CEDR Transnational Road Research Programme

Call 2012: Noise: Integrating strategic noise management into the operation and maintenance of national road networks

Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

funded by Belgium/Flanders, Germany, Ireland, Norway, Sweden, United Kingdom

QUESTIM

Cost/benefit analysis and Life Cycle Costing of noise mitigation measures and methodology for implementation into pavement management systems

Deliverable 5.1, June 2014

QUietness and Economics STimulate Infrastructure Management

Partners:

M+P consulting engineers (coordinator) (NL)

Transport Research Laboratory (UK)

Müller-BBM GmbH (D)

Aalto University (SF)

This page is intentionally left blank

CEDR Call2012: Noise: Integrating strategic noise management into the operation and maintenance of national road networks

QUESTIM: QUietness and Economics STimulate Infrastructure Management

Cost/benefit analysis and Life Cycle Costing of noise mitigation measures and methodology for implementation into pavement management systems

Due date of deliverable: 30.06.2014
Actual submission date:
Draft submission: 31.07.2014
Final submission: 18.12.2014

Start date of project: 01.02.2013 End date of project: 31.07.2014

Author(s) this deliverable:
Tom Buckland and Matthew Muirhead, TRL, United Kingdom

Quality Review:

On behalf of the Author's Institute				
Author:	Name	Matt Muirhead	Signature	
Technical Reviewer:	Name	Mike Ainge	Signature	

Version: Final Report, December 2014

This page is intentionally left blank

Table of contents

This page is intentionally left blank

Executive summary

With increasingly restricted budgets, road authorities are being required to manage their existing networks with greater efficiently in order to keep the roads in a serviceable condition and meet the expectations of their stakeholders.

An increase in the disparity of the demands on highway assets and the availability of resources is becoming a world-wide issue. Good quality asset management and appropriately designed systems can help to manage this disparity and enable highway authorities to make more robust decisions. 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.

Cost-benefit modelling and whole-life costing are established methods that are used within asset management to assist the road authorities and support the decisions they make. These methods use road network data to analyse the impacts of different investment scenarios in order to build a programme of work that best meets the policies and objectives of an organisation.

There is a growing importance being placed on the role of environmental considerations within these systems and this work package presents a methodology for integrating noise into such a Pavement Management System (PMS) and the data required, before demonstrating the inclusion of noise through a case study.

In addition, examples on developing an appropriate dataset are described, although it is expected that datasets should be localised where possible (e.g. referencing the specific pavement surfaces used on a local network). One clear area for improvement with this data is in being able to determine a ‘per km’ noise value for individual sections of a road which is not possible with the current data.

The noise data used to build up the noise datasets for this methodology (e.g. noise change values) were documented so that when new noise data become available they can be substituted into the process to create more up-to-date noise datasets.

The types of questions that can be investigated using this methodology are:

- What are the implications on a road maintenance programme between the different choices of noise surface available?
- If low-noise surfaces are selected at times of maintenance what are the implications on developing a maintenance programme?
- What are the longer-term effects (e.g. the timing and number of future interventions) when choosing low-noise surfaces for maintenance?

The noise methodology developed can help a road authority develop a greater understanding of the impacts from these types of questions, especially when compared to a more traditional approach that doesn’t include externalities alongside the direct works costs when developing a maintenance programme.

1 Introduction and background

Pavement networks have developed significantly over the last century (e.g. in terms of design, size) and coupled with the advances in road transport, their growth and improvement has led to a dramatic increase 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 (ERF, 2006). Conversely, without suitable investment and management the networks can deteriorate to levels which can result in adverse impacts.

With increasingly restricted budgets, road authorities are being required to manage their existing networks with greater efficiently in order to keep the roads in a serviceable condition and meet the expectations of their stakeholders.

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. 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.

Cost-benefit modelling and whole-life costing are established methods that are used within asset management to assist the road authorities and support the decisions they make. These methods use road network data to analyse the impacts of different investment scenarios in order to build a programme of work that best meets the policies and objectives of an organisation.

There is a growing importance that is being placed on the role of environmental considerations within these systems and this work package looks at how noise can be incorporated into a Pavement Management System (PMS) and the principles of whole-life costing. It considers the data required and demonstrates the inclusion of noise through a case study. The full objectives of the work package are outlined in Section 1.1 and the structure of the report is explained in Section 1.2.

1.1 Objectives of WP4

This work packeage aims to provide:

- A review of existing cost-benefit mechanisms with an emphasis on noise mitigation
- An understanding of the structure of existing cost-benefit and life-cycle cost models used to inform policy on strategic road networks
- The development of a state-of-the-art cost-benefit analysis methodology to assess

mitigation measures at a scheme level

- Ways in which noise mitigation measures can be integrated into strategic models and pavement management systems to help inform long-term planning

It is important to note that the focus is on the development of an appropriate *approach* for considering noise impacts within the structure of a PMS to help answer questions on the ramifications of mitigation options. It is not the purpose of the work package to provide detailed technical recommendations on the integration of noise data to a PMS since these will vary wildly depending upon the level of noise data available, the level of noise data and validation considered necessary for the decision support process and the format of the PMS being used for the cost-benefit analysis.

1.2 Structure of the report

The report is structured as follows:

- Chapter 2 introduces the concepts of a PMS and whole-life costing. It presents the key definitions and aims of these systems and methodologies, including how they deal with externalities such as environmental factors like noise.

