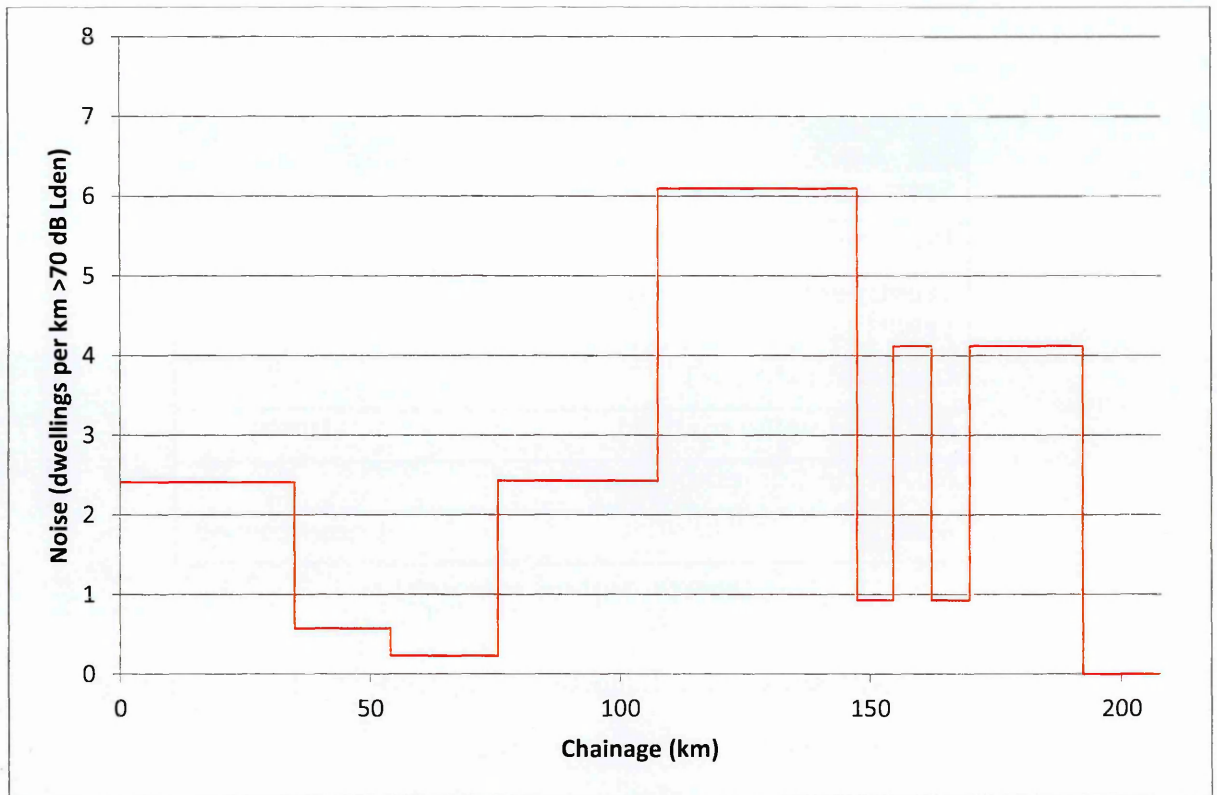


Figure 7-9: N4 noise

The traffic level sharply increases as the N4 approaches and enters Dublin (around chainage 190km). The peak in traffic levels is found where the N4 intersects with the M50 (the motorway around Dublin). The low traffic levels along the majority of the route (less than 10,000 AADT) are primarily where the road is currently constructed as a single carriageway, reflecting the lower demands placed on those sections of the route.

The condition graphs reflect the varying condition along the route. It is the homogenised condition data (designed to reflect grouped lengths of condition) that are used by the model to generate the maintenance schemes.

The noise data shows the noise levels along the route generated from the different noise maps at a county level. The greatest number of dwellings affected by noise over 70 dB (from 107.580 to 147.440 km) are in Westmeath County, with the lowest levels (from 54.042 km to 75.509 km) in Leitrim.

7.4.1 Analysis setup

Table 7-3 shows the setup for the N4 case study.

Table 7-3: N4 analysis setup

Parameter	Value
Start year	2013
Programme period (year(s))	1
Treatment evaluation period (year(s))	30
Discount rate (%)	3.5
Residual value method	Linear
No. of Do Something options	1
Budget	Unconstrained

(source: authors research)

There were no constraints (e.g. budgetary) imposed on the analysis, thereby simulating an unconstrained maintenance budget.

7.4.2 Works costs only

The first analysis created a maintenance programme where only the works costs were used in creating the total scheme cost. For every scheme identified the model could potentially choose from either a Do Minimum (or Do Nothing) or a Do Something maintenance option, prioritised by an economic indicator based on the works costs and user delays costs. The summary outputs from the analysis were:

- Identified schemes: 33 (see Table 7-4);
- Selected schemes: 16;
- Number of selected Do Minimum schemes: 14 out of 16;
- Length of selected schemes: 27.1km.

Table 7-4: Scheme lengths identified and selected

Scheme No	Direction⁴⁴	Do Something Start Chainage⁴⁵ (km)	Do Something End Chainage⁴⁵ (km)	Do Something Scheme Length (km)	Treatment Option Selected⁴⁶	Selected Year 1 Treatment Length (km)
1	EB	0	0.5	0.5	DM	0.5
2	EB	19.7	20.4	0.7	-	-
3	EB	21.5	22.8	1.3	DS	1.3
4	EB	48.3	48.8	0.5	-	-
5	EB	50.7	54.042	2.942	DS	2.942
6	EB	54.042	55	0.958	-	-
7	EB	55.8	56.7	0.9	-	-
8	EB	62.7	67.4	4.7	-	-
9	EB	81.9	82.4	0.5	-	-
10	EB	97.5	102.9	5.4	DM	2.6
11	EB	125.5	126.74	1.24	-	-
12	EB	137.9	138.575	0.675	-	-
13	WB	5.2	6.2	1	-	-
14	WB	31.5	32.543	1.043	-	-
15	WB	64.2	67.8	3.6	-	-
16	WB	78.1	79.8	1.7	DM	1.1
17	WB	82.7	83.6	0.9	-	-
18	WB	88.9	90.7	1.8	DM	1.7
19	WB	92.1	92.7	0.6	-	-
20	WB	93.4	100.4	6	DM	0.8
21	WB	101	107.57	6.57	DM	4.9
22	WB	107.57	112.3	4.73	-	-
23	WB	114.5	115	0.5	DM	0.5
24	WB	117.3	125	7.7	DM	4.2
25	WB	126.1	126.741	0.641	DM	0.641
26	WB	136.4	138.462	2.062	-	-
27	WB	138.462	141.7	3.238	DM	0.638

⁴⁴ EB = Eastbound; WB = Westbound.

⁴⁵ The chainages on opposite carriageways align with each other (i.e. 5km on the EB is in the same physical location as 5km on the WB carriageway).

⁴⁶ DS = Do Something; DM = Do Minimum.

Scheme No	Direction ⁴⁴	Do Something Start Chainage ⁴⁵ (km)	Do Something End Chainage ⁴⁵ (km)	Do Something Scheme Length (km)	Treatment Option Selected ⁴⁶	Selected Year 1 Treatment Length (km)
28	WB	145.6	147.457	1.357	DM	0.157
29	WB	147.457	151	3.543	DM	2.1
30	WB	152.7	154.631	1.931	-	-
31	WB	181.1	183.9	2.5	-	-
32	WB	191.883	192.6	0.717	DM	0.717
33	WB	201.567	203.9	2.333	DM	2.333

(source: authors research)

In the analysis all Do Minimum schemes that had an identified treatment in their first year were selected (i.e. those with a cost in the first year, as opposed to just a 'Do Nothing' where no condition parameter was above the respective Do Minimum thresholds in year one). Those were selected to address the requirement for keeping the network in a safe condition and they were all selected because there was no budget constraint.

For all remaining Do Something schemes⁴⁷ (i.e. all 33 schemes) the Do Something option was checked to see if it:

1. Was above a set economic indicator⁴⁸; and
2. Gave a cost saving for the whole-life period compared to the Do Minimum.

When running a scenario that has a budget constraint there is an additional third criteria that is also applied (although this was not applied in this case study due to no budget constraint being imposed):

⁴⁷ The model does have the option of forcing specific Do Something schemes to be selected before considering the Do Minimums (e.g. if maintenance has already been funded for a particular scheme). However this functionality was not used in this case study.

⁴⁸ The economic indicator was set at -10 to still allow Do Something schemes to be considered that did not offer an immediate direct economic benefit.

3. Check that the Do Something option remains under any budget cap if the Do Something had a greater first year cost than the Do Minimum.

If all three of the above criteria were met then the Do Something scheme would be included in the programme (with the respective Do Minimum being removed if it had been previously selected). This happened for schemes 3 and 5 in this analysis, with the economic indicators being 0.09 and 0.26 respectively and the cost savings over the whole-life period being €3,768 and €42,864 respectively. No other Do Something schemes were substituted in place of their Do Minimum option because (irrespective of the economic indicator) no other Do Something offered a whole-life cost saving compared to the Do Minimum (see section 5.3.7.1 for the summary of the budget prioritisation process).

The resulting cost outputs for the whole programme are shown in Table 7-5.

Table 7-5: Cost outputs using only works costs

	Works Costs (€k)	Total Agency Costs (€k)
Year 1	1,409	1,409
Year 1 (scheme min⁴⁹)	17	17
Year 1 (scheme max⁵⁰)	197	197
Year 1 (avg per scheme⁵¹)	88	88
Year 1 (avg per km⁵²)	52	52
All years Whole Life Cost (WLC)	5,737	5,737
All years WLC (scheme min)	37	37
All years WLC (scheme max)	875	875
All years WLC (avg per scheme)	358	358
All years WLC (avg per km)	212	212

(source: authors research)

⁴⁹ The minimum scheme cost from all selected schemes

⁵⁰ The maximum scheme cost from all selected schemes

⁵¹ The average scheme cost per scheme for all selected schemes

⁵² The average scheme cost per kilometre for all selected schemes

At the end of the programme period of the analysis (i.e. after one year) the resultant percentages of the lengths in different threshold categories is shown in Table 7-6.

Table 7-6: Condition outputs from works costs only analysis

Condition Category	Percentage of network (%)
Length not exceeding threshold for any condition parameter	87.5
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	12.4
Length exceeding Do Minimum thresholds for any condition parameter	0.1

(source: authors research)

If the policy of the road authority is to keep the network in a safe condition (against the Do Minimum thresholds) whilst using their funds as economically efficiently as possible (assessing cost savings over the whole-life period) then the model predicted maintenance programme could be used to support a funding request for this route.

However, if as in past times the maintenance policy targeted minimising spend in the current year (year one of the analysis) regardless of future implications then the two Do Something schemes (no's 3 and 5) would not have been selected and neither would their respective Do Minimum's because they have a zero cost in year one (i.e. there were no immediate safety needs to address). However, this would have resulted in a less efficient spend overall when looking over the whole-life cost period.

7.4.2.1 *Prioritised scheme order*

When schemes are being selected the model analyses the list of schemes in a prioritised order (see section 5.3.7). The prioritisation orders the Do Minimum

schemes by their year 1 costs and orders the Do Something schemes by their economic indicator.

Ordering the Do Minimums by cost gets the most return from any budget by committing to the largest costs first. If there are not enough funds left for a particular scheme the model will pass that scheme and move to the next one (and so on) until it finds one within the remaining budget. This is repeated until either there are no more schemes left or the model has used up the entire budget.

The Do Something schemes are prioritised by their economic indicator, a measure of the economic benefit of the scheme related to the savings the scheme offers (or not) compared to the associated Do Minimum. The prioritised order of the selected schemes is shown in Table 7-7.

Table 7-7: Prioritised order of selected schemes

Prioritised Order	Scheme No	Treatment Option	Year 1 Works Cost (£k)	Cumulative Year 1 Works Cost (£k)
1	29	DM	197	197
2	33	DM	189	386
3	21	DM	182	568
4	24	DM	165	732
5	10	DM	106	838
6	18	DM	77	916
7	27	DM	60	975
8	32	DM	58	1,033
9	16	DM	41	1,075
10	1	DM	35	1,109
11	25	DM	30	1,140
12	20	DM	30	1,169
13	23	DM	18	1,188
14	28	DM	17	1,205
15	5	DS	164	1,369
16	3	DS	40	1,409

(source: authors research)

In this example case study there were no budget constraints. However, if the analysis was subject to budget constraints the cumulative costs of the schemes would have been used to determine the selected schemes. Suppose there was a budget cap of €1M. Schemes up to and including the 7th ranked scheme would have been selected, initially leaving €25k in the budget. The model could not have committed to the next scheme because the next scheme was €58k. The prioritisation process would have worked down the list until it reached the first scheme under the remaining €25k which was scheme 23 (the 13th ranked scheme). With just €7k remaining after scheme 23 was selected no more schemes could be selected and so only 8 schemes would have been selected under a budget cap of €1M.

With only those 8 Do Minimum schemes selected this example would have left even some of the Do Minimum schemes unfunded. Those unselected Do Minimum sections of the network would be under the minimum level of safety and a road authority might have to make difficult choices such as to borrow money from other budgets or take more drastic action, such as closing a lane or a road due to the safety risk of accidents. Although this is a fictional budget cap it shows one of the strengths of the model in how it can be used to give a road authority valuable information on the future potential effects of different budget levels.

7.4.3 Works and delay costs

This analysis was setup to prioritise the maintenance schemes using delay costs in addition to works costs. The summary outputs were identical when compared to the previous analysis using only works costs:

- Identified schemes: 33;
- Selected schemes: 16;
- Number of selected Do Minimum schemes: 14 out of 16;
- Length of selected schemes: 27.1km.

Although the selected schemes (and therefore the works costs) were identical, the resulting total agency costs were marginally increased due to the addition of the user delay costs in the overall calculations (see Table 7-8).

Table 7-8: Cost outputs using works and delay costs

	Works Costs (€k)	User Delay Cost from Maintenance (€k)	Total Agency Costs (€k)
Year 1	1,409	40	1,449
Year 1 (scheme min)	17	0	17
Year 1 (scheme max)	197	2	199
Year 1 (avg per scheme)	88	3	91
Year 1 (per km)	52	1	53
All years WLC	5,737	187	5,925
All years WLC (scheme min)	37	1	38
All years WLC (scheme max)	875	30	905
All years WLC (avg per scheme)	358	12	370
All years WLC (per km)	212	7	218

(source: authors research)

The works costs (see Table 7-8) are over 95% of the total agency costs, demonstrating the marginal impact that delay costs had in this analysis and the reason why the addition of delay costs had no impact on the resulting maintenance programme. For a road agency this has the effect of being able to say that the inclusion of user delays results in no change to the maintenance programme, although this might change for different trafficked networks.

Referring back to the traffic data (see Figure 7-4) the AADT is under 20,000 for the majority of the route. In this analysis, no schemes were identified where traffic levels were greater than 30,000 AADT.

Therefore, at the end of the programme period of the analysis (i.e. after one year) the resultant percentages of the lengths in different threshold categories were no different from the analysis with only works costs (see Table 7-9 and Table 7-6).

Table 7-9: Condition outputs from works and delay costs analysis

Condition Category	Percentage of network (%)
Length not exceeding threshold for any condition parameter	87.5
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	12.4
Length exceeding Do Minimum thresholds for any condition parameter	0.1

(source: authors research)

7.4.4 Works, delay and carbon costs

This analysis is based on the same principles as the previous two analyses (i.e. choosing between a Do Minimum and the one standard Do Something as the only viable options) except that carbon costs are included alongside the works and delay costs, all of which are subsequently used in the economic indicator calculations and the prioritisation of the schemes.

The summary outputs were:

- Identified schemes: 33;
- Selected schemes: 16;
- Number of selected Do Minimum schemes: 14 out of 16;
- Length of selected schemes: 25.9km.

All the selected schemes also came from the same 33 identified schemes as in the initial analysis. Introducing carbon would not be expected to introduce any additional schemes because carbon is a reporting only function of the model, and not a maintenance driver. The cost outputs are shown in see Table 7-10.

Table 7-10: Cost outputs from analysis including carbon costs

	Works Costs (€k)	Delay Costs (€k)	Carbon Costs (€k)	Total Agency Costs (€k)
Year 1	1,364	36	18	1,417
Year 1 (scheme min)	17	0	1	18
Year 1 (scheme max)	197	2	6	205
Year 1 (avg per scheme)	85	2	1	89
Year 1 (per km)	53	1	1	55
All years WLC	5,436	164	222	5,821
All years WLC (scheme min)	37	1	2	40
All years WLC (scheme max)	875	30	37	942
All years WLC (avg per scheme)	340	10	14	364
All years WLC (per km)	210	6	9	225

(source: authors research)

With carbon costs included in the model calculations it was possible to report that the carbon quantity for the maintenance in year 1 was 292 t CO₂e⁵³ and over the whole analysis period it was 4,398 t CO₂e. The year 1 value of 292 t CO₂e equates to approximately 0.002% of the annual transport total.

A study by the Asian Development Bank (ADB) looked at methods for estimating the carbon footprint associated with road projects for construction, operation and maintenance (Asian Development Bank, 2010). For the maintenance phase, which calculated carbon using the same categories as the methodology in this model (i.e. embodied carbon from materials, material transport and on-site emissions from construction machinery) the four sample projects ranged from 2.71 t CO₂ per km for a rural road to 17.73 t CO₂ per km for a state highway.

Averaging the carbon emissions from maintenance in this analysis of the N4 in Ireland produced approximately 11 t CO₂e per km which fell within the recorded

⁵³ This is in context of a reported 2008 gross emissions value of 67.680 Mt CO₂e for Ireland, with transport contributing 14.208 Mt CO₂e of that total (Gormley, 2010).

range from the ADB study and aligned closely with results from the ADB national network sample project of 11.14 t CO₂ per km (although the CO₂e includes a greater number of GHGs, not solely carbon).

In this analysis, the year1 carbon costs contributed a lower proportion than the delay costs, although when looking across all years of the analysis the carbon costs summed to be greater than the contribution of the delay costs, but still a very small proportion of the total costs (delay and carbon costs were each approximately 3-4% of the total costs).

The resultant condition threshold categories were slightly different from the previous analyses (see Table 7-11 and Table 7-6). The small reduction in maintenance has resulted in a related increase in the amount of network in poor condition at the end of year 1.

Table 7-11: Condition outputs from works, delay and carbon costs analysis

Condition Category	Percentage of network (%)
Length not exceeding threshold for any condition parameter	87.1
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	12.6
Length exceeding Do Minimum thresholds for any condition parameter	0.3

(source: authors research)

The relative impact of introducing embodied carbon costs as a reporting mechanism of the schemes was negligible and the total impact on the overall maintenance programme was that it remained unchanged and the condition of the network at the end of the year 1 had deteriorated slightly (although the actual increase in the length exceeding the Do Minimum thresholds for any condition parameters had increased by 300% from 0.1% to 0.3%) .

7.4.5 Works, delay and noise costs

This analysis is based on the same principles as the previous analyses except that noise costs are included alongside the works and delay costs, all of which are used in the economic indicator calculations and the prioritisation of the schemes.

The summary outputs were:

- Identified schemes: 33;
- Selected schemes: 13;
- Number of selected Do Minimum schemes: 12 out of 13;
- Length of selected schemes: 25.8km.

All the selected schemes came from the same 33 identified schemes as in the initial analysis. Of the 13 schemes selected when noise costs were added (as an agency cost) alongside works and delays, 10 were exactly the same as schemes without noise costs. The other 3 schemes had grown in their extents when noise costs were added but the lengths treated in year 1 had not increased significantly. For example, with noise costs included 5 of the previous schemes (from the initial analysis using the base model) were merged into 3 larger schemes, effectively replacing a larger number of shorter schemes with fewer larger schemes, but not adding maintenance in year 1 for the additional scheme lengths.

The cost outputs are shown in Table 7-12.

Table 7-12: Cost outputs from analysis including noise costs

	Works Costs (€k)	Delay Costs (€k)	Noise Costs (€k)	Total Agency Costs (€k)
Year 1	1,365	32	79	1,476
Year 1 (scheme min)	28	0	3	31
Year 1 (scheme max)	182	7	19	208
Year 1 (avg per scheme)	105	2	6	113
Year 1 (per km)	53	1	3	57
All years WLC	6,867	157	-2,185	4,839
All years WLC (scheme min)	71	0	-16	55
All years WLC (scheme max)	734	34	-49	718
All years WLC (avg per scheme)	528	12	-168	372
All years WLC (per km)	266	6	-85	187

(source: authors research)

For all schemes, the inclusion of noise adds costs to the year 1 costs (i.e. the selected schemes generate a cost for noise in year 1 and not a benefit). Where a new surface is laid the noise benefits do not outweigh the noise costs associated with the lengths that have no new surface (i.e. the parts of the Do Minimum schemes that are not treated in year 1 and therefore represent Do Nothing lengths).

However, when comparing the whole-life costs all but one scheme generated an overall total noise saving⁵⁴ and the noise savings were a significant proportion of the total scheme costs. Comparing these analyses, noise therefore had a greater effect on the total scheme costs than carbon. This is due however to the choice of monetised values used in the analyses and this was a potential limitation noted during the literature review of externalities. Whilst it is not easy to value some externalities the concept of valuing them in monetary terms provides a common platform for comparison, otherwise there is a risk they become separate mini-

⁵⁴ One scheme did not generate any noise costs because there was no noise data.

analyses that are not fully integrated. A sensitivity analysis of the monetised values of carbon and noise follows in section 7.4.7.2.

The resultant percentages of the lengths in different threshold categories were different from the previous analyses (see Table 7-13 and Table 7-6). There was a small increase in the good condition lengths as a result of adding noise.

Table 7-13: Condition outputs from works, delay and noise costs analysis

Condition Category	Percentage of network (%)
Length not exceeding threshold for any condition parameter	87.7
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	12.2
Length exceeding Do Minimum thresholds for any condition parameter	0.1

(source: authors research)

7.4.6 Works, delay, carbon and noise costs

This analysis is based on the same principles as the previous analyses (i.e. one Do Minimum and one standard Do Something option) except that both carbon and noise costs are included alongside the works and delay costs, all of which are subsequently used in the economic indicator calculations and the prioritisation of the schemes. Even though carbon and noise costs are included in this analysis, no additional Do Something options were included (i.e. there were no special Do Something options that offered environmental benefits, such as a low-noise surface).

The summary outputs were:

- Identified schemes: 33;
- Selected schemes: 13;
- Number of selected Do Minimum schemes: 12 out of 13;

- Length of selected schemes: 25.8km.

The selected schemes came from the same 33 identified schemes as in the previous analysis. The carbon quantity in year 1 was 287 t CO₂e, and over the whole analysis period it was 5,405 t CO₂e.

Of the three fewer schemes in this analysis (compared with the base 'works costs only' analysis) one of the dropped schemes was previously selected as a Do Something option in the base analysis but was not chosen in this analysis (scheme 3). For scheme 3, the addition of carbon had little effect on the overall economic indicator (being very similar between the Do Minimum and the Do Something) but noise costs led to much larger noise savings for the Do Minimum compared to the Do Something. When these savings were included in the overall economic indicator calculation it meant that the economic indicator which was previously positive (i.e. in favour of the Do Something) became negative (i.e. the Do Something did not offer any economic saving or benefit over the Do Minimum) because the Do Something cost more in year 1 and it didn't offer any savings over the whole-life cost period. The negative economic indicator meant that the Do Something was dropped and the Do Minimum for the same scheme was not selected either.

The cost outputs from this analysis are shown in Table 7-14.

Table 7-14: Cost outputs from analysis including carbon and noise costs

	Works Costs (€k)	Delay Costs (€k)	Carbon Costs (€k)	Noise Costs (€k)	Total Agency Costs (€k)
Year 1	1,364	32	18	79	1,493
Year 1 (scheme min)	28	0	0	3	31
Year 1 (scheme max)	182	7	1	19	209
Year 1 (avg per scheme)	105	2	1	6	115
Year 1 (per km)	53	1	1	3	58
All years WLC	6,867	157	285	-219	5,123
All years WLC (scheme min)	71	0	3	-16	58
All years WLC (scheme max)	734	34	30	-49	749
All years WLC (avg per scheme)	528	12	22	-168	394
All years WLC (per km)	266	6	11	-85	198

(source: authors research)

The resultant percentages of the lengths in different threshold categories were the same as the previous analysis, showing a slight improvement over the condition distribution from the first 'works costs only' analysis (see Table 7-15).

Table 7-15: Condition outputs from works, delay, carbon and noise costs analysis

Condition Category	Percentage of network (%)
Length not exceeding threshold for any condition parameter	87.7
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	12.2
Length exceeding Do Minimum thresholds for any condition parameter	0.1

(source: authors research)

The result of adding carbon and traffic noise emissions from maintenance into the analysis for the N4 was that 1.3 km less maintenance was selected in the first year of the analysis (compared with the initial 'works costs only' analysis). That slight

change however still resulted in the works costs per km in year 1 being consistently around €52-53k across this and all preceding analyses.

However, the works costs per km across all the years rose by over 25%, from €212k to €266k showing a significant upturn of maintenance works in subsequent years of the whole-life period. Conversely, the total agency costs fell from €218k per km to €198k across all years. So although there was considerably more works costs across all years of the 30 year treatment evaluation period (an extra €55k), the generated savings from the inclusion of the noise assessment led to considerable benefits in the overall agency costs when the overall assessment included the wider impacts.

In this analysis the total noise savings over the 30 year analysis period were just under €220k, representing approximately 3% of the total works costs.

What is interesting from the scale of costs is the higher costs (or savings) that carbon and noise exhibit over delays. Delays is the cost element that road users ranked as the most important in the focus groups, yet it actually contributes the least proportion overall in these analyses for any cost element and therefore has the least direct influence over the overall costs and the least contribution to the resulting calculated economic indicators.

In summary, in adding the impacts of carbon and noise emissions to the overall agency costs at this stage of the analysis (i.e. including their costs alongside works and delay costs for the standard maintenance options) it makes very little difference to the maintenance programme. From a road agency perspective this would perhaps seem an ideal time to therefore incorporate these costs into the maintenance decision process without any significant change to outputs from the process. It could allow an agency to enhance its environmental considerations without wide sweeping changes in the processes, outputs or the resulting maintenance programme.

Why include the parameters though if it makes little difference? During this bedding-in period it would allow all stakeholders to be educated on the implications of including carbon and noise emissions from maintenance in programme development decisions. Once these processes become embedded there is a greater likelihood that stakeholders would be more accepting of including those externalities within the maintenance programmes and agencies could begin to investigate introducing different treatment options that provide improved environmental benefits, but which using the current approach would not show their true benefits if they were assessed using only works and delay costs.

The next section looks at what would be expected to change if, as well as including environmental costs, additional treatment options that maximise environmental savings are also available for selection (i.e. treatments with a lower carbon content or lower noise characteristics when compared to the standard options).

7.4.7 *Analysing environmentally enhanced maintenance options*

In addition to including the costs of carbon and noise, specific Do Something options were created that were tailored to reflect:

- Low-carbon maintenance;
- Low-noise maintenance; and
- Low-carbon and low-noise maintenance combined.

The tailoring of these Do Something options (e.g. by material choice, bitumen content, deterioration rates) meant that as well as a Do Minimum and the standard Do Something option to select from, an additional 3 Do Something options were available for the model to select for each scheme (reflecting the 3 bullet points above). When these additional maintenance options were introduced into the analysis the following results were generated.

The summary outputs were:

- Identified schemes: 33;

- Selected schemes: 16;
- Number of selected Do Minimum schemes: 11 out of 16;
- Length of selected schemes: 38.3km.

The selected schemes came from the same 33 identified schemes as in the previous analysis. The carbon quantity in year 1 was 580 t CO₂e, and over the whole analysis period it was 6,442 t CO₂e.

In this scenario of including environmentally focused options (compared with only being able to choose between the Do Minimum and standard Do Something) it led to four additional Do Something schemes being selected, one of which was a Do Minimum that was upgraded to a Do Something, the other three schemes were not previously selected.

Of the four additional Do Something options, the upgraded Do Minimum changed to a low-carbon, low-noise Do Something option. Two out of the three new Do Something options were low-carbon, low-noise options and the other was a standard carbon, low-noise option. Without the availability of these environmental options and the consideration of environmental costs maintenance on the three newly chosen schemes was previously not justifiable. Therefore, the inclusion of environmental maintenance options and costs meant additional schemes became economically viable.

The output costs are shown in Table 7-16.

Table 7-16: Costs when choosing between a Do Minimum and four Do Something options

	Works Costs (€k)	Delay Costs (€k)	Carbon Costs (€k)	Noise Costs (€k)	Total Agency Costs (€k)
Year 1	2,473	86	35	-171	2,423
Year 1 (scheme min)	30	1	1	-7	26
Year 1 (scheme max)	766	50	10	-178	649
Year 1 (avg per scheme)	155	5	2	-11	151
Year 1 (per km)	65	2	1	-4	63
All years WLC	9,033	279	242	-4,318	5,337
All years WLC (scheme min)	115	1	3	-109	10
All years WLC (scheme max)	734	34	30	-49	749
All years WLC (avg per scheme)	565	17	21	-279	334
All years WLC (per km)	236	7	9	-112	140

(source: authors research)

One of the interesting outcomes from this analysis is that the total agency costs are much higher in the first year of the analysis (see Table 7-16 compared with Table 7-14). As would be expected, the result of increasing the treatment lengths by approximately 50% has the effect of almost doubling the works costs. However, due to the inclusion of all the other cost elements (which includes the noise savings) the overall year 1 agency costs per km only actually experience an increase of less than 10%.

The reason for the higher works costs (and the significant noise savings) is the selection of the low-noise maintenance option, which whilst commanding a higher unit cost rate, offers noise savings which help balance the additional cost. Without these additional maintenance options available for selection, noise savings were not previously seen in the first year of the analysis.

Where the inclusion of the additional environmental options really excels is across the whole-life evaluation period. The noise savings offered by the environmental schemes are equivalent to almost 50% of the works costs across the whole-life cost

period. The end result however is that there is a 25% reduction in the total agency costs per km across the whole-life period. Delay costs are the only cost element to experience an increase in per km costs across the whole-life period.

For carbon emissions from maintenance, this analysis represented both an absolute increase and an increase on a per km basis of the carbon emissions in year 1. However, over the whole-life period it represented a decrease on a per km basis for the whole analysis period, from 209 t CO₂e/km to 168 t CO₂e/km. This is because one of the environmental enhancements to the Do Something options was in offering a low-carbon alternative. This additional option proved economically viable for three of the four new Do Something options and although the additionally selected Do Something's meant more work in the first year (i.e. an increase in materials, transport etc. and therefore an increase in carbon) over the whole-life period the low-carbon option resulted in the substantial reduction in carbon emissions.

It demonstrates the importance of considering a whole-life approach to asset management decisions, especially when looking at environmentally enhanced options. The savings that can be generated over these longer time periods could be used by stakeholders (primarily contractors) to justify more environmental scheme choices. However, some of these choices will also require a road agency to be willing to invest more upfront in order to generate the greater savings in later years, something the contractors during the consultation did not necessarily feel was the current situation.

The resultant percentages of the lengths in different threshold categories showed the best profile of any previous analysis, with a greater percentage of the network in the good category (see Table 7-17).

Table 7-17: Condition outputs from works, delay, carbon and noise costs using 4 Do Something options

Condition Category	Percentage of network (%)
Length not exceeding threshold for any condition parameter	88.6
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	11.3
Length exceeding Do Minimum thresholds for any condition parameter	0.1

(source: authors research)

The improvement in the good condition resulted from the increase in the Do Something schemes selected, shown by the related drop of the percentage of the network in the Do Something category.

There was a two-fold benefit to including carbon and noise costs in the analyses:

1. Even with only a standard Do Something option available for selection the total agency costs are lower when carbon and noise costs are included (Table 7-8 compared to Table 7-14); and
2. When specific environmentally targeted maintenance options are included in the analyses the cost savings can be even greater when the environmental savings can be directly included within the cost calculations.

This is important for road authorities. By considering more cost elements in their analyses (i.e. carbon and noise) it could allow them to justify scheme selections that would otherwise not get approval.

It is important to remember though that in these analyses the costs for carbon and noise were attributed to be agency costs. If carbon costs were not treated like this it would not have a significant impact on the stated findings because the carbon costs are a relatively small proportion compared to the works costs. However, if noise costs were not treated as an agency cost then there would be less benefit to offset against the actual cost of the works.

7.4.7.1 Changing the one available Do Something option

In this scenario only one Do Something option is available along with the Do Minimum. The Do Something option available was the low-carbon, low-noise alternative that represented the furthest divergence (in environmental characteristics) from the standard Do Something (used in section 7.4.6)

The summary outputs were:

- Identified schemes: 33;
- Selected schemes: 14;
- Number of selected Do Minimum schemes: 11 out of 14;
- Length of selected schemes: 34.4km.

The selected schemes came from the same 33 identified schemes as in the previous analysis. The carbon quantity in year 1 was 540 t CO₂e, and over the whole analysis period it was 5,794 t CO₂e.

The cost outputs from this analysis are in Table 7-18.

Table 7-18: Costs when choosing only between a Do Minimum and low-carbon, low-noise Do Something

	Works Costs (€k)	Delay Costs (€k)	Carbon Costs (€k)	Noise Costs (€k)	Total Agency Costs (€k)
Year 1	2,278	80	33	-169	2,221
Year 1 (scheme min)	28	0	0	3	31
Year 1 (scheme max)	766	50	10	-178	649
Year 1 (avg per scheme)	163	5	2	-12	159
Year 1 (per km)	66	2	1	-5	65
All years WLC	8,174	241	306	-4,177	4,543
All years WLC (scheme min)	115	1	3	-109	10
All years WLC (scheme max)	1,054	4	44	-534	568
All years WLC (avg per scheme)	584	17	22	-298	325
All years WLC (per km)	238	7	9	-121	132

(source: authors research)

When the model was given the choice of only selecting either a Do Minimum option or a low-carbon, low-noise Do Something it resulted in a 4km (just over 10%) drop in the total year 1 treatment lengths. However, the per km total agency costs across the whole-life cost period fell to just €132k, the lowest of any of the previous analyses.

The reason for this comparatively low total agency cost was that the noise savings generated from the selected schemes amounted to over 50% of the works costs, therefore offsetting a large proportion of the agencies direct spend on works. Such significant noise savings would be expected from the schemes in this analysis because it will always result in a low-noise treatment.

The works costs across the whole-life period were some of the largest of all the scenarios which would also be expected because the environmentally enhanced Do Something option does come at a cost in terms of the materials and mixes and in terms of the shorter expected life-time, therefore resulting in more frequent interventions.

The resultant percentages of the lengths in different threshold categories shared the same percentage profile as when all costs were included with just the standard Do Something available (see Table 7-19).

Table 7-19: Condition outputs from works, delay, carbon and noise costs using only the low-noise, low-carbon Do Something

Condition Category	Percentage of network (%)
Length not exceeding threshold for any condition parameter	87.7
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	12.2
Length exceeding Do Minimum thresholds for any condition parameter	0.1

(source: authors research)

The overall point from this scenario is that by limiting the choice between these two options it actually lead to the best cost savings overall and the lowest total agency cost over the whole-life cost period. However, it does require more upfront investment in terms of the works costs.

7.4.7.2 Sensitivity of carbon and noise monetised values

One of the potential limitations of including externalities within the modelling is in the choice of monetised values chosen. Within this model there are two ways of investigating this sensitivity:

1. Changing the unit rates used directly; or
2. Applying weightings to the cost elements to change their relative proportions.

Analyses were first completed that changed the unit rates for noise and carbon. Sensitivity analyses for noise changed the unit rates to be 50% and 150% of the default values. The effect this had on the selected maintenance schemes is shown in Table 7-20.

Table 7-20: Noise costs scheme sensitivity

	Default noise costs	50% noise costs	150% noise costs
Identified schemes	33	33	33
Selected schemes	16	13	21
Selected Do Minimum schemes	11	11	7
Selected scheme length (km)	38.3	27.5	78.7

(source: authors research)

When the default noise costs were reduced by 50% three Do Something schemes were dropped from the programme due to the economic savings for those schemes switching from a positive saving to a negative saving, therefore not representing an economic return and so not a preferred option anymore. The total length of the selected maintenance fell by approximately 28%.

When the noise costs were increased by 50% the effect was more significant. The number of selected schemes increased from 16 to 21 and 4 Do Minimum options switched to Do Something's due to the increase in noise costs resulting in noise benefits becoming larger and the overall savings and economic indicator being enhanced.

However, a variation in the maintenance programme when the noise costs were changed was only witnessed when environmental Do Something options were included in the analysis. When the analysis included only the one standard Do Something option there was no change to the resulting maintenance programme.

Sensitivity analyses were also undertaken that changed the carbon unit rates to the low (approximately 50% of default) and high (approximately 150% of default) WebTAG values for the price of carbon. The effect this had on the selected maintenance schemes is shown in Table 7-21.

Table 7-21: Carbon costs scheme sensitivity

	Default (central) carbon costs	Low (~50%) carbon costs	High (~150%) carbon costs
Identified schemes	33	33	33
Selected schemes	16	16	16
Selected Do Minimum schemes	11	11	11
Selected scheme length (km)	38.3	38.3	38.3

(source: authors research)

When low carbon costs were used all scheme options remained the same. When high carbon costs were used only one scheme option experienced a change; a Do Something option (low carbon, low noise) switching to a different Do Something option (standard carbon, low noise). The result in both cases was that the overall scheme breakdown and maintenance lengths were the same and therefore the effect of carbon is much less sensitive to the cost values used.

Although the magnitude of the changes in costs is different between parameters, there will be tipping points for each parameter that significantly change the outcome. This is not a weakness of monetisation but it shows the need to have confidence in the values chosen so that the results stand robustly.

As stated at the start of this section, the other method for investigating the sensitivity of the outputs to the costs used is to change the relative weightings of the cost elements (see section 6.4). An analysis was undertaken where the cost weighting for noise was set to 1 and all other weightings were set to 0. This has the effect of purely minimising noise because noise is the only parameter considered in the economic calculations and prioritisation. A similar analysis was setup for carbon as a comparison. The results from both analyses are shown in Table 7-22.

Table 7-22: Noise and carbon cost weighting sensitivity

	Default weightings	Noise only cost	Carbon only cost
Identified schemes	33	33	33
Selected schemes	16	33	29
Selected Do Minimum schemes	11	1	10
Selected scheme length (km)	38.3	132.4	79.3

(source: authors research)

Prioritising purely on noise costs led to all schemes being selected and only one Do Minimum being chosen. In all cases a specific noise reducing Do Something offered the best noise benefits but the one Do Minimum was chosen along a length where there was no noise data. However, in reality this would result in some of the maintenance programme being completed on lengths of the network which were still below the condition thresholds, which is why with works costs included less schemes in total are justifiable.

Prioritising against only the carbon costs also led to an increase in the resultant maintenance programme compared to using default weightings. With only carbon

costs included in the economic calculations, more schemes offered a saving due to the total carbon costs of the Do Something being less than the total carbon costs of the Do Minimum, leading to a positive economic saving. However, as with noise, in reality if carbon was the only cost parameter used to create the maintenance programme it would result in some maintenance being completed on lengths where the condition was below the maintenance thresholds, therefore not representing a true minimisation of carbon if the condition of some sections did not merit any maintenance.

Although these analyses can be used to show the changes in a programme if just one parameter is used in the scheme assessment (and in the case of noise could represent a true minimisation of the noise values) they demonstrate why one analysis cannot provide 'the' answer but rather a suite of analyses need to be used to inform the creation of a maintenance programme to address the trade-offs that need to be made.

7.4.7.3 Implications of carbon and noise costs being attributed to society

An analysis was undertaken to investigate the implications on the selected maintenance if the costs of carbon and noise were attributed to society (as opposed to the agency) in which case the significant benefits previously seen from the noise savings could not be used to offset the works costs.

The summary outputs were:

- Identified schemes: 33;
- Selected schemes: 14;
- Number of selected Do Minimum schemes: 12 out of 14;
- Length of selected schemes: 27.1km.

The selected schemes came from the same 33 identified schemes as in the previous analysis. The carbon quantity in year 1 was 292 t CO₂e, and over the whole analysis period it was 5,519 t CO₂e.

In this analysis, all treatment options were available for selection (one Do Minimum and four Do Something's) and the cost outputs are shown in Table 7-23.

Table 7-23: Overall costs when carbon and noise costs are attributed to society

	Works Costs (€k)	Delay Costs (€k)	Carbon Costs (€k)	Noise Costs (€k)	Total Agency Costs⁵⁵ (€k)
Year 1	1,405	33	18	80	1,438
Year 1 (scheme min)	28	0	0	3	28
Year 1 (scheme max)	197	2	6	3	199
Year 1 (avg per scheme)	100	2	1	6	103
Year 1 (per km)	52	1	1	3	53
All years WLC	7,023	161	291	-2,230	7,184
All years WLC (scheme min)	71	0	3	-16	72
All years WLC (scheme max)	1,054	4	44	-534	1,059
All years WLC (avg per scheme)	502	12	21	-159	513
All years WLC (per km)	259	6	11	-82	265

(source: authors research)

As expected from this scenario, the total agency costs were much higher over the whole-life period because the benefits of the significant noise savings (although still quantified) are not passed onto the agency and therefore cannot be used to offset any of the other agency costs (e.g. works or delays).

The resultant percentages of the lengths in different threshold categories showed an improvement over the previous profile but did not exceed the amount in good condition when all four Do Something options were available (see Table 7-24).

⁵⁵ Summed from the works and delay costs only.

Table 7-24: Condition outputs from works, delay attributed to the agency and carbon and noise costs attributed to society

Condition Category	Percentage of network (%)
Length not exceeding threshold for any condition parameter	88.0
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	11.9
Length exceeding Do Minimum thresholds for any condition parameter	0.1

(source: authors research)

7.4.8 Demonstration of effects on treatment profiles

Based on the previous scenarios and discussions it is clear that the effect on future treatment profiles within the treatment evaluation (or whole-life cost) period changes, depending on the Do Something option(s) available to choose from. This section looks at a single scheme and shows the changes in the treatment profile that one scheme experienced through the different scenarios.

Scheme 5 was a scheme selected across all the different investigations, consistently being chosen as a Do Something option. However, the option chosen for the scheme varied due to the different environmental and cost constraints imposed.

- In an initial analysis with only works costs and user delays costs included in the calculations (section 7.4.3) the standard Do Something was selected (see Figure 7-10);
- When carbon and noise costs were added to the scheme costs only the standard Do Something was available for selection (section 7.4.6) and therefore the standard Do Something was selected but with additional cost categories reported upon (see Figure 7-11);
- When carbon and noise costs were added to the scheme costs and all four Do Something options were available for selection (section 7.4.7) the

standard carbon, low-noise Do Something was selected (see Figure 7-12); and

- When carbon and noise costs were added to the scheme costs but only the low-carbon, low-noise Do Something was available for selection (section 7.4.7.1) the low-carbon, low-noise Do Something was selected (see Figure 7-13).