- Chapter 3 provides a brief overview of the main methods of modelling, costing and mitigating noise giving context to its inclusion in a PMS and highlighting how this would add to existing methods of approaching traffic noise on National road networks.

- Chapter 4 covers the main topic of how noise could be integrated into a PMS so that, for example, different treatment options can be evaluated, and the corresponding data requirements.

- Chapter 5 pulls together the ideas from Chapter 4 into a case study on the integration of noise and evaluation of treatment options within the context of network maintenance.

2 Systems, data and processes

2.1 Pavement Management Systems

A Pavement Management System (PMS) is an asset management system specifically for road pavements and is one of the key tools for road asset management used by many highway authorities. 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 used by a highway authority.

A PMS is commonly used to store data about a road network (e.g. inventory, condition, traffic) and apply rules to that data to identify sections that need maintenance and prioritise the maintenance sections against any given time or budget constraints. However, the variation in both the characteristics of a pavement network and the surveyed data means that there is not one overall assessment approach or set of algorithms that can be universally applied to a pavement network.

Among other things, data is required to enable engineers 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 the networks to be kept operational more of the time; and
- Better understand the impacts (positive and negative) of the road pavement networks.

2.1.1 Existing systems

The asset management systems available all address the common aim of providing decision-making support. Some systems are concerned with only one asset type (e.g. HDM-4[1] for road pavements) while others can be used across multiple asset types (e.g. dTIMs[2], whose use has included road pavements, bridges, water and safety systems).

The main focus of systems and literature reviewed was from the UK, Europe, United States, Australia and New Zealand. A list of the systems reviewed is in Appendix A: Reviewed systems.

Generally two categories of systems exist on the market:

- General application systems; or

[1] http://www.hdmglobal.com/default.asp
[2] http://www.deighton.com/dtims9.html

- Bespoke application systems.

General application systems, or 'off-the-shelf' solutions, can be misleading in their name because they often require significant effort in being calibrated against local data and local conditions. The bespoke systems tend to be built for specific needs and data, and again are therefore calibrated for local conditions. However, due to their bespoke nature, if often means that the customised rules and algorithms are not suitable for use on other networks.

The degree to which the models fit into one of these categories is however ambiguous and significant effort is required for either approach. The quality and quantity of the data is the factor that normally exerts the greatest influence on the level of calibration obtainable.

2.1.2 Level of operation

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 in those systems.

2.1.3 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.

2.2 Whole-life costing

The concept of whole-life costing 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 life of the service 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 (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.

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, Armitage, Gallagher and Osorio, 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, Danielson and Snaith, 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).

However, pavements affect the wider society (e.g. delays, gaseous emissions) and so any maintenance decisions needs to recognise that externalities may also be affected.

2.3 Externalities

An externality is a cost or benefit that is 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 the outcome of a change of decisions in which they may not have direct involvement. 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 societal health and well-being.

The rapid growth of economies over recent decades, as well as an increased awareness of the wider impact of actions, 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, Friedrich, Link, Stewart and Nash, 2006).

Road transport is a key area within the transport sector. For more than a decade, a stated objective of the European Commission (European Commission, 2000; European Commission, n.d.) 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 is one example where there had been a common acceptance of their inclusion within the appraisal process.

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.

2.4 Whole-life value

Value for money is defined by the Office of Government Commerce (OGC, 2007) as

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

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.

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

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.

Noise is one of the key transport externalities currently discussed for inclusion within option appraisals but there is still a lack of recognised approaches at either a scheme or a network level, especially where a quantitative (or costed) methodology is desired.

This page is intentionally left blank

3 Noise

3.1 Introduction

Environmental noise is a significant problem and a major concern for public health and annoyance in Europe. According to the recent WHO-JRC report on the burden of disease from environmental noise (WHO, 2011), traffic-related noise may account for over one million healthy life years lost per year in the EU and other Western European countries. Urbanisation and a steep increase in traffic are the main drivers of escalating environmental noise exposure in Europe.

The social costs of traffic, rail and road noise across the European Union were recently estimated at €40 billion per year, equivalent to 0.35% of the EU's GDP. According to the European Commission's 2011 White Paper on Transport, the traffic noise-related external costs will increase to roughly €20 billion by 2050, unless further action is taken.

From the perspective of NRAs, it is noise from road traffic that is the source of concern. Noise levels at noise sensitive receivers will be heavily influenced by factors such as traffic volume, composition, speed and proximity.

Many governments/road authorities have their own national guidelines or legislation for controlling road traffic noise. These may include approaches such as

- Type-approval legislation governing the permissible noise from new vehicles to be sold in the country
- The mandatory evaluation of the potential noise impacts for new schemes, leading to enforcement of environmental noise limits/thresholds
- Taxation policy
- Noise mitigation policies for new or improved road schemes.

Additionally the introduction of the Environmental Noise Directive (EC, 2002) has sought to address noise pollution by requiring Member States to determine exposure to environmental noise through strategic noise mapping and action plans to reduce noise pollution. This information also serves to inform the general public about the levels of noise they are exposed to and about actions undertaken to reduce noise pollution to a level not harmful to public health and the environment. The noise maps and action plans are produced on a five year cycle and it is anticipated that future cycles may well use the CNOSSOS-EU noise model (Kephalopoulos et. al., 2012).