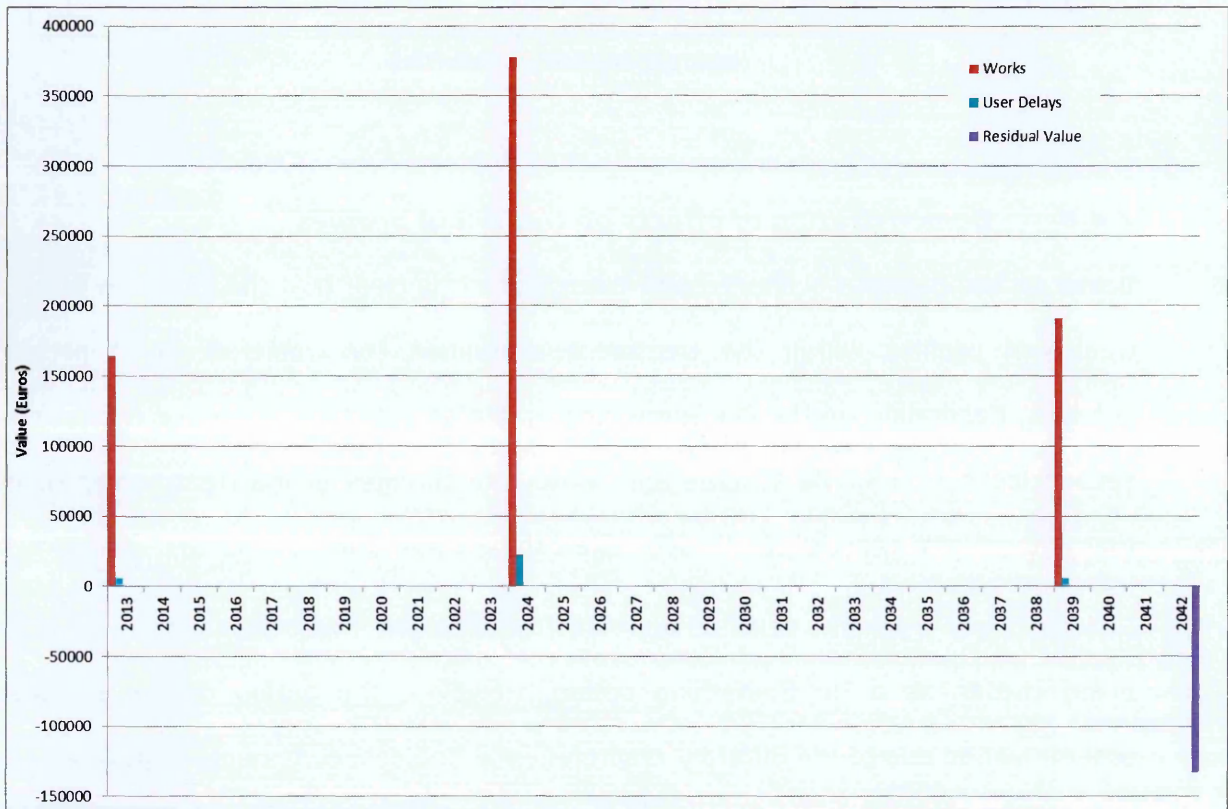


Figure 7-10: Scheme 5 treatment profile in initial analysis with only works and delay costs cost profile (Euros per year)

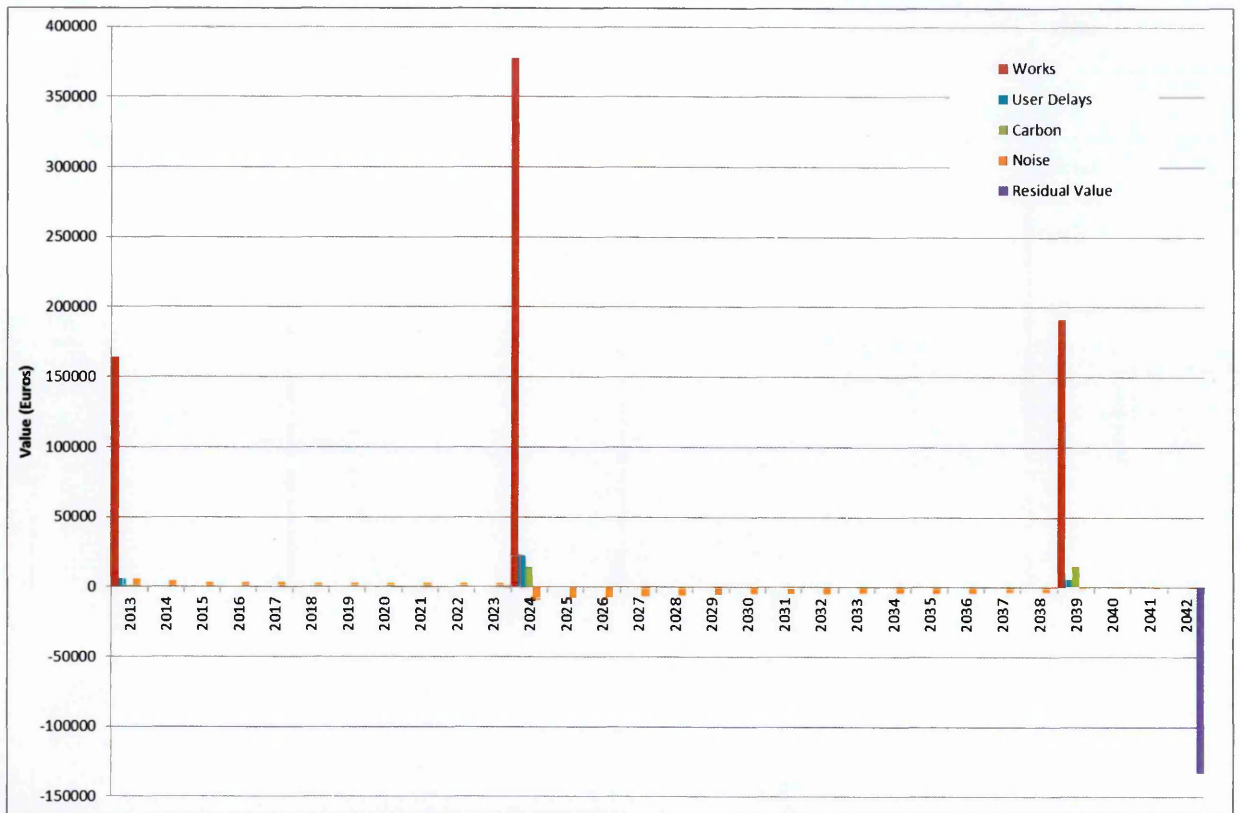


Figure 7-11: Scheme 5 treatment profile, standard Do Something including carbon and noise costs cost profile (Euros per year)

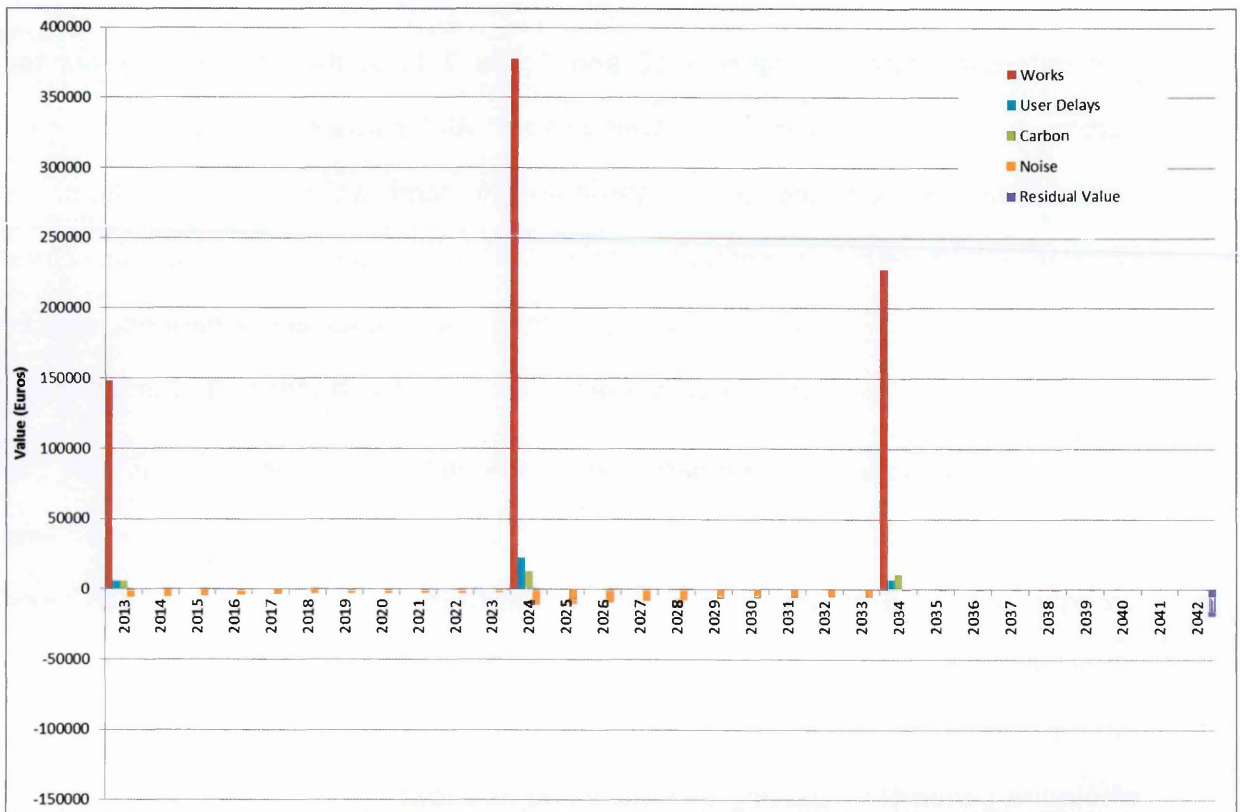


Figure 7-12: Scheme 5 treatment profile, Do Something standard carbon, low-noise cost profile (Euros per year)

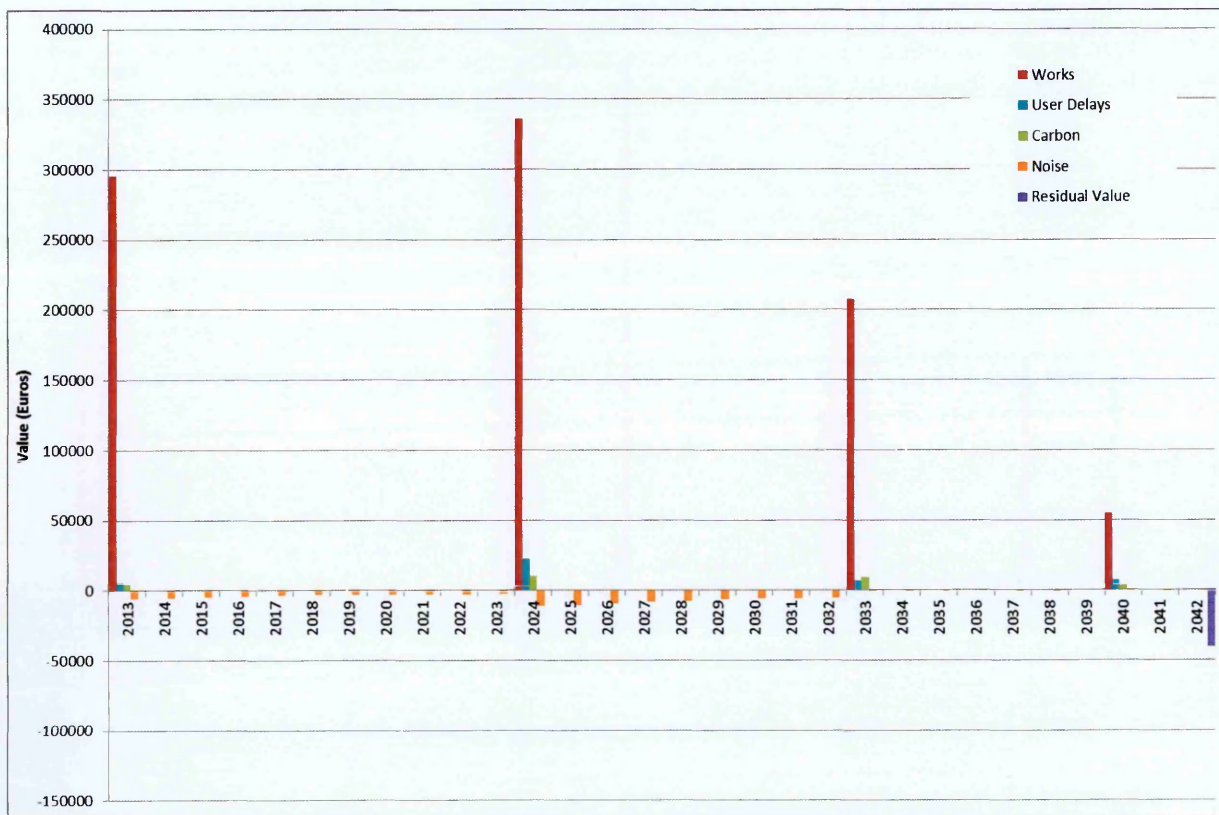


Figure 7-13: Scheme 5 treatment profile, Do Something low-carbon, low-noise cost profile (Euros per year)

The difference between Figure 7-10 and Figure 7-11 is the addition of costs for carbon and noise emissions from maintenance. All treatment interventions, works costs, delay costs and the residual value are the same when comparing the same standard Do Something maintenance option with or without carbon and noise costs because there is no difference to the deterioration rates and treatment effects between these two scenarios (due to them both using the standard Do Something).

The effect of choosing the standard carbon, low-noise Do Something was that the third maintenance intervention (originally in 2039 in the first two figures) was brought forward in time to 2034. This was due to the enhanced deterioration rates associated with the low-noise element of the maintenance options. Due to the third intervention being brought forward and no further interventions occurring in the whole-life period the resulting residual value was lower at the end of the analysis. Also in comparing Figure 7-11 and Figure 7-12 the noise benefits for the low-noise

surface in Figure 7-12 are immediately apparent following the first intervention in year 1, changing from a cost to a benefit.

The fourth scenario, in which the low-carbon, low-noise Do Something was the maintenance option selected resulted in a greater difference when compared to the treatment profile of the standard Do Something option. This scenario resulted in four maintenance interventions within the whole-life period as a result of the further enhanced deterioration rates of the low-noise characteristics and the low-carbon characteristics (primarily reduced bitumen content).

For just this one scheme, quite different treatment profiles were created for the different scenarios, demonstrating that the inclusion of carbon and noise effects as well as environmentally enhanced maintenance options can have a noticeable impact on the resultant maintenance.

Overall, when all four Do Something options were available for selection it was the standard carbon, low-noise option (Figure 7-12) that was chosen and this therefore represents the best option for scheme 5 and importantly, compared to the base run with just the one standard Do Something option, it shows a noticeable difference in intervention timing across the whole-life period. If scaled up to a network level, these impacts would therefore be expected to lead to considerable changes in overall maintenance programmes.

7.4.9 Summary

This case study for developing a maintenance strategy for a route has shown how the model outputs and maintenance programmes can be affected by the inclusion of the externalities of carbon and noise emissions from maintenance.

When costs of carbon and noise emissions from maintenance were added to the base model alongside the costs of works and the costs of the additional delays from maintenance it resulted in a small reduction in the amount of maintenance selected. The reduction in maintenance lengths was as a result of one of the Do

Something schemes becoming economically unviable when carbon and particularly noise costs were added to the total scheme costs.

The resulting works costs in the first year were consistent between the two analyses although the inclusion of carbon and noise costs meant the total agency costs increased by approximately 5%. The works costs over the whole-life cost period increased by almost 25% but the addition of carbon and noise (the latter generating significant cost savings over the whole-life cost period) meant that the total agency costs actually fell by approximately 10% due to the calculated noise savings. This reduction in overall scheme costs is based on all cost elements being attributed as agency costs.

When additional Do Something maintenance options were included as available treatments in the analyses it resulted in significant environmental benefits across the whole-life period. Carbon quantities from the maintenance reduced (from 209 t CO₂e/km to 168 t CO₂e/km) and the noise savings increased (to be approximately 50% of the works costs). Benefits and savings in year 1 were not always so apparent, and this was partly due to the higher initial investment for some of the environmentally tailored schemes which outweighed any initial benefits. However, it served to demonstrate the importance of taking a whole-life approach to valuing these environmental externalities.

A recent study by Pellecuer et al. (2014) attempted to look at the environmental life cycle benefits of a surface maintenance along an example 1km section for a case study. When analysing the total benefits for this case study it was found that the benefits arising from noise formed the most significant proportion of the total benefits, consistent with the outcomes from this case study. Again, consistent with this research, the results from Pellecuer et al. (2014) showed that greenhouse gas emissions only had a minimal impact on the resulting maintenance strategy. Unlike this research though, there was no general model for use and one of the conclusions was that there needs to be a mechanism for discounting environmental impacts separately, a feature which has already been programmed into this model.

7.5 Developing a maintenance strategy for a region

The second case study looks at the effects at a county level. The county chosen was Kilkenny, which is in the south-east of Ireland (Figure 7-14) and is the 16th largest of the 32 counties. A more detailed map of the county is shown in Figure 7-15 where it can be seen that the county includes a mixture of different road types, containing a motorway (M9), lengths of primary network (e.g. N10, N24) and lengths of secondary network (e.g. N76, N77). The total length of the road network analysed was 200 route km.

Whilst being similar in total length to the N4 case study, Kilkenny was chosen because it has a mixture of road classes (e.g. motorway and non-motorway) and also because the data coverage was not as complete as in the first case study. The incomplete data coverage would act as a test for the model in dealing with missing data and thereby use a further set of algorithms developed in the model that were not tested through the first case study.

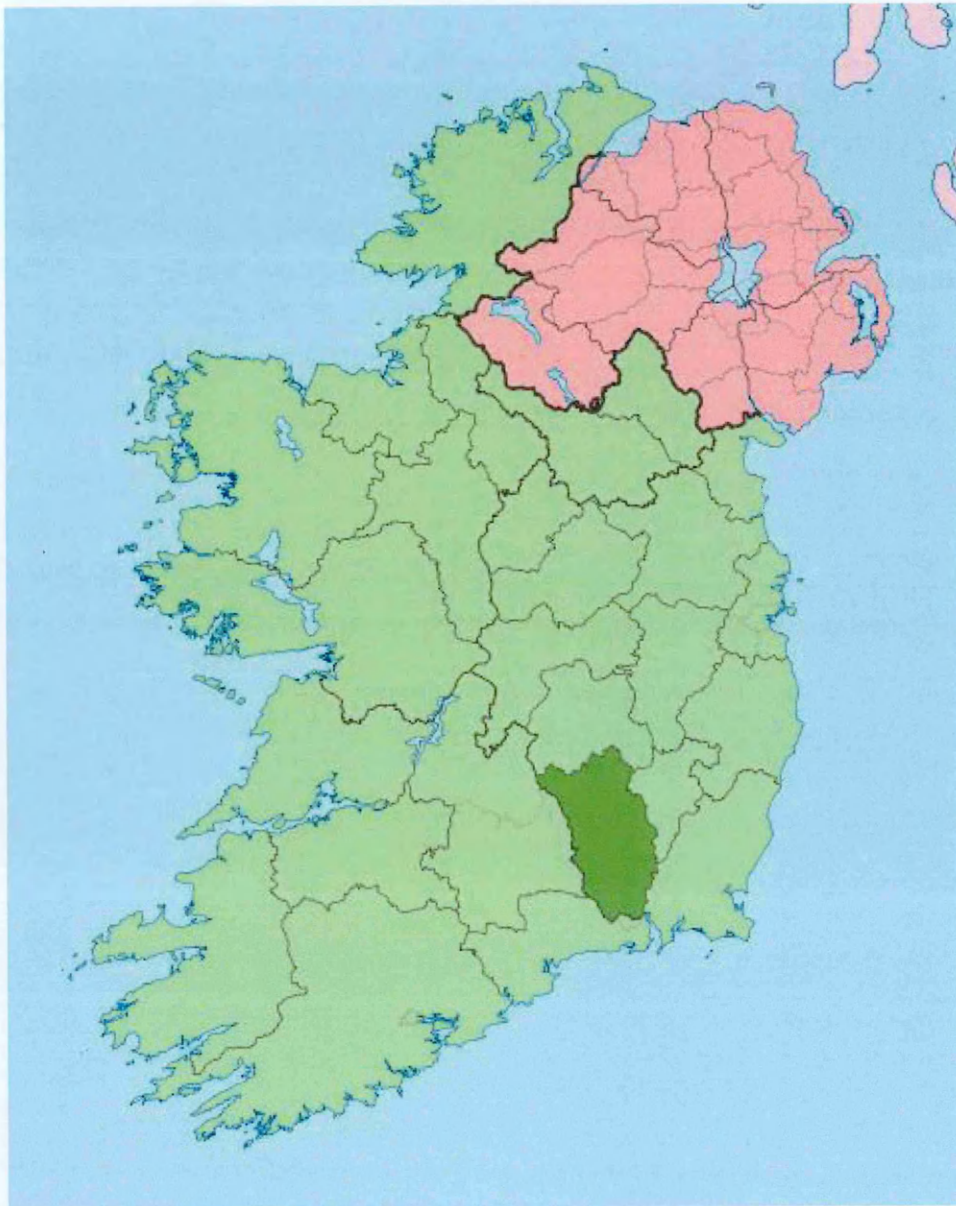


Figure 7-14: Location of County Kilkenny in dark green (source: Wikipedia, 2010)

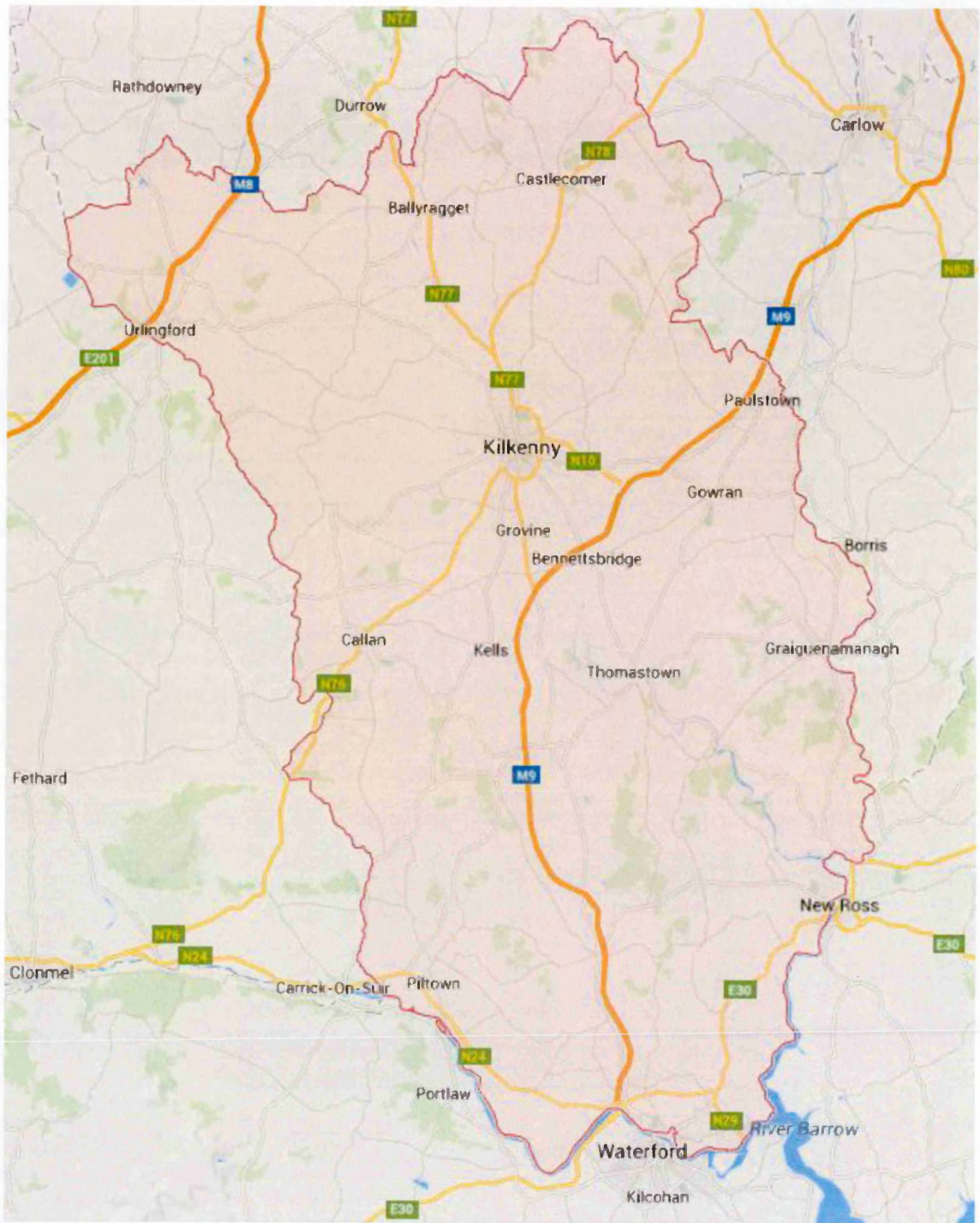


Figure 7-15: Map of Kilkenny County (source: Google Maps, 2015c)

The inputs for this case study are shown in Table 7-25.

Table 7-25: County Kilkenny analysis setup

Parameter	Value
Start year	2013
Programme period (year(s))	1
Treatment evaluation period (year(s))	30
Discount rate (%)	3.5
Residual value method	Linear
No. of Do Something options	1
Budget	Unconstrained

(source: authors research)

This case study was undertaken using all four cost parameters to investigate the difference at a county level when choosing between the different maintenance options available in the whole-life value model.

The data coverage for this network is shown in Table 7-26. Where there were data gaps these were filled with default values.

Table 7-26: Data coverage for County Kilkenny

Data source	Coverage (%)
Rut	79
Longitudinal Profile	79
Texture	79
SCRIM	79
Noise	81

(source: authors research)

7.5.1 Works, delay, carbon and noise costs

The first analysis completed in this regional case study was to select from either the Do Minimum or the standard Do Something for all maintenance schemes that had been identified.

The summary outputs were:

- Identified schemes: 40;
- Selected schemes: 17;
- Number of selected Do Minimum schemes: 13 out of 17;
- Length of selected schemes: 26.0km.

The carbon quantity in year 1 was 127 t CO₂e, and over the whole analysis period it was 3,493 t CO₂e.

The cost outputs from this analysis are shown in Table 7-27.

Table 7-27: Cost outputs for Kilkenny (Do Minimum and standard Do Something)

	Works Costs (€k)	Delay Costs (€k)	Carbon Costs (€k)	Noise Costs (€k)	Total Agency Costs (€k)
Year 1	922	32	8	-7	955
Year 1 (scheme min)	5	0	0	0	5
Year 1 (scheme max)	130	5	1	0	136
Year 1 (avg per scheme)	54	2	0	0	56
Year 1 (per km)	35	1	0	0	37
All years WLC	4,580	186	184	-566	4,384
All years WLC (scheme min)	62	1	3	-22	45
All years WLC (scheme max)	691	59	22	0	774
All years WLC (avg per scheme)	269	11	11	-33	258
All years WLC (per km)	176	7	7	-22	169

(source: authors research)

This analysis echoes the trends seen in the first case study on the N4 route. Over the whole-life period the carbon costs approximately equate to the delay costs, whereas the noise costs (or savings) are an order of magnitude greater. In this specific analysis the noise costs are over three times greater than the delay or

carbon costs. What can also be seen is the significant savings that are calculated by the parameters of noise when it is assessed over the whole-life period.

The low impact of the delay costs on the overall agency costs is a result of the relatively low traffic levels across the region. The highest modelled traffic flow on this Kilkenny network is 56,678 vehicles, although the majority of the network is under 30,000 AADT and over half is below 10,000 AADT. The relatively low traffic flows (compared to capacity) result in the low impact that the delay costs have on the overall costs.

A sensitivity analysis was undertaken on the traffic data to look at how the impact changes with higher traffic. The result was that increasing the traffic levels to a flat level of 75,000 AADT across the county resulted in the delay costs equating to 10% of the works costs. Therefore, as documented earlier in the N4 case study the relatively low impact of the delays costs seen in the existing case studies (and likely across most of Ireland) is dominated by the relatively low traffic levels seen across the network. When traffic levels increase, the influence of delay costs increase significantly to be greater proportions of the agency costs; more in line with the proportion of delay costs that would be expected over other higher trafficked networks. In the sensitivity analysis undertaken for Kilkenny county, the delay costs were over double the carbon costs on a per km basis (€18k compared to €7k) and equated to just over 10% of the works costs (of €176k) when they were artificially increased to 75,000 AADT.

The comparative low cost of carbon compared to the delay and works costs should not be confused however with an inability for the model to minimise carbon. In order to minimise carbon the model can look at the relative differences in the carbon costs between any analyses and therefore that carbon comparison is independent of other costs. However, all selected cost elements will become summed when analysing the total costs (both for year 1 and the whole-life period) and so the relative impact of carbon on the totals will be reduced. Therefore, if a

user wishes to conduct an analysis purely focusing on minimising carbon they should weight all other costs to 0 in the run configuration.

That type of question (i.e. minimising carbon) was one reason why functionality within the model was included that allowed a carbon cap to be used as a constraint in an analysis. A combination of this constraint with the ability to only model carbon costs would result in an enhancement ability to minimise carbon and generate an associated maintenance programme.

7.5.2 *Analysing environmentally enhanced maintenance options*

This second scenario in the Kilkenny case study was based on the whole-life value model being able to select any maintenance option from either the one Do Minimum or four Do Something options.

The summary outputs were:

- Identified schemes: 40;
- Selected schemes: 18;
- Number of selected Do Minimum schemes: 12 out of 18;
- Length of selected schemes: 27.3 km.

The carbon quantity in year 1 was 198 t CO₂e, and over the whole analysis period it was 3,664 t CO₂e.

The cost outputs for this analysis are shown in Table 7-28.

Table 7-28: Cost outputs for Kilkenny (Do Minimum and four Do Something options)

	Works Costs (€k)	Delay Costs (€k)	Carbon Costs (€k)	Noise Costs (€k)	Total Agency Costs (€k)
Year 1	967	34	12	-26	987
Year 1 (scheme min)	5	0	0	0	5
Year 1 (scheme max)	130	5	1	0	136
Year 1 (avg per scheme)	54	2	1	-1	55
Year 1 (per km)	35	1	0	-1	36
All years WLC	4,788	193	194	-758	4,417
All years WLC (scheme min)	62	1	3	-22	45
All years WLC (scheme max)	691	59	22	0	774
All years WLC (avg per scheme)	266	11	11	-42	245
All years WLC (per km)	175	7	7	-28	162

(source: authors research)

As in the previous analysis, the costs of the delays and carbon are approximately equivalent when compared over the whole-life period but in this analysis the savings generated by noise have an impact four times greater than either the delays or carbon on the final agency costs.

7.5.3 Summary

The results from these county level analyses in Kilkenny could be scaled up to understand the likely outputs from an analysis of the whole network. For the second scenario in the Kilkenny case study (i.e. where all Do Something options were available) the analysed network was 200km from the total available network of 5,459km (or 3.7% of the total network).

7.5.3.1 *Scaling carbon to the entire network*

If the carbon quantities are scaled up appropriately that equates to a carbon quantity across the network in year 1 of 5,409 t CO₂e, and over the whole analysis period it is 100,109 t CO₂e.

The scaled up value for the network carbon quantity in year 1 amounts to less than 0.05% of the 2008 reported annual total for transport suggesting that the impact of maintenance is limited⁵⁶ when considered in the context of addressing carbon targets for transport. These figures represent the total carbon associated with this one maintenance programme and so the difference when choosing between the various maintenance programmes (i.e. how much could be saved between strategy x or strategy y) would be even less.

This in part demonstrates the dominance of other transport issues (primarily vehicle emissions) on the overall carbon targets. To put into context the maximum influence that maintenance could have against the total transport carbon totals; a very extreme maintenance scenario of maintaining the entire 5,459km network in a single year would result in approximately 0.8 Mt CO₂e, equating to approximately 6% of the annual transport total⁵⁷.

The change in vehicle emissions through the use of electric vehicles (using low-carbon electricity) for example are the transport areas that have the most influence on the carbon assessments, and the areas therefore that need to lead changes. If electric vehicles (using low-carbon electricity) become a significant proportion of

⁵⁶ The analysis reported in section 7.4.7.2 (where carbon costs were weighted to 1 and carbon was therefore the only cost parameter used in the analysis) had a carbon year 1 output of 995 t CO₂e, which scaled to the network equated to 26,253 t CO₂e or 0.18% of the 2008 reported annual total for transport.

⁵⁷ Assuming that the entire network had an average width of 7.5m and was treated with the most severe carbon treatment of a Do Something overlay, which using model specified default data results in a combined planning and treatment carbon quantity of 20.4 kg CO₂e/m².

the vehicle fleet in the future and successfully lower the overall transport emissions, the carbon from maintenance would be a higher proportion of the total and therefore become more important in the calculation of overall emissions from the transport sector.

7.5.3.2 *Scaling noise to the entire network*

The calculated savings for noise (as a proportion of the works costs) generated by the different analyses are shown in Table 7-29.

Table 7-29: Calculated noise savings

Analysis	Noise savings Yr 1 (%)	Noise savings WLC period (%)
Standard Do Something only	0.8	12.4
Four Do Something options available	2.7	15.8

(source: authors research)

The advantage of providing additional environmentally focused Do Something options can clearly be seen by the increase in noise savings in year 1. Over the whole-life period the savings are also greater when Do Something schemes with a low-noise element are included in the analysis and they contribute to offsetting a significant proportion of the works costs.

Over a complete network analysis the scaled up noise savings over a whole-life period (for the analysis where all four Do Something's are available) could be over €21M if the rest of the network is assumed to behave similarly and generate a similar amount of maintenance.

7.6 Discussion

This chapter presented results from using the developed whole-life value tool. Compared with other network level pavement costing models, calculations for the carbon and noise emissions impacts from the maintenance were integrated into this

model in order to demonstrate their impact when developing a maintenance programme.

Two case studies were undertaken to investigate the impacts of carbon and noise on different sub-networks of the Irish national network. The analysis showed that the inclusion of carbon has a limited effect on the overall agency costs (due to the low relative cost compared to the direct works costs) but that noise costs significantly lowered the overall agency costs, with the whole-life noise costs (or benefits) equating to approximately 50% of the works costs over a comparable period. If a road authority is accountable for these costs or even a proportion of them (e.g. noise compensation claims) then by including them into an analysis it demonstrates the benefits that some maintenance schemes can generate that would otherwise only produce lower economic benefits.

In addition, the initial costs were often higher where the environmentally favoured Do Something (e.g. low-carbon, low-noise) was used due to high upfront material costs of these enhanced treatments. However, the long-term effects that these schemes generated showed that the higher upfront cost resulted in the better value over the whole-life period in many cases.

Depending on the scenario being investigated the route case study showed how individual scheme treatment profiles can vary. The scheme documented from the N4 showed how maintenance interventions can be brought forward, or indeed how extra interventions might be needed under some scenarios. This is a result of the change in treatment characteristics (e.g. deterioration rates) that can be experienced through using different treatment materials and mixtures and it was one element of the model calibration that was key to gaining additional robustness in the calculations for the whole-life calculations.

The second case study for a region (county Kilkenny) showed a similar pattern of results in terms of the proportion of cost elements to one another. Scaling the results up for a complete network demonstrated that the carbon influence over representative annual transport carbon budgets is negligible but the noise savings

generated over the whole-life period can be substantial, equating to over €21M when scaled up for the whole network.

If a strategy was required that minimised carbon or noise then careful use of the cost weightings would allow different policies or objectives to be fully tested. For example, running a scenario with only the noise costs used in economic calculations would result in a maintenance strategy that produced the maximum noise benefit. Being an economic model the results are sensitive to the choice of monetised value used but the flexibility of applying weightings allows sensitivities to be investigated, as shown for the sensitivity of the choice of carbon and noise costs.

The conversion of the externalities into monetised values essentially happens once the effect on noise has already been expressed by the change in dwellings exposed to noise, or when carbon has already been expressed as a quantity of CO₂e. Regardless of the costs used therefore, the previous step of calculating the respective quantities of the measure will not change and those quantities (e.g. the cap on carbon quantity that can be applied as a constraint) could also be used to minimise the impact of the externality. Before a road authority adopts carbon reporting procedures they should fully understand all the carbon sources they can quantify to give a fuller summation of the impact of carbon, which in turn will make them aware of the impacts they will be minimising against (e.g. embodied material carbon in this model, as opposed to vehicle emitted carbon).

Chapter 8 Conclusions and future work

This chapter presents a summary of the work completed during this research along with the conclusions of this thesis. A new methodology for integrating the main research aim of incorporating the externalities of carbon and noise emissions with direct costs and indirect user delay costs from maintenance into a pavement whole-life value model has been met and demonstrated. The specific research objectives are discussed in the following section.

By meeting the research objectives set out at the beginning it can be argued that the research contained in this thesis has advanced the consideration of externalities in the modelling of pavement maintenance.

8.1 Research objectives

The introduction to this thesis outlined the need for this research, in that maintenance investment appraisals need to include more elements within their assessments than they currently do, namely consideration of environmental externalities. The introduction documented the main research aim and outlined the research objectives that were required to meet that aim. Those research objectives outlined in the introduction are shown again in this section in bold.

Overall this thesis has involved a number of different streams of work that were required to address the research aim and objectives:

- A critical literature review;
- The development of a base whole-life cost model for Ireland;
- A consultation with key stakeholders and groups to identify their needs and requirements in terms of road maintenance planning and wider impacts;

- The development of methodologies to model carbon and noise emissions from maintenance; and
- Quantitative analysis of the model outputs through case studies.

A brief summary justifying how each research objective was met is included below.

1. To review current knowledge on externalities and look for options to incorporate them in pavement maintenance assessment, to take account of their impact in assessing maintenance schemes.

A review of available literature indicated that models used by, or for road authorities, generally do not consider the effects of all externalities in their analysis capabilities. Where consideration of externalities is included in assessments the results are often subjective, with results neither incorporated nor integrated into the main body of the assessments.

Even though life-cycle costing is used by a number of road agencies and across other industries, the consistent cost elements used in the majority of documented analyses were the costs of the works and the costs of delays experienced by road users as a result of the maintenance. Any whole-life costing of road pavements was done taking account of construction costs, maintenance costs and user costs (the latter including time and accident costs).

Primarily this is a result of the data collected and available for analysis, which has focused on the condition data and engineering aspects of maintenance in order to meet set design standards. Even though this type of data has a long history of being used across a vast range of different road networks there were no common relationships for modelling the deterioration that could be universally applied.

The review on externalities highlighted that there are current drivers for including additional externalities in appraisal assessments, and that these are only likely to grow in demand as future legislation and targets are set for environmental criteria. This opinion was also obtained from the stakeholder consultations with individual experts.

The main difficulties with modelling environmental externalities are obtaining suitable data and converting the externality measures into units (costs) for a consistent analysis approach. To date there has been limited integration of environmental externalities within fully developed pavement models. Both the literature review and the consultations with stakeholders therefore confirmed that the research was justified and the aims of this thesis have not already been met.

2. To develop a network level pavement model specific for use on the Irish national network.

The first part of the model development was to build a base whole-life cost model, tailored for use on the Irish national network, for which a review of available models was undertaken. The review highlighted elements that should be included in the base whole-life cost model developed for use on the Irish network, in addition to identifying that consideration of environmental parameters in the reviewed models was a current gap.

The development of the base whole-life cost model was completed in a modular form, allowing easier incorporation of the value elements. This model allowed for maintenance needs to be identified on selected lengths of the network and prioritised based on a combination of the works costs and the costs of additional delays from road works closures experienced by the road users.

Although the model was tailored for use on the Irish network, if the reference data is changed appropriately it would be possible to use this model on other pavement networks.

3. To develop methodologies that allow carbon emissions and traffic noise from maintenance to be integrated within a network level pavement whole-life value model. The methodologies need to make sure that the costs of carbon and noise impacts of maintenance are

modelled in a way that is comparable to other direct (e.g. works) and indirect (e.g. delay) costs, and suitable to be used to prioritise maintenance options.

To understand the opinions of key stakeholders on the importance of carbon and noise emissions from maintenance a consultation exercise was undertaken in addition to the earlier literature review. The participants of the consultation exercise were both individual experts and groups of road users and their opinions were documented and analysed.

In conjunction with the literature review, the results of the consultations were used to inform the development of methodologies for modelling carbon and noise in a pavement maintenance model. The methodologies were developed and incorporated into the base model which resulted in a whole-life value model that modelled and prioritised maintenance options taking into consideration costs of the works, additional delays from maintenance, carbon emissions of the maintenance and the change in traffic noise resulting from the maintenance. This wider model allowed more comprehensive maintenance appraisals to be made within a whole-life approach to consider the maintenance alternatives.

4. To develop a strategy to address the impacts on the resulting maintenance programme of carbon emissions and traffic noise from maintenance. The impacts will be demonstrated through case studies based on data from the Irish national network.

Two detailed case studies were completed using the final whole-life value model. The first looked at developing a maintenance programme for one strategic route (the N4) and the second developed a wider regional maintenance programme for a county (Kilkenny). They demonstrated that carbon and noise do have impacts on the prioritisation of a maintenance programme with noise being the more significant factor of the two elements. Although it depended on the type of road and network

being analysed, the costs of carbon were often the same order of magnitude as the costs of the additional delays experienced from the maintenance, for the monetised values used in this work. However, the noise costs were an order of magnitude greater than either the carbon or delay costs and had a significant impact on the cost outputs for the maintenance programmes.

Overall the model can be a driver to change behaviour, and to do this it is also important to think about other activities that are linked to the carbon and noise impacts:

- By setting carbon targets the impacts of maintenance could result in carbon materials reducing, meaning the same supply of material will last for a longer period, potentially alleviating demand problems in other sectors; and
- The benefits to health of reduced noise have also been well-documented.

Externalities are felt by third parties and are therefore complicated to assess, hence why they are often not included in the impacts of models. There is not always a commonly accepted methodology for their assessment, being difficult to monetise, but that does not mean they should always remain external to the main assessments.

5. Make recommendations for future consideration of carbon and noise in road maintenance assessment, based on outputs from the modelled case studies and any general implications for modelling externalities.

The recommendations for future work are made in section 8.3.

8.2 Conclusions

The whole-life value model provides a framework for including carbon and noise emissions in a whole-life value model for road pavement maintenance. The datasets for running the model were not readily available from NRA, Ireland, and a wider

review of input data and methodologies showed they were not an exception. Therefore the development of the methodologies and creation of suitable datasets (e.g. noise changes from treatments) required a significant amount of work. However, this data development added value to the overall research and can be used by other road authorities who have similar needs but lack the required input data (e.g. the process for generating a robust noise input dataset can be applied by any authority that has undertaken noise mapping of its network or has other noise data).

The carbon and noise modules developed in the final model allow the study of the impact of carbon and noise from alternative maintenance options to be made in the context of road pavement maintenance, even being included in the prioritisation process. The ability to weight the total scheme cost based on the works, delays, carbon and noise elements allows for the sensitivity of different impacts to be investigated to address different stakeholder needs.

The impact of carbon was similar in extent to the costs of user delays, although the price of carbon has suffered recent falls and therefore it could be argued that the carbon impact will be further limited if revised prices that reflect the recent falls in the price of carbon are used. This reflects the fact that the monetised values chosen are those which markets and policies are willing to tolerate. Although the carbon price may fall it doesn't mean the cost of adapting to climate change in the future will be low. Using the chosen carbon prices is a limitation of the study and potential future work could reflect on this to investigate using values that reflect predictions of climate change adaptation.

Partly for this reason, the model includes the ability to specify a carbon cap so that carbon impacts from maintenance can be limited in the model based on the carbon quantity, either in addition to or instead of the prioritisation including the carbon costs of maintenance.

The impact of noise is more significant, and has been demonstrated to be equivalent to up to 50% of the works costs over the whole-life period. In addition,

the noise impact methodology often generates significant savings and therefore the overall impact of the noise is to significantly reduce the overall maintenance budgets when the savings are considered alongside the other costs. This however assumes that all costs are met by a road authority and the extent of the realised noise savings may not be as large in reality if the costs are considered a cost to society, and thereby not considered as direct savings, an assumption which is applicable for all externalities.

The analyses reported (and the relationships between them and the maintenance programmes they resulted in) are valid for the set of input data used. This includes the cost data and therefore the magnitudes of the modelled effects are a result of the chosen costs. All identified maintenance schemes are driven by condition but the choice of maintenance options is influenced by the total costs, due to the economic indicators being a key decision parameter. The costs used were the government advised appraisal costs at the time of the analyses and any changes to these costs could result in the magnitudes of the individual cost elements changing, which in turn could affect the maintenance programme and selected maintenance options.

Although whole-life costing is a well-established mantra in project appraisals the case studies in this research clearly demonstrated the different impression that can be obtained if results are assessed on only an initial cost basis short-term compared to a long-term whole-life cost basis. The significance of the noise savings in particular are only experienced when looking at strategies over the longer whole-life period.

8.3 Future work

The methodologies developed in this research make use of the current available data in their development, testing and demonstration, and have advanced the understanding of the impact of carbon and noise emissions from maintenance when

included in pavement models. However, additional research could lead to further value being gained.

Specific research on detailed elements of the data used by the model would potentially allow for more detailed investigations to be completed, or at the very least provide further confidence to the modelled outputs. For example, the noise methodology developed requires knowledge of the change in noise experienced when changing from one surface to another. This data is hard to obtain in a consistent format and that was one of the reasons why a considerable amount of the work developing the methodology for noise also included developing both reference and input data for use by the methodology, analysing sources of data to try and determine the change in noise that can result from a change in pavement surface types. Therefore there is scope to develop and use more detailed data sets, especially with noise change values or with detailed noise mapping data that is held at a more granular level. However, the model has been developed so that when improvements to data are available it can be used by the model.

Although the treatment profiles reflect interventions that are reasonable in terms of their timing in a 30 year analysis period, it would be interesting to have some (Irish) specific sites where surfaces with different noise and carbon characteristics are monitored to generate a better understanding of how their performance does change and to allow for enhanced validation of the model outputs. Such studies will however take time to setup and will need to be monitored for multiple years across a range of different conditions (e.g. traffic) before appropriate trends can be determined.

There are other externalities that are not included, some of which are specific to a Highway Authority. A further element of potential work would be in extending this type of approach to include additional externalities (e.g. biodiversity, water quality, vehicle emissions). This model has demonstrated that carbon and noise can be included alongside the costs for works and delays (as modelled more traditionally) but there is no reason why other externalities cannot be included. The greatest

problem will be in finding a common method of assessing all the elements (e.g. cost) to make sure that the inclusion of any additional externalities goes beyond just adding them as qualitative, subjective assessments.

The outputs from the model could be used in a further round of stakeholder consultations in order to discuss the outcomes from the research and refine, where relevant, the methods that have been used in the developed model. This type of feedback consultation could also be used to test the acceptance of the produced maintenance programmes with different stakeholder groups.