Sections 3.2 to 3.4 give a brief overview of mitigation measures, modelling noise impacts and costing noise impacts respectively in order to provide some background on the factors which are being considered for implementation in a PMS (see Chapter 4**Error! Reference source not found.**).

3.2 Mitigation

The most common mitigation measures used by the majority of NRAs are road surfaces and noise barriers. The former addresses noise mitigation at the source, while the latter acts on the noise propagating from the road to noise sensitive receivers.

A wide range of studies have been undertaken to investigate and understand the influence of road surfaces on road traffic noise or to develop new and innovative surface solutions. These research initiatives cover topics such as the acoustic classification of surfaces (Padmos et al, 2005), the performance of two-layer porous asphalt surfaces and thin layer surfaces (the Dutch IPG (Innovatie Programme Geluid) programme; Morgan, 2008), developing the experimental concept of poro-elastic road surfaces into a feasible noise mitigation measure (PERSUADE; persuade.fehrl.org), the performance of road surfaces over time (Chandler et al, 2003; Muirhead et al, 2010; van Blokland et al, 2014a) and the monetisation of such impacts (Veisten and Akhtar, 2011). A comprehensive review of all of these programmes is not required here, suffice to say that sufficient data exist which can readily be incorporated into a PMS as part of the assessment of this potential mitigation measure.

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. Within QUESTIM, WP2 assesses the acoustic durability of low-noise surfaces and develops an acoustic degradation formula, based on a thorough review of existing data, which would be appropriate for inclusion within a PMS (van Blokland et al, 2014a).

Noise barriers are a widely used form of noise mitigation on European roads and within QUESTIM, WP4 has assessed the acoustic durability of noise barriers and assessment techniques (Morgan, 2014). As part of the development of European Standards, standardised tests have been developed for characterising their acoustic performance. These test methods focus on **intrinsic** and not **extrinsic** characteristics of performance, i.e. the performance of the individual materials or components rather than on how the product is used.

It has been concluded in WP4 (Morgan, 2014) that the addition of lifetime acoustic performance data for noise barriers within a PMS is not feasible or beneficial due to the lack of existing data and the difficulties of relating intrinsic characteristics to far-field noise levels in a manner that could be simply implemented without any noise mapping/modelling. However, the use of a PMS as a broader data repository for noise barrier records, so that asset information is held within a common location is recommended and (within WP4) proposals are set out for the type of data that could potentially be incorporated.

Of the 19 NRAs who responded to the QUESTIM noise barrier survey, 13 use noise barriers as their primary mitigation measure, 5 use low-noise surfaces and one uses façade insulation.

In addition to these primary noise mitigation measures, which may fit directly into a PMS, there are other measures which have the potential to have either a direct or indirect benefit to road traffic noise but whose integration into a PMS is not explicit.

These measures include type-approval noise limits for vehicles (revised levels for which have just been agreed by the European Commission, see http://ec.europa.eu/enterprise/sectors/automotive/environment/noise/index_en.htm), Intelligent transport Systems (ITS) used to control the speed and flow of vehicles on busy roads and restrictions on Heavy Good Vehicles at certain times of day such as the London Lorry Control Scheme (www.londonlorrycontrol.com). Some of these measures are investigated in more detail within the CEDR funded DISTANCE project.

3.3 Modelling noise impacts

In addition to the strategic noise mapping performed under the END, as mentioned in Section 3.1, it is often necessary to model and assess traffic noise impacts associated with proposed changes to road networks. This might be, for example, to assess entitlement to noise insulation or compensation, to determine the required level of mitigation for the scheme or to understand the change in noise climate brought about by the change to the road network.

These assessments follow national guidance on permitted environmental noise levels and tend to use national calculation methods. Such methods are often quite complex, requiring detailed spatial, topographical and traffic data in order to perform the calculations; see for example (Morgan and Nelson, 2000) for a review of methods used at that time.

Although such calculations can be quite comprehensive they are largely reactive rather than proactive in their assessment in that they are used to estimate the noise climate arising from a pre-defined change to the road network. Sometimes they will be used to consider different mitigation measures or even small adjustments to the road layout but even then the results are rarely integrated with either other factors such as journey time improvements, maintenance and safety requirements (scheme level) or the potential benefits of alternate changes to other parts of the road network (strategic level).

For example, in a practical application, Kent Highway Services (2008) produced a method for prioritising their investment on using quieter surfacing options. They acknowledged they had no influence on tyre choice or engine noise and therefore their focus on vehicle noise was by including the road surface noise as a measure in maintenance prioritisation. For different maintenance scenarios the total number of people bothered was determined across the scenarios, and the cost of the maintenance was divided by reduction in the number of people affected by noise for each scenario. 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).

It is the aim of integrating noise into a PMS to address many of these shortcomings but in doing so it would likely be computationally, logistically and time prohibitive to expect the enhanced PMS model to perform these detailed noise calculations. Therefore, when this issue is looked at in detail in Section 4.4, baseline noise data are taken from existing noise maps. This neatly circumvents the need for complex noise propagation calculations and allows the focus of the noise data to rest on determining the nature of potential mitigation options together with the number of people who are likely to benefit from such mitigation.