The model was developed in a modular format so that modules could be swapped or added as new ideas, knowledge, data, policies etc. lead to new approaches. A choice was made at the beginning of this research to develop the model as a deterministic model but there could be scope in future work to look at the effect of changing the fundamental processes of condition deterioration to a probabilistic approach. This type of future work could be used to build an assessment of risk into an updated version of the model through the use of probabilistic algorithms which predict how the distribution of condition could change. This may be particularly useful for small subsets of a main network (e.g. rural roads on a more local network) where less data is available and their performance tends to be more variable.

Finally, additional sensitivity analyses of any future scenarios could be used to compare with the case studies already reported in this research to check for consistencies in the operation of the model. Analysis of further case studies would help in generalising the results of the model when run on different networks.

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Appendix A Summary of existing asset management systems

Summary of information obtained on existing asset management systems (arranged alphabetically by the name of the software).

Model: AgileAssets Suite, Agile Assets Inc

- Provides a suite of management systems which include Network Manager, Maintenance Manager and Pavement Manager.
- Specialises in new technologies for infrastructure asset management which includes browser-enable database systems, GIS and integrated multimedia.
- Pavement Manager holds detailed data for all of an organisations network which includes inventory, condition, traffic and construction data.
- Analysis procedures are used to determine pavement deterioration and predict any future maintenance needs.

Model: Asset Manager, FHWA, AASHTO and Cambridge Systematics

- AssetManager is a visualization tool that enables transportation agencies to explore the performance implications of budget allocation strategies.
- AssetManager provides a management-level capability to investigate the implications of budget strategy options.

Model: ATLAS, Exor (now part of Bentley)

- Exor applications are developed using Oracle products.
- Exor's Asset Hub integrates entire asset data regardless of how or where it is stored so the user can retain existing applications yet benefit from a single corporate view of the network and associated assets.
- The software is compatible with AASHTO's BMS-PONTIS.

Model: CONFIRM, MapInfo

- The Highway Agency maintains its road database in CONFIRM.
- It provides capabilities for asset management, maintenance, planning and service.
- CONFIRM does not include models for pavement performance and prediction and economic analysis.

Model: dTIMS, Deighton Associates

- dTIMS is a customizable framework application for asset management that combines data management and asset analysis into one centralized application.
- The user can capture cost, maintenance and construction history and depreciation information and present the results for various budgets through reports, web browsers or GIS.
- The user can also export analysis results to other compatible financial or work order management systems.
- dTIMS is for various types of infrastructure including roads, waste water, airports and pipelines.
- It models sections by assigning unique ID's and can run on subsets of the defined network.
- Analyses can take from a couple of hours up to 24 hours depending on the network size and constraints.

Model: HDM-4, World Bank

- HDM-4 is one of the most comprehensive road analysis tools available that predicts future economic, technical, social and environmental outcomes of possible investments concerning road assets.
- The system allows integration with present and future road management systems and includes detailed road deterioration models that predict initiation and progression of distresses and their effect on pavement roughness and ride quality.
- There have been noted concerns regarding the applicability of the road deterioration and user models in application in US

Model: HIMA, Harfan

- HIMA is an integrated programme with GIS functionality and has an integration system for data warehouse, conditions, remaining service life, sustainability of investment and what's needed to be done and when.

Model: HIMS, HIMS Ltd

- HIMS Ltd is a New Zealand based company, whose main software product is HIMS Ltd.

Model: HMS-2, HMS Ltd

- HMS-2 is an integrated highway maintenance management system.
- It is primarily a PMS and is written in Visual Basic for Applications with Microsoft Access 97 as the database.

Model: Insight Enterprise, Symology Ltd

- This programme encompasses all functions from cyclic inspections and routine maintenance works through to condition projection and strategic pavement management.
- It makes use of mobile devices, machine-based surveys and GIS representation.

Model: Integrated Asset Management System, WDM Ltd

- UK based WDM offers a series of programme modules with GIS and GUI interface, conforming to UK-PMS, for road asset management.
- The modules can store and process data collected by RAV, SCRIM and Deflectograph surveys.

Model: MARCHpms, Yotta Ltd

- Complying fully with UKPMS requirements, MARCHpms is a pavement management system designed specifically for those working to UKPMS standards.
- MARCHpms has been developed to comply with national standards and allows visual and machine survey data to be processed in accordance with UKPMS.
- It allows the user to setup a network, compile an item inventory and input condition surveys, either in HMDIF format from a data capture device or in Excel format.
- Automatic processing is available, enabling a number of operations to be carried out including condition rating, treatment selection, prioritisation by condition, estimating and budgeting.
- Condition projections, economic ranking and the projection of network trends are standard features.

Model: Maximo, IBM

- Covers range of assets: production, infrastructure, facilities, transportation and communications.
- Aims to optimize performance of assets.
- Stores and manages data through the whole lifecycle.

Model: MicroPaver, American Public Works Association

- This was initially developed for road and airfield pavement maintenance on military bases and is currently used by over 600 cities, counties, airports and private consulting firms.
- This programme has been set as the American Standards for road and airfield pavements.

Model: Optram, Bentley

- Used to analyse current and historic track and rail asset data for generating maintenance programmes.
- Asset, condition and historical data is presented in track charts and includes a GIS.
- Includes deterioration relationships and condition trending.

Model: PARMMS, PARMMS Software Solutions

- The programme is based on the attributes of the World Bank Deterioration Models, Austroads Design Guide and probability theory.
- The treatment selection is based on decision trees which allow full interaction and interrogation by an engineer.

Model: PMS, Dynatest

- Dynatest PMS has been in operation since 1981, being used on the road systems of municipalities, towns, counties, motorway and State authorities in Europe, the United States and Africa.
- The system uses visual PCI data, structural data from the Heavy Falling Weight Deflectometer, skid resistance data, functional data from the road surface profilometer and videos.
- The system can output optimised budgets and an optimal combination of maintenance and rehabilitation alternatives over a user defined number of budget years (optimisation).

Model: RDM, TRL

- Inventory and condition pavement management system for roads.
- Includes a separate bridge management system tool.
- Stores survey data and reports on network condition.
- Contains a range of in-built reports to assist an asset manager in making maintenance decisions.
- Links to HDM-4 for economic analysis using an automatic export process.

Model: RoadAsyst and BridgeAsyst, Pitt and Sherry

- RoadAsyst is a road maintenance and inspection software module.
- It allows easy interpretation of road management plans to provide a fully auditable and transparent trail of road management practices.

Model: Road Manager, Vanasse Hangen Brustlin Inc

- Sits within ArcGIS 9.x

Model: RoSyPMS, Grontmij and CarlBro

- These programmes can run under SQL, Oracle, or MS Access.
- RoSy PMS is an integrated database which includes a number of modules and is used for the daily planning and management of the road maintenance in 19 countries, including Germany, Denmark and Norway.

Model: Total Infrastructure Management System (TIMS), Alberta Infrastructure and Transportation, Canada

- Tailor made integrated system of a Pavement Management System (PMS) and Bridge Management System (BMS) with a GIS interface.
- All data is referenced to a common network.
- An analysis module uses expert opinion to define current and future conditions of the road network and this can be used to assign work activities to road sections (from data collection to rehabilitation).

Model: WiLCO, SEAMS

- Software model for a range of asset types that uses algorithms to predict future conditions, interventions and budget needs.
- Models allow trade-offs between different constraints and budgets.
- Resulting information is aimed at helping an asset manager make informed decisions.

Table A-1: Asset Management Tool Comparison

System	Asset type								Analysis features								Level		Refer-encing		Database			Platform			
	Pavement ⁵⁸	Drainage	Geotechnics	Bridges	Airports	Rail	Ports	Utilities	Condition Indicator	Condition Projections	Life-cycle Analysis	Asset Valuation	Treatments	Budgeting	Environment Impacts	Project	Network	Linear	Point/GPS	Oracle	SQL	MS Access	Visual Basic	Web-based	Java	GIS	
AgileAssets	✓	✓		✓				✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓				
Asset Manager	✓		✓					✓	✓		✓	✓	✓	✓		✓	✓			✓					✓		
ATLAS	✓		✓					✓	✓		✓	✓	✓	✓		✓	✓			✓					✓		
Confirm	✓		✓					✓	✓		✓	✓	✓	✓		✓	✓	✓		✓					✓		
dTIMS	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓		
HDM-4	✓							✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓					
HIMA	✓							✓	✓	✓	✓	✓	✓	✓		✓	✓								✓		
HIMS	✓		✓					✓	✓	✓	✓	✓	✓	✓						✓					✓		

⁵⁸ Includes street lighting, safety fencing and road markings

System	Asset type										Analysis features							Level		Referencing		Database				Platform			
	Pavement ⁵⁸	Drainage	Geotechnics	Bridges	Airports	Rail	Ports	Utilities	Condition Indicator	Condition Projections	Life-cycle Analysis	Asset Valuation	Treatments	Budgeting	Environment Impacts	Project	Network	Linear	Point/GPS	Oracle	SQL	MS Access	Visual Basic	Web-based	Java	GIS			
HMS-2	✓							✓	✓	✓	✓	✓	✓	✓						✓	✓	✓	✓						
Insight Enterprise	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓				✓					✓			
Integrated Asset Management System	✓	✓		✓				✓	✓	✓	✓	✓	✓			✓	✓				✓					✓			
MARCHpms	✓								✓	✓	✓	✓	✓	✓		✓	✓									✓			
Maximo					✓	✓	✓		✓				✓											✓					
MicroPaver	✓				✓				✓	✓	✓	✓	✓			✓	✓					✓	✓						
Optram						✓			✓	✓	✓	✓	✓			✓	✓						✓	✓		✓			

System	Asset type										Analysis features								Level		Refer-encing		Database			Platform			
	Pavement ⁵⁸	Drainage	Geotechnics	Bridges	Airports	Rail	Ports	Utilities	Condition Indicator	Condition Projections	Life-cycle Analysis	Asset Valuation	Treatments	Budgeting	Environment Impacts	Project	Network	Linear	Point/GPS	Oracle	SQL	MS Access	Visual Basic	Web-based	Java	GIS			
PMS	✓			✓					✓			✓	✓	✓		✓	✓	✓		✓									
RDM	✓		✓						✓	✓		✓	✓	✓		✓	✓			✓			✓						
RoadAsyst /BridgeAsyst	✓		✓		✓				✓	✓	✓	✓	✓	✓		✓	✓			✓									
Road Manager	✓								✓	✓	✓	✓	✓	✓		✓	✓	✓		✓						✓			
RoSyPMS	✓			✓					✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓				✓			
TIMS	✓	✓		✓					✓	✓	✓	✓	✓	✓		✓	✓	✓					✓						
WILCO	✓	✓				✓			✓	✓	✓	✓	✓	✓		✓	✓						✓						

(source: authors research)

Appendix B Equations proposed by Shiyab

Using the age and ESAL variable the full set of formulae proposed by Shiyab are shown below.

Table B-1: Proposed age and ESAL formulae

Variable	Lane	Relationship
Age	Fast	$IRI(\text{fast lane}) = 0.0028 \text{ Age}^2 + 0.0121 \text{ Age} + 0.744$
		or
		$IRI(\text{fast lane}) = 0.7442e^{(0.0507\text{Age})}$
	Slow	$IRI(\text{slow lane}) = 0.0035 \text{ Age}^2 + 0.0215 \text{ Age} + 0.769$
		Or
		$IRI(\text{slow lane}) = 0.7691e^{(0.059\text{Age})}$
ESAL	All	$\Delta IRI = 0.0078 \times ESAL^{(1.1164)}$
		with the actual roughness value determined by:
		$R(t) = R_0 + \Delta IRI$

(source: Shiyab, 2007)

where:

IRI = roughness

Age = age of the surface (years)

ESAL = equivalent standard axle load

R(t) = roughness level at time t

R_0 = roughness level at zero age (which also varied between the fast and slow lanes).

Appendix C Phase 1 SWOT analysis

Table C-1: SWOT analysis following completion of phase 1 individual consultations

Strengths	Weaknesses
<ul style="list-style-type: none"> • The stakeholder consultation leads on from previous stages of the research project. • Aware of current limitations and gaps in existing software. • Further future contacts identified: key stakeholder (NRA Strategic Planning Unit) that deals with quantification of environment and schemes; added into phase 2 consultations. • Fitness for purpose of the proposed model and development concept: <ul style="list-style-type: none"> ○ Carbon and noise are being discussed internally in the NRA, and considered a future growth area. ○ Examples of schemes with environmental issues were discussed. • As an issue, noise is more widely reported than carbon. • Costs of works (for local roads) provided for model testing data. 	<ul style="list-style-type: none"> • No defined methods for assessment – no consistent approach. • No thresholds used in scheme triggers. • Lack of data to use in model. • At the end of phase 1 there are information gaps. These need addressing in phase 2.
<ul style="list-style-type: none"> • Due to a lack of tools, there is currently limited use made of carbon and noise in scheme assessment. • No defined methods for assessment – no consistent approach. • There is a current gap in network environmental modelling. • Although carbon and noise issues are not yet seen as critical, they are debated and their importance is likely to grow. Therefore, now is the time to begin development of a framework that will allow them to be modelled. 	<ul style="list-style-type: none"> • From the phase 1 consultations, carbon and noise are not perceived to be important to road users. • Environmental objectives can change due to outside factors (e.g. political changes). What would any impacts be on the development of a model? • Are other models being developed?
Opportunities	Threats

(source: authors research)

Appendix D Phase 2 SWOT analysis

Table D-1: SWOT analysis following completion of phase 2 individual consultations

Strengths	Weaknesses
<ul style="list-style-type: none"> • Talked to key stakeholders and developed further contacts from initial discussions. • Robust information sourced from phase 2 consultations, which lead on from the literature review and the phase 1 consultations. • NRA like to control the works specification quite tightly but currently have no integration option for assessing environmental benefits on schemes, highlighting the need for such a tool. • Discussions on noise directives and noise limits. • Prices for carbon identified from central government documents, along with noise costs and costing rules (e.g. discount rates). • Contractor's opinions given for scheme drivers; used for developing treatment selection rules. 	<ul style="list-style-type: none"> • No consistent methodology identified for modelling the environment in road maintenance. • Additional contacts were identified.
<ul style="list-style-type: none"> • No consistent methodology identified for modelling the environment in road maintenance. • The method for assessing schemes was discussed, which presented an opportunity for developing the scheme rules in the model. • Additional contacts were identified. 	<ul style="list-style-type: none"> • Environmental issues were not an active priority for contractors. This was partly due to the need to meet their client's requirements, with no reward for exceeding them. • The environment was not perceived as being important to users. • The environment was discussed as being less of an issue in times of recession.
Opportunities	Threats

(source: authors research)

Appendix E Consultation background note

Developing a pavement whole life value model

Background

My project is to produce a pavement network level whole life value model for the development of 'value for money' maintenance strategies for the Irish National network. The main functionality of the model will be to estimate the budgets required to manage the network, in addition to addressing the consequences of different budgets, objectives and the effect of any restrictions on the network.

In the whole life value model I plan to include environmental impacts alongside the traditional direct costs (e.g. cost of maintenance). My aim is to model the effects of the environmental parameters of carbon and noise and develop the capability within the model to examine the impact of alternative policy objectives of including the consequences of these effects in the development of road maintenance strategies.

Including these indirect costs is not straightforward. The different perspectives and priorities of the various stakeholder groups is one of the aspects that contributes to the complexity. This consultation is aiming to get an understanding of these differences and take account of them in developing the model.

I would like to hold face-to-face discussions with a number of key stakeholders including experts, policy makers, asset owners and road users, who have an interest in the environmental factors of carbon and noise and the impact of including them on the management of highway assets.

On the reverse of this document I have included a more detailed guide to the questions that I would like to discuss. In summary, I would like to discuss the engineering driven issues that affect the road network, as well as some of the indirect sustainability issues, specifically the impacts of carbon and noise in road maintenance. This will include discussions on the policies that are important for road maintenance, the impact they have and how environmental policies might be relevant within road maintenance. I would also like to discuss the drivers for road maintenance (e.g. condition), how environmental parameters interact with the more traditional drivers and how these different issues are costed and balanced together.

I realise that not all of the research areas will be relevant to all those consulted and the discussions with each contributor will be flexible to fit around their experience.

I will provide a summary of the main points from the consultation exercise to all those who participated. Following on from this stage, I plan to use the information obtained to develop a questionnaire for circulation to mainly road users, as well as industry specialists.

Thank you for reading this document and I hope that you will be happy to participate in the discussion.

Stakeholder Discussion Proforma

Policy Objectives

- What are the policy objectives that drive the management of the road network?
- Are there any environmental policies that influence decisions on road maintenance?
- What impact do the policies have on different groups? – e.g. asset owners/users
- Are any policy objectives for road maintenance related to meeting wider environmental targets?

Road Maintenance

- What are the key drivers for road pavement maintenance?
- Have they changed over time?
- Are environmental drivers considered in road maintenance?
- What importance do you believe environmental parameters have in road maintenance? For example:
 - For road agency staff, is any weighting given to schemes that consider the benefits of maintenance on the environment?
 - For contractors, are any materials considered that are known to have a benefit in terms of their environmental values? – e.g. quieter surfacing, materials that have lower embodied carbon.
- When there are budget constraints, how are the different drivers balanced?

Data

- In what ways are carbon and noise currently measured in the road sector?
 - What tools exist for this?
- How are carbon and noise costed?
 - What costs are currently used?
 - How are long-term costs considered?
- How are direct (e.g. works costs) and indirect (e.g. carbon or noise) costs balanced?
 - If costs were available for all parameters would they be considered equally?
- For road maintenance schemes, would you spend more on carbon or noise issues?

Appendix F Intial focus group guide

Pavement value model focus groups Planning guide

Focus group overview

6 individual consultations were completed in phase 1 and 2 of the consultation exercise. The consultations gathered the opinions from a range of key stakeholders and the analysis and interpretation of those opinions identified gaps and opportunities for both future consultations and the development of methodologies to include value parameters within the pavement cost model.

The primary issue identified was the current gap in being able to model the wider benefits (especially environmental issues such as carbon and noise) at a strategic level. This is because there are no tools available that allow this. Particular issues were also raised over the quality of the data available for modelling carbon and noise costs.

From these previous consultations, the experts consulted converged on the opinion that users do not actively rank carbon and noise as highly as other more traditional elements such as cost. A number of experts noted that this can be exaggerated in a poor economic climate which is where we currently find ourselves. However, this was not the users' views, but rather the opinions of the individual experts consulted, who (apart from one person) were not representing users in their roles. Therefore, we haven't directly asked or represented the importance of the users' in these consultations to date.

The next phase of the consultation will therefore be a number of focus groups that directly aim to gather the users' opinions

Focus group aims

The outcomes of the focus group will feed into the development of the pavement value model methodologies for carbon and noise. The initial pavement cost model that has been developed for the NRA will be extended into a pavement value model through the inclusion of parameters for carbon and noise.

The aggregates and products used in road maintenance have calculable amounts of carbon within them, depending on the source of the material, bitumen, processing plant options etc. Road surfaces can also be classified by the noise levels they should produce. Using these characteristics along with government recommended costs for carbon and noise allows monetary values to be calculated for these parameters. All costs associated with a pavement maintenance option can be included to lead to a more encompassing cost-benefit analysis. By using centrally defined costs it allows for consistency across the industry. As such it should be noted that these focus groups are not aiming to discuss what costs are suitable for carbon and noise in any detail; partly because its meaning in an everyday context is lost and also because there is a large body of work on that already.

I will assess the awareness the users have towards the monetisation of carbon and noise but I will not explore the costing of the parameters in any detail. More important to come from the focus groups, and what I want to explore further before developing the model is to what extent are users prepared to accept trade-offs between all these competing factors in order for a maintenance option to reduce its impact on the environment? For example, if a product brought carbon and/or noise benefits but its costs meant that less maintenance could be undertaken are people accepting of that? The information obtained from these focus groups will be used to inform the

prioritisation rules within the model once the methodologies of carbon and noise have been incorporated.

Through the focus groups I am setting out to generate an understanding of how the different parameters (e.g. work costs, delays, carbon, noise) should be weighted when used together in modelling pavement maintenance. The sensitivity of these weightings can be explored as part of the sensitivity testing within the development of the modelling methodologies and the generation of a case study.

In terms of putting these weightings into the model, then it may be an option to have prioritisation options of the form:

- Minimum carbon - choose options that reduce the carbon impact on the network;
- Minimum noise - choose options that reduce the noise impact on the network;
- User preference - choose options that meet the users' requirements.

The user could then select the preferred prioritisation option within their scenario that they are running, with the 'user preference' option reflecting the weightings that the users discussed in the focus groups.

The focus groups will explore the same general questions and exercises in each one, except that the focus for the discussion on trade-offs will be:

- Focus group 1: Carbon;
- Focus group 2: Noise;
- Focus group 3: Combined carbon and noise.

The participants will be selected to provide a mix of gender and age at each focus group.

Focus Group timetable

- Activity 1: Welcome to focus group (5 minutes)
- Activity 2: Introductions and common ground (15 minutes)
- Activity 3: Managing maintenance (20 minutes)
- Activity 4: Prioritisation and trade-offs (35 minutes)
- Activity 5: Communicating value savings (10 minutes)
- Wrap-up (5 minutes)

Evening timetable

- 19:00 Welcome
- 19:05 Introductions
- 19:10 Topics
- 19:15 Environmental awareness
- 19:20 Activity 3.1 - Importance in getting the job done
- 19:30 Activity 3.2 - Conflicting town exercise
- 19:40 Trade-off scenarios
- 20:10 Ultimate hierarchy ranking
- 20:15 Communicating value savings
- 20:25 Wrap-up
- 20:30 End

Equipment list

- All focus groups
 - Paper, pens/pencils
 - Recorder, fully charged
 - Images of roads and maintenance to cycle through during participant arrival
 - Labels for name badges
- For Activity 1
 - Spare consent forms
- For Activity 2
 - -
- For Activity 3
 - -
- For activity 4
 - -
- For Activity 5
 - Examples of outputs
- For wrap-up
 - Incentive forms
 - Incentive cash

Room set-up

Semi-circular setup to include all participants.
Flip-chart and screen at centre front of group.

Activity 1: Welcome to focus group

Objectives

- Ensure participants understand the process and what is expected from them
- Ensure consent has been provided
- Ensure the group has a common understanding of the rules of the focus group

Materials

- Slide images on roads/road maintenance/environmental meanings such as carbon and noise (e.g. green spaces/recycling/tunnels/noise barriers) to be displayed as people arrive
- Consent forms (for completion, but they should have given consent as part of recruitment process)
- Name badges/sticky labels & pens

Process

1. Introduce myself and any other non-participants and introduce PhD and research

Actively point out slides that are cycling in background.

"Hi, and thank you all for taking the time out to come along this evening. My name is Tom [and this is my colleague _____] and I will be running the focus group this evening."

"As I explained briefly in the confirmation letter I am currently doing a PhD that aims to develop a process to compare road maintenance options using both works costs and environmental criteria. The environmental criteria could include issues such as carbon emissions, noise levels, impact on water quality, landscaping or archaeological significance and I am focussing on carbon emissions and noise levels."

[Focus group 1/Focus group 2/Focus group 3]

"Tonight we will explore how [carbon emissions/noise/carbon emissions and noise] can be used alongside the more traditional measures of works costs and delays to road users to choose when and where maintenance should be completed. The key issue that I am looking to address tonight is how [carbon emissions/noise/carbon emissions and noise] should be used alongside actual works costs in choosing the lengths for roadwork's. This information can then be used in my model to assess what impact it has when analysing lots of maintenance schemes? Does it result in some schemes being changed or costing more?"

2. What I expect from participants

"You are here this evening to assist me in my research, which is why you will be pleased to be reminded that at the end of the evening you will all receive £25 to cover your expenses."

"It should be fun work, as the job is to tell me what you think and how you see things."

"There are no right answers which makes it even easier! Everyone differs in their opinions and so whatever you personally think is the right answer. There is no test at

the end! In settings like this, it is all too easy to feel tempted to say what we think we should say, rather than what we actually think. But if you tell me what you actually think then it will make my analysis of all my consultations much more meaningful."

3. Workshop process

"There is no need for us all to agree on everything. But please listen respectfully to what everyone has to say and if you have a different opinion then feel free to explain that."

"If you feel like you are the only one with a particular opinion then please don't be tempted to stay quiet. Remember that you are just a sample of road users here today and so even if no-one else shares your opinion in this room there are likely to be many others outside of this room that you are effectively representing. And please make sure that we make room for everyone to speak within the group if they want to."

"Throughout the discussion this evening you do not have to say anything that you don't want to. And please remember that if you do not wish to answer anything you don't have to and you can withdraw from this discussion at any point during the evening."

4. Recording and consent

"So that I can concentrate on what you are all saying and make sure I keep up with your discussions I will be recording what we all say. This will allow me to listen back to it and make detailed notes at a later date. This should all have been mentioned to you previously. And so that it is easier for me to make notes when listening back to the recordings can I ask that you take it in turns to speak and don't talk over one another."

"If any of the things that you say tonight get used as quotations in my final thesis they will all be made anonymous."

"If you are happy to proceed based on what I have stated then please hand your consent form back to me if you have not done so already."

Check for any questions before continuing

Activity 2: Participants introductions and setting common ground

Objectives

- Allow participants to introduce themselves to the group
- Introduce topics so that people build more of a common understanding

Materials

- Flip chart and pen

Process

1. Introductions

Explain that you would like the participants to introduce themselves to the group and provide some background as to how they use roads (business/leisure/commuting) and what they drive and how often.

They can do a short introduction using:

- Name
- Background to road use
- What they drive and how often

5 minutes

If some participants seem quiet then probe a little more to try and make them feel more relaxed with the group and generate relationship.

2. Introduce topics to all participants

Discuss topics in terms of current maintenance practice.

- Whole life cost: not just cheapest initial costs, but best return over lifetime of investment; But more recently looking towards...
- Whole life value: not just about cost but about best value/quality however that is measured
 - You might think these concepts are not relevant to you and seem theoretical. But...examples of determining 'value' in everyday life:
 - Car:
 - WLC: Price, economy, servicing interval, depreciation;
 - WLV: looks, colour, make;
 - TV:
 - WLC: Price, size, guarantee;
 - WLV: delivery speed, features, brand, design, looks;
- Environmental considerations/issues: a number of key issues that individuals/companies have to address;
- Carbon emissions: targets have been set internationally, therefore UK and companies have to meet their targets and so need to monitor and act upon carbon emissions;
- Noise: not just annoyance but serious health impacts, which has huge cost to society.

5 minutes

3. What information are people aware of for either their own or others environmental savings and responsibilities?

General discussion to get people thinking of the environment - in order to make sure that as far as possible, the focus group begins the main discussion with a more equal understanding of what we are setting out to discuss.

Prompt questions:

- Are people aware of the carbon/noise issues?
- Have people seen a change in the emphasis on carbon/noise over time? Is it more widely reported in the media?
- Do people receive information in how they can lower their carbon footprint? Does it make them respond?
- Do people care about others environmental promotions? E.g. supermarket carrier bags not readily on display, marks and spencer promoting a lot of 'greener' initiative (e.g. on side of lorries about fuel efficiency, different factories)

5 minutes

Activity 3: Managing maintenance

Objectives

- Discuss how a road owner/operator has conflicting factors that mean an 'ideal' solution is rarely feasible
- Get participants to rank what they feel are the important factors in completing maintenance

Materials

- Flip chart and pen

Process

1. Discuss how a road authority has to manage their different assets together and maintain them within their allocated budgets.

Make sure that people are familiar with what the different assets are (e.g. lighting, road pavements, tunnels, earthworks, bridges, signs, drainage).

Maintenance is primarily driven by cost. But, a road owner has to ensure that all roads provide a level of service that a user expects, whilst at the same time trying to meet any policy objectives that they have been set and working within allocated budgets. This can lead to conflicts between what users expect and what can be delivered and even between the different assets themselves because invariably there is not enough money to sort out all of the problems.

Are they aware of any maintenance that currently impacts on them?
How many have experienced maintenance recently?

This exercise is to get your opinions on what is important to you in terms of getting maintenance done and what you expect it to be like, both when the maintenance is being done and after the maintenance.

So, first off, when a road requires maintenance what do you think is important in getting the job done (during maintenance) and what do you expect it to be like afterwards (after maintenance).

So let's spend a couple of minutes with you telling me what is important to you either during or after maintenance.

I also had a think about this before and came up with a number of ideas (show flip-chart).

(Are there any of their list that I didn't include - if so add them and also add them to spare labels).

Examples:

- Quiet (either during maintenance or new road surface)
- Minimal disruption
- Reliable estimates of journey times
- Preserving landscape
- Environmental impact
- Sustainable construction (e.g. recycling)
- Visibility - clear sight lines

- Light (during the night)
- Rest areas on motorways
- Clear signing
- Rest areas
- Avoiding peak times
- Pollution

What I would now like you to do is to take those listed items and rank them in order of importance to you. The 'during' maintenance items are in _____ and the 'after' maintenance ones are in _____. I want you to order them in one long list. For example, take dust, how important is that compared to the other items and compared both during and after the works.

If you divide into 2 groups and then spend 5 minutes coming up with your ordered list.

Questions to potentially ask afterwards:

- Why did they choose as they did? Why top choices? Why bottom?
- Are they more concerned with the end result (after maintenance) rather than how it was achieved (during maintenance)?
- Any general comments from the groups?

10 minutes

2. Undertaking an ordering exercise, but this time set the groups to have conflicting interests and see if this has an influence.

If you can stay in your groups we will now repeat the exercise but with a different viewpoint given to each group.

The aim of this is to help me interpret if opinions change depending on the location of individuals to the maintenance.

There is a road running around town A. This road is going to have 6 weeks of maintenance on it to lay a new road surface due to the existing one being in poor condition. At the same time the existing junctions will be improved. The result at the end of the 6 weeks will be a newly surfaced, wider road that will be able to accommodate increased traffic flows, resulting in fewer delays.

Group A: all live in town A alongside the road that is to be maintained. From their houses they can all see and hear the road, and they use it on a daily basis.

Group B: all live in a rural town B, 5 miles from town A. They live a long distance away from the road and cannot see or hear it but they do use it most days on their journeys.

Using the same list of maintenance actions both 'during' and 'after' maintenance I would now like you to order them based on putting yourself in the position of your town situation.

Questions to potentially ask afterwards:

- What are the noticeable differences from previously?
- Why did they change their minds from before?
- Why do the two groups now think differently?
- Does location have an impact on their opinions?

This aims to provide some information on the trade-offs that different users may make when in different situations. The outcome will help inform the level of sensitivity for the different parameters that could be tested in the developed value model as part of building a case study.

10 minutes

Activity 4: Prioritisation and trade-offs

Objectives

- Participants to think about what different aspects of maintenance they would be willing to compromise on
- A number of examples will be presented to the groups for them to discuss (in each example) which of the given options they would opt for
- Different examples will relate to carbon, noise or both and will be used in the different focus groups

Materials

- Flip chart and pens
- Paper and pens

Process

1. What maintenance options would people prefer when considering a range of value parameters?

This exercise aims to get the participants to think about trade-offs for the specific different maintenance treatments/options/materials that might exist.

When maintenance is occurring what trade-offs do users accept?

Having an understanding of the users' prioritisation preferences allows for weightings to be derived which gives good flexibility in modelling the different parameters.

What is important to them?

Do they prefer materials which meet the benefits of the environment or do they prefer cheaper options that just allow for more maintenance to be carried out? Explore through discussions and prompting.

Is there any noticeable difference based on the demographic characteristics of the individuals?

Carbon:

Description	Pros	Cons
Night working	Less traffic, less delays	More lighting
	Less delays, less car emissions	Smaller working window, getting less done, takes longer
Lighting off	Saving energy	Driving in dark
Concrete barriers	Embodied CO2 ~1/5 of steel over 50 years	Initial costs much higher - costs of work higher
	Significantly reduce crossover accidents	Less verges and natural drainage
Black top roads	Less carbon emissions in construction	Shorter life
	Less carbon emissions in construction	Requires more maintenance
Recycled material	Means less new material needs quarrying	More dusty during maintenance More equipment on site
	Less loads needed by lorry	Quality of recycled aggregate
	Landfill savings	Shorter interval until maintenance
Hard shoulder running	Increasing capacity, less delay, improved emissions	No standard emergency hard shoulder lane
	Prevents need for immediate widening - protecting landscape	Investment needed to improve hard shoulder condition
VMS	Up-to-date travel info	Installation and running costs/energy
Variable speed limits	More consistent speeds, less sudden braking, improves fuel efficiency	Perception of being slowed
Cars	Convenience	More emissions
Carbon	Meeting targets	Costlier maintenance

Noise:

Description	Pros	Cons
Concrete central reservation	Act as additional noise measure	Initial costs much higher than steel
Quieter road surfaces	Quieter for all (in and out car)	Costs more
Black top roads	Initially quieter	Noise levels increase over life
Concrete road	Smoother, better fuel efficiency	Noisier
Night working	Less traffic, less delays	Noise when sleeping
Recycled material	Less lorry loads needed to site, less noise	Wider window of quality of finished product
Tunnels	Reduce local noise	Cost
	Reduce local noise	More materials needed

30 minutes

2. Overall how do users rank cost/user delays/carbon/noise within road maintenance?

Ultimately, out of the above categories that will be represented within the whole life value model, how do users rank them?

Pairwise comparison.

5 minutes

Activity 5: Communicating value savings

Objectives

- When the whole life value model is developed then what will be the best way of communicating the results of the value analysis

Materials

- -

Process

1. How best can the messages/results be communicated

Once the whole life value model is developed, it could be used to communicate results directly to road users. Currently a road authority might communicate the total costs of their maintenance. By including carbon and noise then are users interested to know if certain options for maintenance have lead to a saving in carbon or a reduction in noise? Or is information on carbon and/or noise detail that is not really relevant?

What do the group see as the meaningful outputs?

Are users interested in hearing information about road maintenance schemes being carried out, local or not?

Does it matter more at a local level when a user is affected by the maintenance? - perhaps more so in the case of noise.

Do environmental savings/benefits have a meaning?

Do improvements in noise mean more when expressed as health savings? - over 210 million people in Europe are regularly exposed to noise levels considered to be potentially dangerous to health.

Do people feel differently in economic downturns?

Maybe a road authority can choose to publicise information such as 'the options in the programme this year have resulted in savings of x tonnes of carbon and y% of schemes have lead to a reduction in noise.' Would information like that interest people?

Different feelings towards use of information for internal vs external use?

10 minutes

Wrap-up

Objectives

- Summarise the discussions
- Note if the participants thought anything from the discussions surprised them
- Bring discussion to close

Materials

- Incentive forms
- Cash
- Paper with contact details

Process

1. Summarise the discussions we had

Bring out any summary points that we discussed as a group from the exercises.

2. Ask participants if anything surprised them from the discussions or made them think about certain aspects differently
3. Close discussion and hand out cash

Explain that they can contact me with any further points at a later date - contact information is the same as in the confirmation letter.

Thanks everyone for coming and giving up their time to contribute. Hand out cash once they have completed the incentive form.

Appendix G Amended focus group guide

Pavement value model focus groups Planning guide

Focus group overview

6 individual consultations were completed in phase 1 and 2 of the consultation exercise. The consultations gathered the opinions from a range of key stakeholders and the analysis and interpretation of those opinions identified gaps and opportunities for both future consultations and the development of methodologies to include value parameters within the pavement cost model.

The primary issue identified was the current gap in being able to model the wider benefits (especially environmental issues such as carbon and noise) at a strategic level. This is because there are no tools available that allow this. Particular issues were also raised over the quality of the data available for modelling carbon and noise costs.

From these previous consultations, the experts consulted converged on the opinion that users do not actively rank carbon and noise as highly as other more traditional elements such as cost. A number of experts noted that this can be exaggerated in a poor economic climate which is where we currently find ourselves. However, this was not the users' views, but rather the opinions of the individual experts consulted, who (apart from one person) were not representing users in their roles. Therefore, we haven't directly asked or represented the importance of the users' in these consultations to date.

The next phase of the consultation will therefore be a number of focus groups that directly aim to gather the users' opinions

Focus group aims

The outcomes of the focus group will feed into the development of the pavement value model methodologies for carbon and noise. The initial pavement cost model that has been developed for the NRA will be extended into a pavement value model through the inclusion of parameters for carbon and noise.

The aggregates and products used in road maintenance have calculable amounts of carbon within them, depending on the source of the material, bitumen, processing plant options etc. Road surfaces can also be classified by the noise levels they should produce. Using these characteristics along with government recommended costs for carbon and noise allows monetary values to be calculated for these parameters. All costs associated with a pavement maintenance option can be included to lead to a more encompassing cost-benefit analysis. By using centrally defined costs it allows for consistency across the industry. As such it should be noted that these focus groups are not aiming to discuss what costs are suitable for carbon and noise in any detail; partly because its meaning in an everyday context is lost and also because there is a large body of work on that already.

I will assess the awareness the users have towards the monetisation of carbon and noise but I will not explore the costing of the parameters in any detail. More important to come from the focus groups, and what I want to explore further before developing the model is to what extent are users prepared to accept trade-offs between all these competing factors in order for a maintenance option to reduce its impact on the environment? For example, if a product brought carbon and/or noise benefits but its costs meant that less maintenance could be undertaken are people accepting of that? The information obtained from these focus groups will be used to inform the

prioritisation rules within the model once the methodologies of carbon and noise have been incorporated.

Through the focus groups I am setting out to generate an understanding of how the different parameters (e.g. work costs, delays, carbon, noise) should be weighted when used together in modelling pavement maintenance. The sensitivity of these weightings can be explored as part of the sensitivity testing within the development of the modelling methodologies and the generation of a case study.

In terms of putting these weightings into the model, it may be an option to have prioritisation options of the form:

- Minimum carbon - choose options that reduce the carbon impact on the network;
- Minimum noise - choose options that reduce the noise impact on the network;
- User preference - choose options that meet the users' requirements.

The user could select the preferred prioritisation option within their scenario that they are running, with the 'user preference' option reflecting the weightings that the users discussed in the focus groups.

The focus groups will explore the same general questions and exercises in each one. The participants will be selected to provide a mix of gender and age at each focus group.

Focus Group timetable

- Activity 1: Welcome to focus group (5 minutes)
- Activity 2: Introductions and carbon/noise discussions (20 minutes)
- Activity 3: Prioritisation and trade-offs (30 minutes)
- Activity 4: Managing maintenance (30 minutes)
- Wrap-up (5 minutes)

Not included in main evening but kept as reserve discussion topic:

- Activity 5: Communicating value savings (10 minutes)

Evening timetable

- 19:00 Welcome
- 19:05 Introductions
- 19:10 Environment topics - general and transport discussions
- 19:25 Maintenance topics
- 19:30 Trade-offs
- 19:55 Import in a road
- 20:00 Town A
- 20:10 Town B & town discussion
- 20:20 Pairwise comparison
- 20:25 Wrap-up
- 20:30 End

Equipment list

- All focus groups
 - Paper, pens/pencils
 - Recorder, fully charged
 - Images of roads and maintenance to cycle through during participant arrival
 - Labels for name badges
- For Activity 1
 - Spare consent forms
- For Activity 2
 - -
- For Activity 3
 - -
- For activity 4
 - -
- For Activity 5
 - Examples of outputs
- For wrap-up
 - Incentive forms
 - Incentive cash

Room set-up

Semi-circular setup to include all participants.
Flip-chart and screen at centre front of group.

Activity 1: Welcome to focus group

Objectives

- Ensure participants understand the process and what is expected from them
- Ensure consent has been provided
- Ensure the group has a common understanding of the rules of the focus group

Materials

- Slide images on roads/road maintenance/environmental meanings such as carbon and noise (e.g. green spaces/recycling/tunnels/noise barriers) to be displayed as people arrive
- Consent forms (for completion, but they should have given consent as part of recruitment process)
- Name badges/sticky labels & pens

Process

5. Introduce myself and any other non-participants and introduce PhD and research

"Hi, and thank you all for taking the time out to come along this evening. My name is Tom [and this is my colleague _____] and I will be running the focus group this evening."

"Before we get underway with the main discussions this evening there are a few housekeeping items that I need to run through first. Whilst I am going through these items you may already have noticed that there are some pictures being displayed behind me. These images have been put up to start to get you thinking about the sorts of things that we might be discussing tonight, namely different ways that maintenance can be done and how it impacts upon both you and the environment."

"So, next – just a few introduction and housekeeping items we need to go through together. As I explained briefly in the confirmation letter I am currently doing a PhD that aims to develop a process to compare road maintenance options using both costs and environmental criteria. The environmental criteria could include issues such as carbon emissions, noise levels, impact on water quality, landscaping or archaeological significance and I am focussing on carbon emissions and noise levels."

[Focus group 1/Focus group 2/Focus group 3]

"Tonight we will explore how important [carbon emissions/noise/carbon emissions and noise] are to road users in deciding when and where maintenance should be completed. The key issue that I am looking to address tonight is how [carbon emissions/noise/carbon emissions and noise] could be used alongside actual works costs in choosing the lengths for roadwork's. This information can be used in my model to assess what impact it has when analysing lots of maintenance schemes? For example, does it result in some treatments being changed or some schemes costing more?"

6. What I expect from participants

"You are here this evening to assist me in my research, which is why you will be pleased to be reminded that at the end of the evening you will all receive £25 to cover your expenses."

"It should be fun work, as the job is to tell me what you think and how you see things."

"There are no right answers which makes it even easier! Everyone differs in their opinions and so whatever you personally think is the right answer. And there is no test at the end! In settings like this, it is all too easy to feel tempted to say what we think we should say, rather than what we actually think. But if you tell me what you actually think it will make my analysis of all my consultations much more meaningful."

7. Workshop process

"There is no need for us all to agree on everything. But please listen respectfully to what everyone has to say and if you have a different opinion feel free to explain that. And please make sure that we make room for everyone to speak within the group if they want to."

"If you feel like you are the only one with a particular opinion please don't be tempted to stay quiet. Remember that you are just a sample of road users here today and so even if no-one else shares your opinion in this room there are likely to be many others outside of this room that you are effectively representing."

"Throughout the discussion this evening you do not have to say anything that you don't want to. And please remember that if you do not wish to answer anything you don't have to and you can withdraw from this discussion at any point during the evening."

8. Recording and consent

"So that I can concentrate on what you are all saying and make sure I keep up with your discussions I will be recording what we all say. This will allow me to listen back to it and make detailed notes at a later date. This should all have been mentioned to you previously. And so that it is easier for me to make notes when listening back to the recordings can I ask that you take it in turns to speak and don't talk over one another."

"If any of the things that you say tonight get used as quotations in my final thesis they will all be made anonymous."

"If you are happy to proceed based on what I have stated please hand your consent form back to me if you have not done so already."

Check for any questions before continuing

Activity 2: Participants introductions and carbon/noise discussions

Objectives

- Allow participants to introduce themselves to the group
- Introduce environmental topics so that people build more of a common understanding

Materials

- Flip chart and pen

Process

4. Introductions

Explain that you would like the participants to introduce themselves to the group and provide some background as to how they use roads (business/leisure/commuting) and what they drive and how often.

They can do a short introduction using:

- Name
- Background to road use
- What they drive and how often

5 minutes

If some participants seem quiet probe a little more to try and make them feel more relaxed with the group and generate relationship.

5. Introduce environmental topics to all participants

- There are many international laws and policies relating to pollution into the atmosphere, oceans and seas, protecting habitats and wildlife.
- Traditionally environmental targets and laws were more health based but since 1990s they have shifted towards newer concerns.
- In terms of these newer concerns, the EU has some of highest standards around the world, developed over last few decades
- Today's priorities are:
 - Addressing climate change
 - Preserving biodiversity
 - Reducing health problems from pollution
 - Using natural resources more responsibly
- Much of UK law and policy driven by EU
- Recognised that it is not a case of 'do we need to do something', but rather 'what do we need to do' and 'how should we go about doing it'
 - 2006 Stern report showed that the costs of doing nothing are greater than the costs of acting now - e.g. fixing a tile on the roof
 - So we have to accept that finding ways to improve our carbon output or other environmental credentials (as a society in general) are already in place
 - So, as we have to do something, what should we be doing that best meets the needs of all those involved

Carbon General:

- Green house gas reduction target for EU is 20 percent below 1990 levels by 2020, and UK government and other arguing it should be increased to 30%
 - Although EU target is 20% not all nations have to do same; a 20% reduction in EU meant UK needed to meet 34% drop by 2020
 - All against backdrop of meeting 80% reduction by 2050
- It is all aiming to avoid ending up in a situation with dangerous climate change but sometimes that is hard to imagine and not always easy to understand in terms of scientific forecasts

In terms of generally working towards improving climate change, do you think enough is being done?

Are you aware of the sorts of issues/targets that the government has set and aims to reach?

Do you have any opinions on any carbon offsetting schemes that are advertised, such as when booking flights? Only 7% of people offset flights

Have climate change/carbon schemes ever impacted you in anyway? Has it made you change anything you did or were going to do?

Do people receive information in how they can lower their carbon footprint? Does it make them respond?