Inevitably there are some short comings in this approach as the relative importance of various roads as components to the overall noise level may be lost and lower trafficked roads may not be modelled at all but it is important to outline the structure of the integration and consider the main differentiating factors first before addressing these concerns. This is discussed further in Section 4.4.1.

3.4 Costing noise impacts

Noise is one of the environmental impacts that road agencies may assess in a quantitative way. For modelling the cost impacts of noise within pavement life cycle analyses a number of approaches have been documented. The Noise Sub-Objective (DfT, 2012a) (which forms part of the WebTag guidance from the Department for Transport, UK) advises that if there are data available on either the number of properties or people affected by noise changes then a valuation study should be attempted.

Whilst there is some evidence for the detrimental effect transport noise can have on health through mechanisms such as annoyance, heart disease, stress, sleep disturbance and cognitive development, see (Clark and Stansfeld, 2007), many of the findings are inconclusive and further work is needed before the magnitude of such potential effects can be determined.

Therefore the most common approach at present for valuing transport noise is through the use of hedonic pricing studies, although other approaches are available for developing noise costing datasets. 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, see for example (FEHRL, 2006a). 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 3-1).

Table 3-1: Property price reductions due to noise

Research	Reduction (%)
Lake, Bateman, Day and Lovett (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

Research	Reduction (%)
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

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, Udo and Janssen, n.d.).

When undertaking analyses in a PMS using noise data, sensitivity tests should be completed to test the sensitivity of any results to changes in the noise costs used (e.g. to test the robustness of the analysis to specific costs used from any pricing studies).

This page is intentionally left blank

4 Integrating noise into a PMS

Whilst there are stand-alone tools available that can be used for a preliminary assessment of some environmental elements at the project level, there is a lack of consistent methodologies and robust tools both at the project and at the network level. 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 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.

Overall, although methods exist to help monetise externalities, no one method is documented as the most appropriate to use. In any method, if data from other studies are used 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, n.d.). In this report, central government costs were used as opposed to traneferring costs from other local studies.

This chapter describes the process undertaken to integrate noise into a PMS, first starting with a description of the 'base' PMS (i.e. the developed model without noise incorporated).

4.1 Base model

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:

1. Network database: The network database is 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:

    - 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);

    - 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). Examples of the condition data that would be held in this database could range from rutting, longitudinal profile or non-road profile condition data such as noise; and

- 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.

2. Reference database: The reference database 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 referenced 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:

    - Deterioration rates for the condition parameters;
    - Maintenance thresholds;
    - 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);
    - Unit costs (e.g. for the works);
    - Working patterns (i.e. whether closures for maintenance are 24 hour, off-peak only or night-only);
    - User delay costs (depending on closure type, working pattern and traffic flow);
    - Closure types;
    - Homogenisation correlation values, used to compare a calculated homogenisation statistics against to determine if sections are suitable grouped for homogenisation;
    - Display names (e.g. full county names and not abbreviated names as stored in some database tables);
    - Carriageway types;
    - Default data (i.e. data used to fill gaps where survey data are missing or used to reset condition parameters following a treatment);

- Network class (i.e. whether a road is a primary or secondary road); and
- Surface types.

Additional reference data was incorporated into the reference database later for the noise methodology:

- Unit costs for noise emissions; 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 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 was developed on that basis and uses the data accordingly to allow maintenance strategies to be created and compared.

As new reference data become available (e.g. noise costs, noise deterioration) the reference database should be updated so that any analyses make use of the latest available data.

The network database and reference database link into a workspace are used as the input into the 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 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.

4.2 Consultation

A consultation document was sent out to member partners to gather their wider views on noise and its integration in pavement management systems. A copy of the information request that was circulated can be found in Appendix B: Pavement Management Systems and noise: Information request.

The consensus of opinion agreed with the circulated positional note on noise in pavement management systems. That is, for the responses received (from England, Ireland and Norway) pavement management systems are used but the consideration of costs is primarily focussed on direct costs and no system included noise as a parameter used in costing.

The responses agreed that the systems employed are generally flexible enough that additional parameters could be incorporated in the future and the response from England stated that it is an aim that noise data is considered in the future in asset management and associated systems.

Noise mapping has been completed by the three agencies who responded to the consultation but only limited use has been made of the resulting data (e.g. identifying road sections for noise reducing pavements on a trial basis). Noise management is considered important for maintenance and improvement but noise levels are not routinely considered as part of the pavement management process.

It was stated that better care needs to be made of maintaining the noise reducing elements already in place on existing roads and it was suggested in one response that this could include identifying sections which would benefit from a low-noise surface. A cost-benefit analysis that included these maintenance types and decisions in its appraisal would allow appropriate sections to be flagged in a pavement management system.

Therefore, there was a clear gap for a methodology that allowed for noise to be incorporated as a parameter for including in cost-benefit analyses in pavement management systems.

4.3 Treatment options

4.3.1 How can noise fit into treatment identification?

Parameters used for modelling 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 to address that particular defect. Rutting or unevenness are examples of maintenance drivers.

A parameter that is a reporting function is used to calculate an effect of the selected maintenance option, 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 externality of noise the first step was to determine which category the new parameter belonged to because it has implications for how noise is treated in the model.

In determining 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 noise. Noise is only a direct driver in a small proportion of schemes but stakeholders did recognise that noise was growing as an issue. As both the debate around noise mapping and people's awareness grows, the methodology therefore needed to reflect that a growing number of future maintenance needs are likely to involve noise.

Table 4-1: Maintenance drivers and reporting calculation status for noise

	Driver	Reporting calculation
Noise	✓	✓

4.3.2 How can noise fit into treatment options?

One of the key inputs in deciding how to incorporate noise into the modelling methodologies is in identifying the potential questions and outputs a model would be expected to address.

For example, a highway authority might currently be interested in the impact of a maintenance programme that minimises delays to road users or one that selects the lowest cost option. A natural extension of this for noise is to give the model the ability to ask what the outcome would be if only the lowest noise options were chosen when developing a maintenance programme.

Regardless of the actual externalities modelled, the Do Minimum option has to reflect maintaining a base level of safety as required on the network. Noise does not have a role to play in determining minimum safety levels and therefore the maintenance requirements and impacts of the Do Minimum option remained unchanged.

Because noise is deemed to be a potential driver of maintenance, that meant creating an additional Do Something option that could be used when triggered solely by a noise defect (i.e. a low-noise option). If no condition defects would have led to a maintenance intervention but the noise is above an allotted threshold, the noise Do Something treatment would therefore get selected.

Each required Do Something treatment is still triggered by set engineering standards that a highway authority adheres to but for each identified maintenance scheme there are additional options for that treatment that reflected:

- A standard approach (i.e. not a low-noise surface, although a new surface replacing an old one is still expected to generate initial noise savings); and

- A low-noise approach (i.e. a low-noise surface that delivers enhanced noise savings, but has a shorter expected life and therefore more frequent interventions).

In order for the additional Do Something option to show differences between the resulting treatment profiles (and associated impacts on the network) attributes were associated that could be used to model the expected differences in whole-life performance and outputs:

- Unit cost – with each treatment having a different cost associated it allowed the whole-life cost of each treatment profile to be assessed, and allowed the unit works cost of the treatment to be balanced with the other factors listed (i.e. trying to bring additional factors into the modelling and decision making process);

- Expected life – each treatment having a different expected life allowed questions to be modelled and investigated such as is it better to have a higher-cost treatment with long intervals between interventions, or a lower-cost more frequency maintenance regime; and

- Noise reduction levels – the different treatments would result in a new specific surface type when used and the associated noise reduction would allow for different noise levels to be modelled.

The different values associated with the attributes result in different treatment profiles being generated between the options, allowing the impacts from those different profiles to be assessed. For example, the attributes allow documented shorter expected lives and higher costs to be associated with a low-noise treatment.

The base model was enhanced to allow for these additional Do Something options for each treatment so that the complete list of options was as shown in Table 4-2.

Table 4-2: Model treatment options

Driver	Noise
Do minimum	-
Do something$_{\text{standard}}$	Standard
Do something$_{\text{low-noise}}$	Low

In order to programmatically include the Do Something options for low-noise alongside the standard Do Something, and to get the most output from modelling these different treatment options, specific methodologies were developed for incorporating noise into the model as key data parameters.

4.4 Developing a noise reporting mechanism

The noise methodology developed was based on using actual data available for a road network and used data from the Irish road network.

The noise data for use in a PMS needs to reflect the network and analysis being undertaken. For example, if a scheme level analysis is being undetrtaken, detailed localised noise data are most appropriate if they are available. However, if a network level, strategic analysis is being undertaken then coarser level noise data will allow adequate modelling of policy senarios at a network level, especially considering that the detailed localised noise data are unlikely to be available for a whole network.

The development of a methodology discussed making best use of available data. As such, European directive driven noise maps are suggested as a potential source of noise data that are likely to provide the best coverage across networks. However, other sources of noise data can be substituted in place of noise map datasets as long as the format provides a measure of the number of properties in different noise bands along the network.