Do people care about others environmental promotions? E.g. supermarket carrier bags not readily on display, marks and spencer promoting a lot of 'greener' initiatives (e.g. on side of lorries about fuel efficiency, different factories)

Noise General:

- Noise is inevitably part of society today, comprising natural and man-made sources
- It is subjective and defined as unwanted sound, but one person's noise is another's sound
- Split between environmental noise (road, rail, air transport) and neighbourhood noise (people and activities, e.g. pubs, dogs, music)
- From a previous survey at turn of millennium, 42% of people felt noise affected their everyday lives
- Cost of noise pollution in UK from environmental noise alone estimated between £7 billion and £10 billion per year. Comprised from annoyance to public, health effects, loss of productivity
- Noise can come from many sources, even those we might initially feel are 'green' e.g. wind turbines

Has anyone been annoyed by noise in their everyday lives?

Does anyone have any examples of noise affecting them?

Carbon Transport:

- In the last few years about 20% of UK greenhouse gas emissions have come from the transport sector (2nd biggest sector behind the energy sector) so transport has a significant role to play
- In terms of carbon dioxide emissions specifically, road transport contributes about 25% of the total
- Perhaps some more obvious ways of tackling this are addressing emissions emitted from vehicles or by developing electric vehicles
- London introduced a low emission zone, effectively collecting penalties from higher emitting vehicles that enter the zone
- Smoother, less bumpy roads reduce emissions by generating less friction thereby improving vehicle fuel efficiency and reducing emissions

Have issues about emissions or environmental targets made you change anything about your driving habits?

Or has it ever made you think/question/alter journeys you have done or made you take public transport over using your own transport?

Would environmental concerns make you think about fuel efficiency if getting a new car?

Has it made you take public transport or perhaps car-share in situations when you previously wouldn't have?

Noise Transport:

- Most of us hear transport noise at some point during day or night
- With increasing road, rail, air traffic some are experiencing noise that could affect their quality of life and health
- There is an EU Environmental Noise Directive which aims to avoid, prevent or reduce harmful effects due to exposure to environmental noise
- A report by Greater London Authority estimated that up to 108 heart attacks a year in London could be caused by exposure to road traffic noise
- A number of ways in which transport noise could be reduced are:
 - Reducing speeds
 - Night time restrictions for certain transport vehicles/modes in noise sensitive areas
 - Quieter modern vehicles, e.g. buses
 - Noise barriers
 - Sound insulation
 - Vehicles - quieter vehicles, but sometimes quiet is dangerous e.g. for cyclists/pedestrians
 - Tyres - reducing tyre noise shown to be more cost effective than noise barriers and sound insulation

Does anyone have any experience of road noise from a resident's perspective?

Has noise ever affected anyone whilst driving?

Do people notice different noise levels from different routes/road surfaces?

Are people aware of noise barriers on some of the more major motorways and A-roads?

15 minutes

Activity 3: Prioritisation and trade-offs

Objectives

- Participants to think about what different aspects of maintenance they would be willing to compromise on
- A number of examples will be presented to the groups for them to discuss (in each example) which of the given options they would opt for
- Different examples will relate to carbon, noise or both and will be used in the different focus groups

Materials

- Flip chart and pens
- Paper and pens

Process

3. Introduce maintenance practices and different assets

Maintenance is primarily driven by cost. But, a road owner has to ensure that all roads provide a level of service that a user expects, whilst at the same time trying to meet any policy objectives that they have been set and working within allocated budgets. This can lead to conflicts between what users expect and what can be delivered and even between the different assets themselves because invariably there is not enough money to sort out all of the problems.

- Whole life cost: not just cheapest initial costs, but best return over lifetime of investment; For example, a cheap initial maintenance option may result in someone having to come back many times to do repairs but one that costs more at the beginning might mean that it lasts better and needs less repairs so may actually cost less overall, thus representing better value for money in the long-term. But more recently looking towards...
- Whole life value: not just about cost but about best value/quality however that is measured. The parameters that this tries to include generally happen to be more subjective and harder to place a monetary value on. But they can still influence people in the decisions that are made.
 - You might think these concepts are not relevant to you and seem theoretical. But...examples of determining 'value' in everyday life:
 - Car:
 - WLC: Price, economy, servicing interval, depreciation;
 - WLV: looks, colour, make;
 - TV:
 - WLC: Price, size, guarantee;
 - WLV: delivery speed, features, brand, design, looks;

Venn diagram of sustainability

How do you choose something that doesn't fall into the ideal? The right answer might vary between different locations, be different in different years etc.

5 minutes

4. What maintenance options would people prefer when considering a range of value parameters?

This exercise aims to get the participants to think about trade-offs for the specific different maintenance treatments/options/materials that might exist.

When maintenance is occurring what trade-offs do users accept?

Having an understanding of the users' prioritisation preferences allows for weightings to be derived which gives good flexibility in modelling the different parameters.

What is important to them?

Do they prefer materials which meet the benefits of the environment or do they prefer cheaper options that just allow for more maintenance to be carried out? Explore through discussions and prompting.

Is there any noticeable difference based on the demographic characteristics of the individuals?

Some of the trade-offs with have associated graphics to help with explaining them.

Carbon trade-offs:

- Night working
 - More lighting and energy required at night vs less delay
 - If at night, can only do smaller length as costs higher, therefore rest remains bumpy
 - If at night less delays means less emissions from vehicles
- Lighting
 - If road is not busy would they accept the lights being switched off to save energy
 - What if it was an unfamiliar road?
 - What if the road markings were improved?
- Concrete barriers
 - Have one-fifth carbon footprint compared to steel barriers but cost more to install
 - If don't mind, what about the reduction in accidents with concrete barriers
- Recycled materials used in road surface
 - Saving significant haulage of new material to site vs more machinery and noise during maintenance
 - Save recycled material going to landfill - 30% cost savings
- Hard shoulder running
 - Prevents need for developing neighbouring landscape vs hard shoulder replaced with regular emergency lay-bys
 - Both lead to less congestion therefore less emissions but hard shoulder running can be operational much quicker
- Cars
 - More convenient than public transport vs more emissions per passenger
- Electric cars
 - Produce less emissions vs less freedom in journey lengths due to charging

Noise trade-offs:

- Night working
 - Noise at night vs less delay
- Black top-road
 - Quieter road surfaces than concrete but need more maintenance
 - Shorter life
- Noise barriers
 - Protect residents from local roads noise vs visual intrusion
 - Cost more to install therefore less left for other maintenance schemes
- Quieter road surfaces
 - Quieter for road users and residents vs higher costs

25 minutes

Activity 4: Managing maintenance

Objectives

- Discuss how a road owner/operator has conflicting factors that mean an 'ideal' solution is rarely feasible
- Get participants to rank what they feel are the important factors in completing maintenance

Materials

- Flip chart and pen

Process

3. What is important to you in a road?

This exercise is to get your opinions on what is important to you in a road.

To undertake this activity I would like you to split into two groups and for you to order what is important to you from the following list:

- Quiet
- Well lit
- Surface condition
- Clear signing
- Clear markings
- Looking pretty

5 minutes

- The next exercise is to get your opinions on what is important to you when getting maintenance done.

So let's spend a couple of minutes with you telling me what is important to you during maintenance.

In the same groups as before I would now like you to order a list of statements related to maintenance, ranking them from the most important down to the least important.

The list is:

- Quiet
- Well lit
- Clear signing
- Clear markings
- Avoiding delays
- Green construction e.g. recycling
- Clean and dust free
- Limited pollution

I would like you to rank them according to this scenario:

There is a road that is going to have 6 weeks of maintenance on it to lay a new road surface due to the existing one being in poor condition. At the same time the existing junctions will be improved. The result at the end of the 6 weeks will be a newly surfaced, wider road that will be able to accommodate increased traffic flows, resulting in less delays.

The scenario is you all live in Town B. Town B is a rural town. It is a long distance away from the road and you cannot see or hear the road from the town but you do use it most days on your journeys.

10 minutes

Now reveal the rest of the graphic for the towns and show Town A. The road runs through Town A. The scenario now is you all live in Town A. You live next to the road and can see and hear the road from the town and you have to use it everyday for your journeys.

I would now like you to order the same list again but considering the new scenario.

5 minutes

Results from both groups will be displayed against each other for each Town.

Questions to potentially ask afterwards:

- Why did they choose as they did? Why top choices? Why bottom?
- Did they change their minds on the ordering between Towns?
- Are there any differences between the two groups?
- Does location have an impact on their opinions?

This aims to provide some information on the trade-offs that different users may make when in different situations. The outcome will help inform the level of sensitivity for the different parameters that could be tested in the developed value model as part of building a case study.

5 minutes

5. Overall how do users rank cost/user delays/carbon/noise within road maintenance?

Ultimately, out of the above categories that will be represented within the whole life value model, how do users rank them?

Pairwise comparison - use excel spreadsheet.

5 minutes

Activity 5: Communicating value savings

Objectives

- When the whole life value model is developed what will be the best way of communicating the results of the value analysis

Materials

- -

Process

2. How best can the messages/results be communicated

Once the whole life value model is developed, it could be used to communicate results directly to road users. Currently a road authority might communicate the total costs of their maintenance. By including carbon and noise are users interested to know if certain options for maintenance have lead to a saving in carbon or a reduction in noise? Or is information on carbon and/or noise detail that is not really relevant?

What do the group see as the meaningful outputs?

Are users interested in hearing information about road maintenance schemes being carried out, local or not?

Does it matter more at a local level when a user is affected by the maintenance? - perhaps more so in the case of noise.

Do environmental savings/benefits have a meaning?

Do improvements in noise mean more when expressed as health savings? - over 210 million people in Europe are regularly exposed to noise levels considered to be potentially dangerous to health.

Do people feel differently in economic downturns?

Maybe a road authority can choose to publicise information such as 'the options in the programme this year have resulted in savings of x tonnes of carbon and y% of schemes have lead to a reduction in noise.' Would information like that interest people?

Different feelings towards use of information for internal vs external use?

10 minutes

Wrap-up

Objectives

- Summarise the discussions
- Note if the participants thought anything from the discussions surprised them
- Bring discussion to close

Materials

- Incentive forms
- Cash
- Paper with contact details

Process

4. Summarise the discussions we had

Bring out any summary points that we discussed as a group from the exercises.

5. Ask participants if anything surprised them from the discussions or made them think about certain aspects differently
6. Close discussion and hand out cash

Explain that they can contact me with any further points at a later date - contact information is the same as in the confirmation letter.

Thanks everyone for coming and giving up their time to contribute. Hand out cash once they have completed the incentive form.

Appendix H NRA Data trends

The graphs in this appendix have been created from available condition data for the Irish network. Using the available data points they show the slope of trends (i.e. deterioration rates) that existed for each set of points.

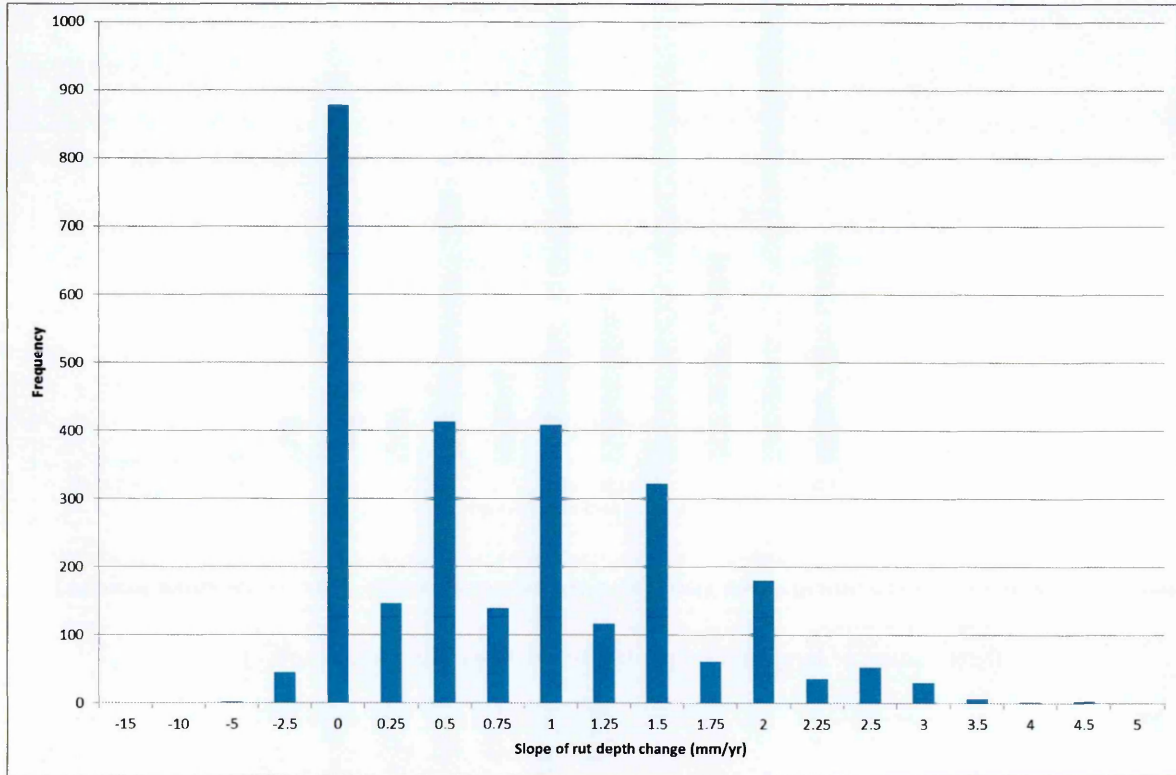


Figure H-1: Rut depth trending data (all trends from 3 or more data points)

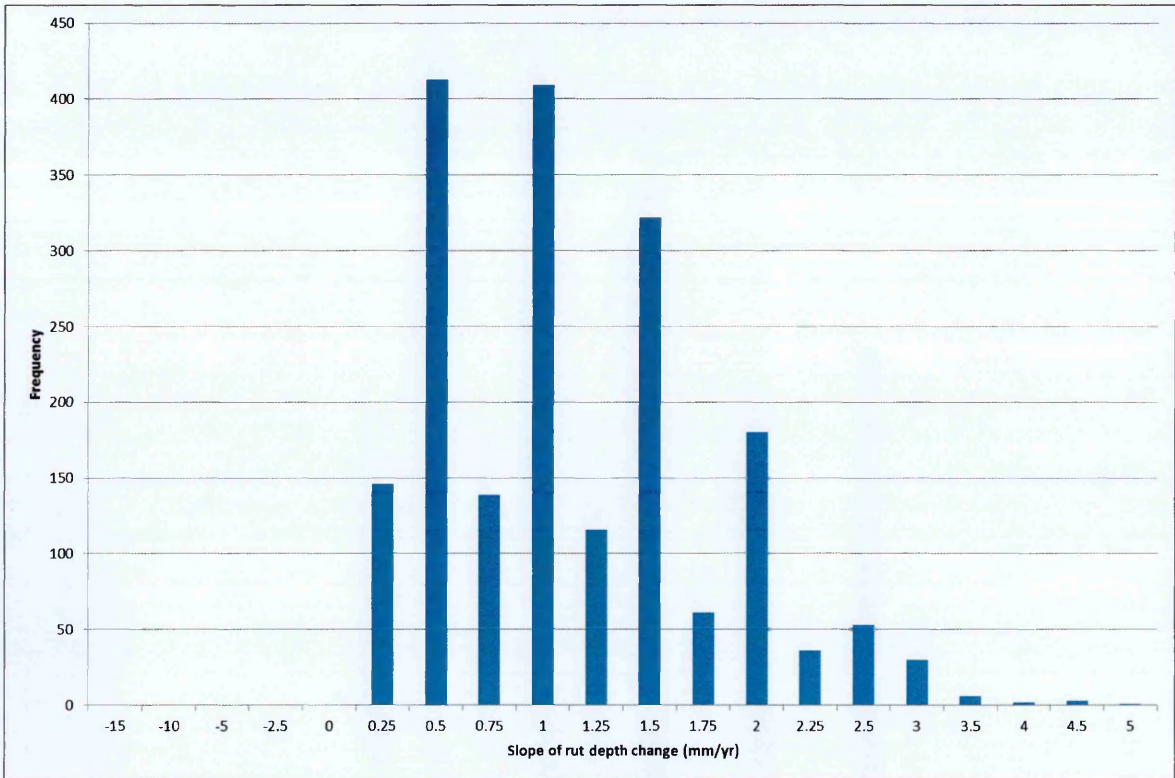


Figure H-2: Rut depth trending data (positive trends only from 3 or more data points)

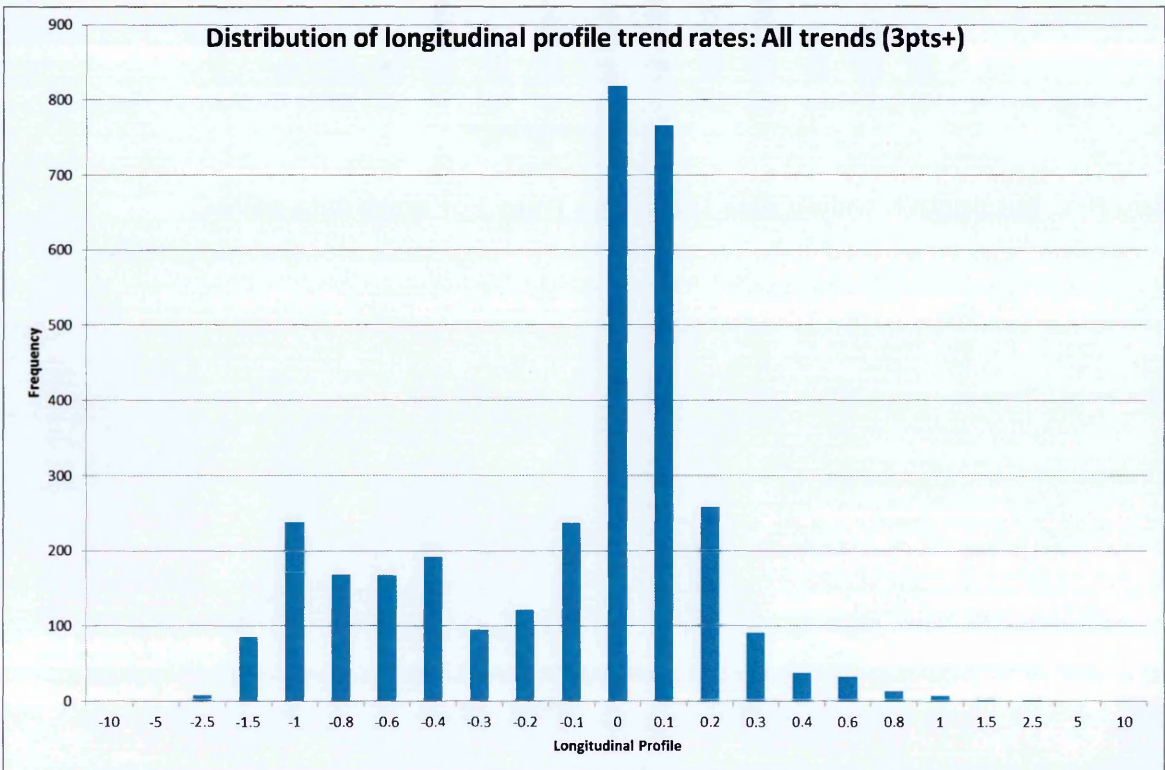


Figure H-3: 3m Longitudinal Profile trending data (all trends from 3 or more data points)

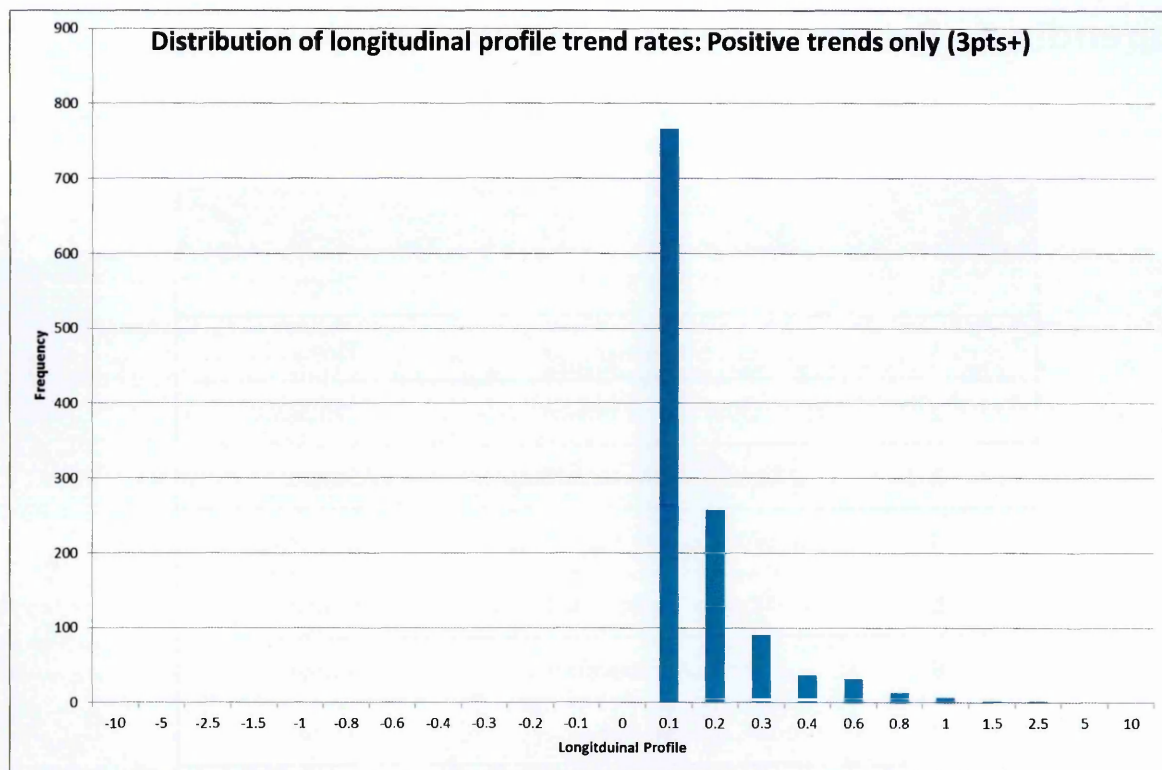


Figure H-4: 3m Longitudinal Profile trending data (positive trends only from 3 or more data points)

For the non-zero rut deterioration rates, the default rate chosen for the model aligns with the peak in trend rates shown by the data in Figure I-1 and Figure I-2. For the non-zero longitudinal profile rates, a change of 0.1 mm²/yr equated to approximately a 2% change based on the average value of the data points in each slope and was therefore chosen as the default deterioration rate for the initial default model setup.

One problem defining deterioration rates in a network level tool is defining a rule applicable to all (or at least a lot of) the network. For strategic level analyses a generic rate often has to be applied due to the type of analysis being undertaken (e.g. a grouped homogenous network with no location information).