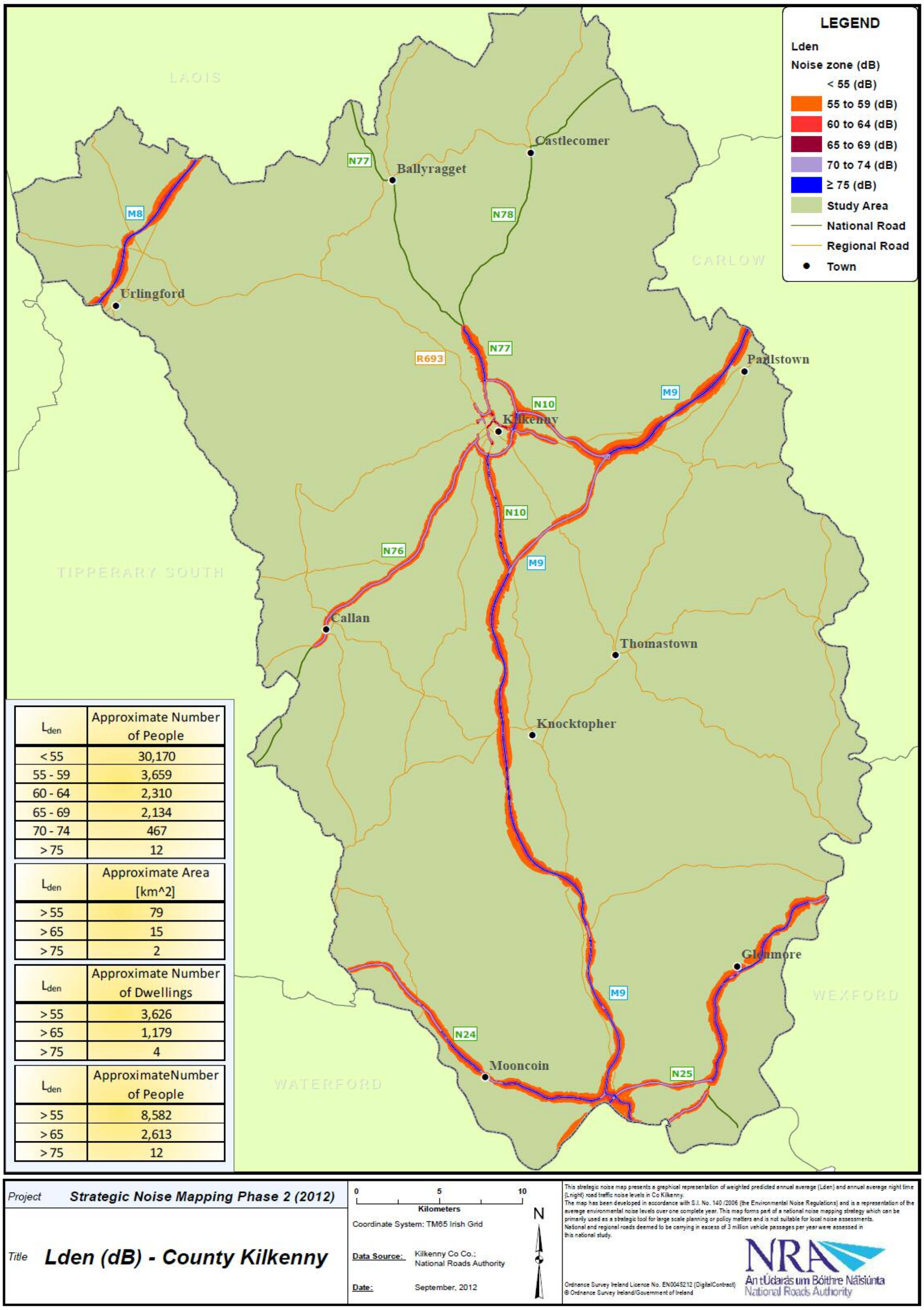
4.4.1 Available data – Noise maps

4.4.1.1 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. The process to create such a dataset is discussed such that it can be applied by other road authorities who have compiled noise maps.

The European Noise Directive (END) requires 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 which 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 4-1) shows the level of outputs from the latest phase of noise mapping undertaken in Ireland.



L_{den}	Approximate Number of People
<55	30,170
55 - 59	3,659
60 - 64	2,310
65 - 69	2,134
70 - 74	467
>75	12

L_{den}	Approximate Area [km^2]
>55	79
>65	15
>75	2

L_{den}	Approximate Number of Dwellings
>55	3,626
>65	1,179
>75	4

L_{den}	ApproximateNumber of People
>55	8,582
>65	2,613
>75	12

Figure 4-1: Phase 2 noise mapping for county Kilkenny, Ireland (source: National Roads Authority, 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:

- Approximate number of people affected;
- Approximate area affected; and
- Approximate number of dwellings affected.

Other available measured noise data may be through direct measurements using Statistical Pass-By (SPB) or Close ProXimity (CPX) methods, see (ISO, 1997) and (ISO, 2000) respectively. If CPX data are available then QUESTIM WP3 (van Blokland et el, 2014b) discusses a method for weighting data which could be used to populate the input dataset. Any CPX data could be used to inform the development of the required noise change datasets. Additionally, if an agency acquire significant coverage for CPX data in the future then the methodology described in WP3 can be used to validate outputs. However, there are trade-offs to be made between the level of detail of the noise data and the coverage, primarily due to the resources required to collect direct measurements across a whole network. A road agency will have to determine the most suitable input data to use. The different noise measurements methods are discussed in QUESTIM WP2.

4.4.1.2 Required data

However, the data required for modelling noise as a condition parameter at network level is different from the noise data found in the map. 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 chainage records of the extents 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 both 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 is 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.

These required data would be routinely expected for scheme specific noise appraisals at a project level but less so at network level. When modelling noise impacts to compare project level alternative options, 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 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 4-1 represented the best source of noise data for the Irish road network. However, as discussed in the previous section, it is not the only source of noise data available; other directly measured noise data may be available depending on the network being modelled. The developed methodology is flexible enough to be used in conjunction with different sources of noise data, which itself might be influenced by the level of analysis being undertaken (e.g. network levels versus project level). A combination of noise data could also be used but this relies on the user being aware of any differences that may exist between the different data sources and the impacts this may have on an analysis. That therefore extends the potential benefits of the developed methodology for use by other road authorities.

If directly measured noise data are available for a whole network it is recommended to use these. However, in place of network wide directly measured noise data and to be consistent with outputs from END across Europe noise mapping data can be used and the worked examples have been developed using this data source. It should be noted that the noise mapping data allows for a correction to be made due to the surface type in deriving the noise values. Whatever surface type correction has been applied to the noise mapping data, it is independent of the surface type used in the primarily PMS data for the main modelling. Therefore, if it has been specified wrongly in the derived noise mapping data, it can be amended if required, but even if the noise data is not amended in that situation the (incorrectly) defined surface type is not carried through into the main PMS database; this parameter is defined directly from a road authority's own records.

The apparent problems in using the noise mapping data as it is available, and the potential mitigation options are described in Table 4-3.

Table 4-3: Problems and mitigation for noise mapping data

Problem	Description	Mitigation
Data are not available for the whole network	Because the END only required noise mapping in phase 2 for roads that carried more than 3 million vehicle passages per year this meant that a significant proportion of the network remained unmapped.	For the road lengths that have not been included in phase 2, noise benefits cannot be calculated for maintenance schemes. If other sources of noise data are available (e.g. localised scheme models) these could be used to fill gaps in the available noise data.
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.

Problem	Description	Mitigation
The mapping includes some regional roads	Regional roads are not the responsibility of the NRA and are not included in the data for 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.	No information was available from the NRA on the length of regional versus national roads that had been mapped in any county.
Data are aggregated to a county level	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 data.	Until more detailed noise data is 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.

4.4.1.3 Creating the mapped noise dataset

The output data presented on the noise maps for both L_{den}[3] and Lnight[4] noise classifications were:

- Approximate number of people (5 dB bands from <55, 55-59, 60-64, 65-69, 70-74 and >75);
- Approximate area (10 dB bands from >55, >65 and >75);
- Approximate number of dwellings (10 dB bands from >55, >65 and >75); and
- Approximate number of people (10 dB bands from >55, >65 and >75).

The most relevant dataset for this modelling was the number of dwellings, or households because this aligned with common practices for costing road noise and could therefore build upon that research. 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 NRA, Ireland that contained the number of dwellings in 5 dB bands, derived from more accurate data of façade level noise. This resulted in a base dataset for the number of dwellings being created in the following format:

[3] 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 period.
[4] 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} 55-59 dB;
- L_{den} 60-64 dB;
- L_{den} 65-69 dB;
- L_{den} 70-74 dB; and
- L_{den} >75 dB.

5 dB bands may be larger than some of the noise reducing effects from a change in pavement surfaces but it is (currently) unrealistic to expect a road agency to have more detailed data for significant parts of their network. Using these 5 dB bands aligns with the noise maps produced under the European directive and therefore hopefully makes the methodology more widely applicable. Even though 5 dB bands have been used here, the smaller differences seen by a change from one surface to another is considered by allowing proportions of the dwellings in each band to move bands, rather than all dwellings in a band.

Additionally, if more detailed noise data are available in smaller bands then datasets could be built around the finer banded data. Costs need aligning the the noise bands used in the methodology and this can be done by starting with the values for changes in 1 dB and aggregating the cost changes up to the required noise bands.

4.4.1.4 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 described here 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.

This stage of the process is key, from a noise perspective, and there is plenty of scope for more refined methodologies should the requisite data be available. Time and computational constraints would prevent such methodologies from approaching the complexity of a detailed, geospatially accurate, noise mapping exercise but could potentially begin to address such issues as:

- The distance of properties from the road and noise reductions associated with noise barriers close to the road
- Accounting for noise reductions where more than one road contributes to the noise at the dwellings but only one of these roads is being considered for maintenance
- More accurately defining the noise level or geographical extent of dwellings modelled to receive the noise benefit of a new surface on a given road.

The methodologies discussed in QUESTIM WP3 resolve some of these issues in cases where CPX data are available.

4.4.2 Available data - Noise costs

Monetising noise allows for the nuisance or benefit impacts from maintenance to be fully costed and included in an economic analysis. WebTAG unit 3.3.2 (DfT, 2012) contains recommended values for the change in noise in 1 dB bands for transport related noise (Appendix C: WebTAG Noise cost data, Table C.1)[5].

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 Table C.1 for source values).

The following table of noise costs for the 5 dB bands is derived using the above method.

[5] These were the current costs available at the time of the research. Any user wishing to use or create a noise costing dataset should consult WebTAG to check for the latest cost data.

Table 4-4: Noise costs

Noise Change in the interval, dB_{Leq}[6]		Value of a change in 5dB band, £ per household per dB per annum	Value of a change in 5dB band, €[7] 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[8]	670.55

The costs for the change in noise in Euros per households were used as the lookup noise cost data in the reference tables for the model.

4.4.3 Derived data - Noise change values

It should be noted that the data used at the time of this report were the most relevant data available. However, the methodology was developed to also be able to use data from QUESTIM WP3, or a road authority's own data if they exist (potentially deteriorated using the relationships defined in QUESTIM WP2).

4.4.3.1 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. Different treatment options can therefore deliver noise benefits and the cost profiles will change depending on when the intervention occurs.

Without a representation of how noise levels change with different surfaces the noise benefits would only be a function of the dwelling data without any consideration of the treatment applied. In this case a true reflection of the noise benefits would not be modelled and that is why noise change data are also required alongside the number of dwellings.