The spread of the deterioration rates highlights the importance of sensitivity analysis around the specified deterioration rates. A potential model enhancement would be to have section specific deterioration rates that use the previous condition measurements to generate localised deterioration rates. This would alleviate some of the issues with assuming a network wide deterioration rate but it would also add in more detail into the model and take more processing time, a trade-off when creating a tool for undertaking high-level network wide analyses. This type of enhancement would be more suited to analysis of smaller networks or specific routes.

The current approach applies an 'average' rate to the whole network which is reasonable to assume when analysing network budgets etc. because the user is not using the model to tell exactly when and where to maintain, but rather to understand high-level budgetary and condition ranges for the policies being investigated.

Appendix I Default carriageway descriptions

Table I-1: Default carriageway descriptions and types

ID	Description	Carriageway
0	2 Lane Road	Single
1	Motorway	Mway
2	Dual Carriageway	Dual
3	3 Lane Road/2 Lane Side	Single
4	3 Lane Road/1 Lane Side	Single
5	One Way Forward	Single
6	One Way Reverse	Single
7	6 Lane Road	Dual
8	TPO	Single
9	3 Lane Motorway	Mway
10	3 Lane Dual	Dual
11	Reduced Single	Single
12	Wide Single	Single

(source: NRA data)

Appendix J Derived carbon quantities for excavation

Table J-1: Carbon quantities for material excavation

Planing depth (mm)	(a)	(b)	(c)
	Carbon for planing off waste (kg CO _{2e} /t)	Carbon for material transport (kg CO _{2e} /t)	Total carbon for given planing depth (kg CO _{2e} /t)
10	11.2	4.59	15.79
20	5.8	4.59	10.39
30	4.2	4.59	8.79
40	3.7	4.59	8.29
50	3.3	4.59	7.89
60	3.2	4.59	7.79
70	3	4.59	7.53
80	2.9	4.59	7.49
90	2.8	4.59	7.39
100	2.8	4.59	7.39
110	2.8	4.59	7.39
120	2.7	4.59	7.29
130	2.7	4.59	7.29
140	2.7	4.59	7.29
150	2.7	4.59	7.29
160	2.7	4.59	7.29
170	2.7	4.59	7.29
180	2.7	4.59	7.29
190	2.7	4.59	7.29
200	2.7	4.59	7.29
210	2.7	4.59	7.29

Planing depth (mm)	(a) Carbon for planing off waste (kg CO_{2e}/t)	(b) Carbon for material transport (kg CO_{2e}/t)	(c) Total carbon for given planing depth (kg CO_{2e}/t)
220	2.7	4.59	7.29
230	2.8	4.59	7.39
240	2.8	4.59	7.39
250	2.9	4.59	7.49
260	3	4.59	7.59
270	3	4.59	7.59
280	3.1	4.59	7.69
290	3.1	4.59	7.69
300	3.2	4.59	7.79

(source: authors research)

Appendix K Carbon costs

Table K-1: Carbon costs used in the model lookup tables (expressed in 2010 prices, in Euros , €/kg CO2e).

Year	DECC Non-traded				DECC Traded		
	NRA	Low	Central	High	Low	Central	High
2010	11.7	28.95	58.98	87.93	13.94	13.94	13.94
2011	12.3	30.03	60.05	89.01	6.43	13.94	18.23
2012	13.1	30.03	60.05	91.15	7.51	15.01	19.30
2013	13.1	31.10	61.12	92.22	9.65	17.16	21.45
2014	15.1	31.10	62.20	93.30	10.72	18.23	22.52
2015	32.8	32.17	63.27	95.44	12.87	20.37	25.74
2016	34.4	32.17	64.34	96.51	15.01	22.52	28.95
2017	36.2	32.17	65.41	97.59	16.09	23.59	30.03
2018	38.0	33.24	66.49	99.73	17.16	25.74	33.24
2019	39.9	33.24	67.56	100.80	18.23	27.88	35.39
2020	41.9	34.32	68.63	101.87	20.37	31.10	37.53
2021	44.0	34.32	69.70	104.02	22.52	35.39	46.11
2022	46.2	35.39	70.78	106.16	24.66	40.75	54.69
2023	48.5	35.39	71.85	107.24	26.81	45.04	62.20
2024	50.9	36.46	72.92	109.38	27.88	50.40	70.78
2025	53.4	36.46	73.99	110.45	30.03	54.69	78.28
2026	56.1	37.53	75.07	112.60	32.17	60.05	86.86
2027	58.9	38.61	76.14	114.74	34.32	65.41	95.44
2028	61.8	38.61	77.21	115.82	36.46	69.70	102.95
2029	64.9	39.68	78.28	117.96	37.53	75.07	111.53
2030	68.2	39.68	79.36	119.03	39.68	79.36	119.03
2031	71.6	43.97	86.86	130.83	43.97	86.86	130.83
2032	75.2	47.18	94.37	141.55	47.18	94.37	141.55
2033	78.9	50.40	101.87	152.28	50.40	101.87	152.28
2034	82.9	54.69	109.38	164.07	54.69	109.38	164.07
2035	87.0	57.91	116.89	174.80	57.91	116.89	174.80
2036	91.4	62.20	124.39	185.52	62.20	124.39	185.52
2037	95.9	65.41	130.83	197.32	65.41	130.83	197.32

Year	DECC Non-traded			DECC Traded			
	NRA	Low	Central	High	Low	Central	High
2038	100.7	69.70	138.34	208.04	69.70	138.34	208.04
2039	105.8	72.92	145.84	218.76	72.92	145.84	218.76
2040	111.1	77.21	153.35	230.56	77.21	153.35	230.56
2041	116.6	80.43	160.86	241.28	80.43	160.86	241.28
2042	122.5	83.64	168.36	252.01	83.64	168.36	252.01
2043	128.6	87.93	175.87	263.80	87.93	175.87	263.80
2044	135.0	91.15	183.37	274.53	91.15	183.37	274.53
2045	141.8	95.44	190.88	285.25	95.44	190.88	285.25
2046	148.8	98.66	197.32	297.05	98.66	197.32	297.05
2047	156.3	102.95	204.82	307.77	102.95	204.82	307.77
2048	164.1	106.16	212.33	318.49	106.16	212.33	318.49
2049	172.3	110.45	219.84	330.29	110.45	219.84	330.29
2050	180.9	113.67	227.34	341.01	113.67	227.34	341.01

(source: NRA & DECC)

Appendix L Derived noise dwelling data

Table L-1: Noise dwelling data in 5 dB bands for Ireland

County	Number of dwellings				
	55-59 dB	60-64 dB	65-69 dB	70-74 dB	>75 dB
Carlow	548	550	321	21	1
Cavan	441	261	209	95	0
Clare	1432	991	816	339	6
Cork	6000	3100	2400	1200	100
Donegal	2320	1605	1425	525	42
Galway City	2699	2019	2349	666	0
Galway County	1550	1141	1239	256	2
Kerry	1261	1352	1447	310	0
Kildare	7089	3481	1990	518	2
Kilkenny	1472	975	931	244	4
Laois	840	474	480	93	0
Leitrim	134	99	94	6	0
Limerick City	1942	1103	1706	1050	2
Limerick County	2591	1302	1326	485	15
Longford	596	400	452	127	0
Louth	1993	997	1201	1284	44
Mayo	659	601	520	54	0
Meath	1806	1191	647	188	6
Monaghan	915	517	711	290	18
N.Tipperary	557	285	275	109	0
Offaly	304	133	195	34	1
Roscommon	505	340	289	45	0
Sligo	1123	618	697	258	0
S.Tipperary	961	565	510	160	0
Waterford City	817	522	659	348	0
Waterford County	495	329	167	84	14
Westmeath	2464	1314	1133	893	0
Wexford	1335	807	822	844	0
Wicklow	3035	1895	1692	405	16

(source: authors research, from NRA noise mapping exercise)

Appendix M Example noise input calculations

This noise data set is derived for county Kilkenny, based on the noise map in Figure 6-4.

Step 1) Determine route lengths from NRA network data.

Table M-1: Route lengths for Kilkenny

Road	Base Route length (km)
N08	11.267
N09	54.685
N10	38.012
N24	15.031
N25	18.880
N29	3.647
N76	23.643
N77	24.363
N78	19.902

(source: NRA data)

Step 2a) An assessment is made of the split between the national and regional roads that have been noise mapped (based on scaling the difference using the noise maps). For Kilkenny, 95% of the mapped noise data is assumed to be on national roads.

Step 2b) The proportion of each road that is noise mapped (again, based on scaling using the noise maps) is determined, and applied to the total route length to derive the length of each road that has been noise mapped.

Table M-2: Assessments of noise mapping extents in Kilkenny

Road	Proportion of road mapped (%)	Length of mapped road (km)
N08	100	11.267
N09	100	54.685
N10	100	38.012
N24	100	15.031
N25	100	18.880
N29	100	3.647
N76	100	23.643
N77	20	4.873
N78	0	0
Total	-	170.037

(source: authors research)

Step 3) See total in above table (170.037 km).

Step 4a and 4b) The number of dwellings was factored by the proportion of data that applies to the national roads (step 4a) before being divided by the total length of national roads that have been noise mapped in the county (170.037 km) to determine the number of dwellings per km in each noise band (step 4b).

Table M-3: Noise dwelling calculation data

Data	55-59 dB	60-64 dB	65-69 dB	70-74 dB	>75 dB
No. of dwellings	1472	975	931	244	4
No. of dwellings factored by national road proportion (Step 4a)	1398	926	884	232	4
No. of dwellings per km of national road mapped (Step 4b)	8.22	5.45	5.20	1.36	0.02

(source: authors research)

The calculated number of dwellings per km was applied to the lengths of the roads in the county that had been noise mapped. For any roads that had not been mapped (i.e. N78), or for the proportions of roads that had not been mapped (i.e. part of N77) the number of dwellings affected for those lengths was set to 0 for each noise band.

This resulted in model input noise data being generated (see Table M-4).

Table M-4: Example model input data for Kilkenny

Route ID	Chainage (km)		No. of dwellings per km				
	Start	End	55-59 dB	60-64 dB	65-69 dB	70-74 dB	>75 dB
N08S1VOSL	127.184	138.453	8.22	5.45	5.20	1.36	0.02
N08S2VOSL	127.357	138.621	8.22	5.45	5.20	1.36	0.02
N09S1VOSL	0.522	55.227	8.22	5.45	5.20	1.36	0.02
N09S2VOSL	0.52	55.184	8.22	5.45	5.20	1.36	0.02
N10S1VOSL	0	38.057	8.22	5.45	5.20	1.36	0.02
N10S2VOSL	0	37.95	8.22	5.45	5.20	1.36	0.02
N24S1VOSL	0.087	10.597	8.22	5.45	5.20	1.36	0.02
N24S2VOSL	0	19.465	8.22	5.45	5.20	1.36	0.02
N25S1VOSL	53.808	72.692	8.22	5.45	5.20	1.36	0.02
N25S2VOSL	53.952	72.828	8.22	5.45	5.20	1.36	0.02
N29S1VOSL	0	2.859	8.22	5.45	5.20	1.36	0.02
N29S2VOSL	0	2.865	8.22	5.45	5.20	1.36	0.02
N76S1VOSL	17.415	20.934	8.22	5.45	5.20	1.36	0.02
N76S1VOSL	23.614	26.09	8.22	5.45	5.20	1.36	0.02
N76S1VOSL	26.09	29.838	8.22	5.45	5.20	1.36	0.02
N76S1VOSL	29.838	43.747	8.22	5.45	5.20	1.36	0.02
N76S2VOSL	17.398	20.934	8.22	5.45	5.20	1.36	0.02
N76S2VOSL	23.6	26.072	8.22	5.45	5.20	1.36	0.02
N76S2VOSL	26.072	29.821	8.22	5.45	5.20	1.36	0.02
N76S2VOSL	29.821	43.683	8.22	5.45	5.20	1.36	0.02
N77S1VOSL	0	4.873	8.22	5.45	5.20	1.36	0.02
N77S1VOSL	4.873	24.359	0	0	0	0	0
N77S2VOSL	0	4.873	8.22	5.45	5.20	1.36	0.02
N77S2VOSL	4.873	24.366	0	0	0	0	0
N78S1VOSL	0	19.899	0	0	0	0	0
N78S2VOSL	0	19.905	0	0	0	0	0

(source: authors research)

Appendix N Noise costs

Table N-1: Noise change costs for transport related noise (WebTAG Unit 3.3.2), and calculated lower and upper half-band values

Noise Change in the interval, dB _{Leq}	Value of a 1dB change within the stated interval, £ per household per dB per annum	Lower half-band values (e.g. 45-47.5)	Upper half-band values (e.g. 47.5-49.9)
< 45	0.00		
45 46	10.91	34.2 (=10.91+14.41+(0.5*17.79))	
46 47	14.41		
47 48	17.79		
48 49	21.16		
49 50	24.67		54.7 (=24.67+21.16+(0.5*17.79))
50 51	28.04	76.9	
51 52	31.42		
52 53	34.93		
53 54	38.30		
54 55	41.68		97.4
55 56	45.18	119.7	
56 57	48.56		
57 58	51.93		
58 59	55.44		
59 60	58.82		140.2
60 61	62.32	162.6	
61 62	65.70		
62 63	69.07		
63 64	72.58		
64 65	75.95		183.1
65 66	79.33	205.3	

Noise Change in the interval, dB _{Leq}	Value of a 1dB change within the stated interval, £ per household per dB per annum	Lower half-band values (e.g. 45-47.5)	Upper half-band values (e.g. 47.5-49.9)
66	67	82.84	
67	68	86.21	
68	69	89.59	
69	70	93.09	225.8
70	71	96.47	248.0
71	72	99.84	
72	73	103.35	
73	74	106.73	
74	75	110.23	268.6
75	76	113.61	290.8
76	77	116.98	
77	78	120.49	
78	79	123.86	
79	80	127.24	311.3
80	81	127.24	318.1
81	82	127.24 ⁵⁹	
82	83	127.24	
83	84	127.24	
84	85	127.24	318.1

(source: WebTAG unit 3.2.2 (DfT, 2012c))

⁵⁹ The research used to derive these costs assumed a constant monetary value for noise changes above 81 dB.

Appendix O Example noise surface change

A change from surface 1 to surface 2 results in the following noise change data:

- Initial change: -3 dB;
- Constant change: -1 dB; and
- Time to constant change: 4 years.

A change from an old surface 2 to a new surface 2 results in the following noise change data:

- Initial change: -2 dB;
- Constant change: 0 dB; and
- Time to constant change: 2 years.

There is an assumption that there is an intervention in year 0, changing from surface 1 to surface 2, and an intervention in year 12, changing from an old surface 2 to a new surface 2.

- Intervention 1 (all reductions based on noise level immediately prior to intervention):
 - Yr 0: 3 dB reduction (the initial change);
 - Yr 1: 2.5 dB reduction (due to a linear change from -3 to -1 in 4 years);
 - Yr 2: 2 dB reduction (due to a linear change from -3 to -1 in 4 years);
 - Yr 3: 1.5 dB (due to a linear change from -3 to -1 in 4 years);
 - Yr 4: 1 dB reduction (the constant change);
 - Yr 5-11: 1 dB reduction (the constant change until the next intervention);
- Intervention 2 (all reductions based on noise level immediately prior to intervention, i.e. yr 11):
 - Yr 12: 2 dB reduction (the initial change);
 - Yr 13: 1 dB reduction (due to a linear change from -2 to -0 in 2 years);
 - Yr 14: 0 dB change (the constant change);
 - Yr 15 onwards: 0 dB change (the constant change until the next intervention).

Appendix P Example noise whole-life calculation

This example of the noise implementation uses the following input data:

- The analysis period is 20 years, starting in 2013;
- Maintenance interventions occur in 2014, 2022, 2030 and 2038;
- The initial surface is a surface dressing;
- A new thin surfacing is applied in all interventions;
- The noise change values are as set in Table 6-19;
- The noise scheme was assumed to be in county Kildare, using initial noise input data from Table L-1;
- The maintenance scheme was assumed to be 200m in length meaning the initial number of dwellings in each band was:
 - 55-59 dB: 294;
 - 60-64 dB: 195;
 - 65-69 dB: 186;
 - 70-74 dB: 49; and
 - 75+ dB: 1.
- The noise costs were as in Table 6-11;
- The discount rate was 3.5%.

Table P-1: Noise pavement emission change due to surfaces

Year	Maintenance & new surface	Existing Surface	Initial change (dB)	Constant change (dB)	Time to constant change (yrs)	In-year change (dB)
Start		SD				
2013		SD	-	-	-	-
2014 ⁶⁰	TS	SD	-3.9	-2.5	5	-3.9
2015		TS	-3.9	-2.5	5	-3.6
2016		TS	-3.9	-2.5	5	-3.3
2017		TS	-3.9	-2.5	5	-3.1
2018		TS	-3.9	-2.5	5	-2.8
2019		TS	-3.9	-2.5	5	-2.5
2020		TS	-3.9	-2.5	5	-2.5
2021		TS	-3.9	-2.5	5	-2.5
2022	TS	TS	-1	0	5	-1.0
2023		TS	-1	0	5	-0.8
2024		TS	-1	0	5	-0.6
2025		TS	-1	0	5	-0.4
2026		TS	-1	0	5	-0.2
2027		TS	-1	0	5	0.0
2028		TS	-1	0	5	0.0
2029		TS	-1	0	5	0.0
2030	TS	TS	-1	0	5	-1.0
2031		TS	-1	0	5	-0.8
2032		TS	-1	0	5	-0.6

(source: authors research)

⁶⁰ The intervention years are shaded

Table P-2: Noise dwelling change due to interventions

Year	In-year change (dB)	Dwellings in noise band					Dwellings changed from reference dwellings ⁶¹				
		55-59	60-64	65-69	70-74	75+	55-59	60-64	65-69	70-74	75+
Start		294	195	186	49	1					
2013	-	294	195	186	49	1	0	0	0	0	0
2014	-3.9	217	188	79	11	0	230	152	145	38	1
2015	-3.6	222	189	87	14	0	213	141	135	35	1
2016	-3.3	228	189	94	17	0	197	130	124	33	1
2017	-3.1	234	190	102	19	0	180	119	114	30	0
2018	-2.8	239	190	110	22	0	164	108	104	27	0
2019	-2.5	245	191	118	25	0	147	98	93	24	0
2020	-2.5	245	191	118	25	0	147	98	93	24	0
2021	-2.5	245	191	118	25	0	147	98	93	24	0
2022	-1.0	234	176	99	20	0	49	38	24	5	0
2023	-0.8	236	179	103	21	0	39	30	19	4	0
2024	-0.6	238	182	106	22	0	29	23	14	3	0
2025	-0.4	240	185	110	23	0	20	15	9	2	0
2026	-0.2	243	188	114	24	0	10	8	5	1	0
2027	0.0	245	191	118	25	0	0	0	0	0	0
2028	0.0	245	191	118	25	0	0	0	0	0	0
2029	0.0	245	191	118	25	0	0	0	0	0	0
2030	-1.0	234	176	99	20	0	49	38	24	5	0
2031	-0.8	236	179	103	21	0	39	30	19	4	0
2032	-0.6	238	182	106	22	0	29	23	14	3	0
2039	-0.8	236	179	103	21	0	39	30	19	4	0
2040	-0.6	238	182	106	22	0	29	23	14	3	0
2041	-0.4	240	185	110	23	0	20	15	9	2	0
2042	-0.2	243	188	114	24	0	10	8	5	1	0

(source: authors research)

⁶¹ The noise reference years (years immediately prior to maintenance) are shaded dark; the associated lighter colour shading indicates the periods using the associated reference data for deriving the change in dwellings for each intervention

The highlighted cells for 2013 and 2014 (shown by the dashed line) are explained in more detail to explain the calculation process.

The changed dwellings in 2014 are calculated by multiplying the reference dwelling in the respective noise band by the in-year noise change:

- 55-59 dB: $294 * (-3.9/5) = 230$;
- 60-64 dB: $195 * (-3.9/5) = 152$;
- 65-69 dB: $186 * (-3.9/5) = 145$;
- 70-74 dB: $49 * (-3.9/5) = 38$; and
- 75+ dB: $1 * (-3.9/5) = 1$.

The dwellings in each noise band in 2014 are calculated by subtracting any dwellings lost from that noise band and adding any that move into that noise band from a neighbouring noise band:

- 55-59 dB: $294 - 230 + 152 = 217$;
- 60-64 dB: $195 - 152 + 145 = 188$;
- 65-69 dB: $186 - 145 + 38 = 79$;
- 70-74 dB: $49 - 38 + 1 = 11$; and
- 75+ dB: $1 - 1 + 0 = 0$.

This process is repeated for each year in the current intervention using the same reference dwelling numbers. The reference dwellings used in the calculations only changes where a new intervention is reached, at which point the reference dwellings becomes the number of dwellings in the last year of the preceding intervention.

NB: Dwelling calculations are rounded to the nearest whole dwelling and therefore rounding differences may be apparent in some of the examples.

The change in dwellings in each noise band is used to produce the change in noise costs (see Table P-3).

Table P-3: Calculated noise costs as a result of the interventions

Year	In-year change (dB)	Costs from changed dwellings (€)					Total costs (€)	NPV (€)
		55-59	60-64	65-69	70-74	75+		
Start								
2013	-	-	-	-	-	-	-	-
2014	-3.9	56,248	51,947	63,620	20,342	418	192,576	186,063
2015	-3.6	52,209	48,218	59,053	18,882	388	178,750	166,865
2016	-3.3	48,171	44,488	54,485	17,421	358	164,924	148,752
2017	-3.1	44,133	40,759	49,918	15,961	328	151,098	131,673
2018	-2.8	40,094	37,029	45,350	14,500	298	137,272	115,579
2019	-2.5	36,056	33,300	40,782	13,040	268	123,446	100,423
2020	-2.5	36,056	33,300	40,782	13,040	268	123,446	97,027
2021	-2.5	36,056	33,300	40,782	13,040	268	123,446	93,746
2022	-1.0	11,988	13,019	10,294	2,651	54	38,005	27,886
2023	-0.8	9,590	10,415	8,235	2,121	43	30,404	21,554
2024	-0.6	7,193	7,812	6,176	1,590	32	22,803	15,619
2025	-0.4	4,795	5,208	4,118	1,060	21	15,202	10,061
2026	-0.2	2,398	2,604	2,059	530	11	7,601	4,860
2027	0.0	0	0	0	0	0	0	0
2028	0.0	0	0	0	0	0	0	0
2029	0.0	0	0	0	0	0	0	0
2030	-1.0	11,988	13,019	10,294	2,651	54	38,005	21,177
2031	-0.8	9,590	10,415	8,235	2,121	43	30,404	16,369
2032	-0.6	7,193	7,812	6,176	1,590	32	22,803	11,861

(source: authors research)