Different pavement surfaces contain different aggregates and have different noise levels. As the surfaces deteriorate and the surface roughness increases, the noise generated from the surface also increases. The noise generated is influenced by the road surface and the vehicle tyre and because this is a road maintenance model only the element of noise from surfaces is relevant. The methodology is required to reflect the noise differences that are

[6] Equivalent Continuous Noise Level
[7] 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
[8] 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.

experienced when changing surfaces and how this might be different for surfaces of different ages, for example, laying a new porous asphalt in place of an older surface dressing.

The review of noise literature (e.g. FEHRL, 2006b) has shown:

1. There is a difference in noise levels between 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 reduction, which is diminished after a couple of years, at which point the surface is no different in noise characteristics to the older surface.

This prompted the development of two different noise change measures:

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.

The following sections present data based on the SILVIA programme and it should be made clear that whilst more recent data are certainly available (and have indeed been analysed carefully as part of QUESTIM WP2) it is the structure and the format of the data set that is important to outline and not the figures themselves.

Even up to date pavement noise values should not be used without careful consideration of local factors. In implementing this process it is envisaged that member states should substitute any figures provided with data from their own measurement surveys that best reflect the status of the roads under consideration.

This concept of an initial noise change plateauing out in later years applies a representative relationship onto the concept being modelled. A further possibility follows a more traditional s-shaped curved, whereby there is a period of little change, followed by an initiation event at which point there is rapid change which then plateaus out. 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 (2006b) (see for example Figure 4-2 and Figure 4-3).

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 (with others showing signs of beginning to plateau). If noise follows standard deterioration curves (as with other pavement parameters) we would expect these relationships to be present. Although the FEHRL data are limited, noise is generally expected to behave as per the examples of SMA and EACC in Figure 4-3.

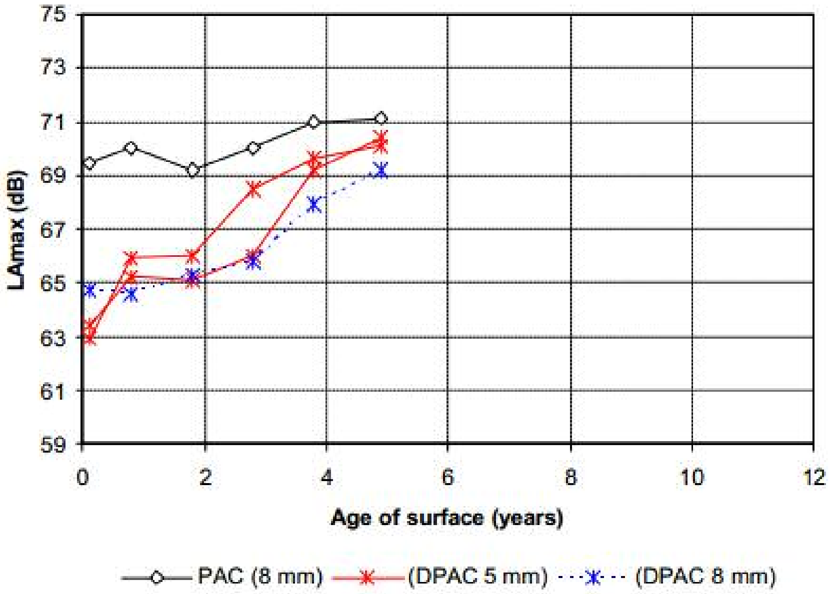


Figure 4-2: Example of noise level increase over 5 years of measurement for porous asphalt (PAC) and double layer porous asphalt (DPAC) surfaces. (The example above is from FEHRL (2006b) and the data was for light vehicles at a reference speed of 50 km/h).

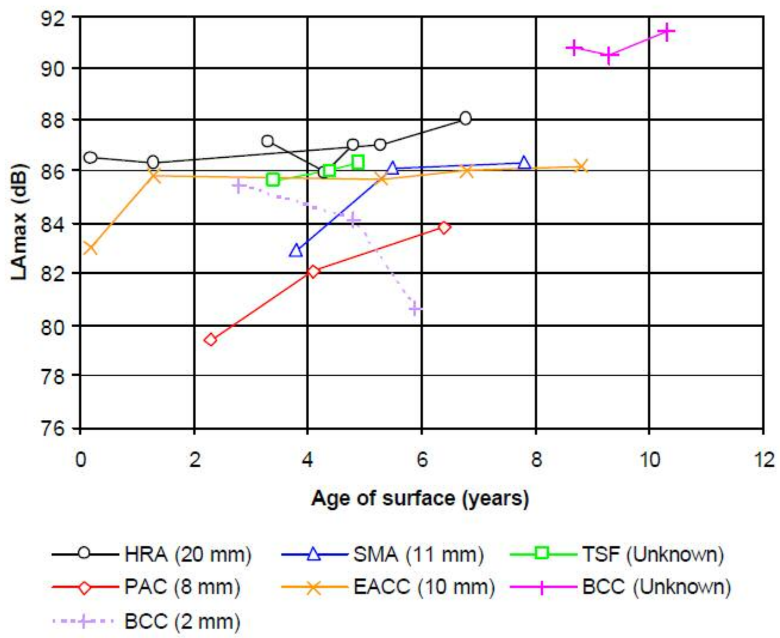


Figure 4-3: Example of how noise data has been shown to demonstrate an initial noise change, followed by a plateauing some years later. (The example above is from FEHRL (2006b) and the data was for medium heavy vehicles at a reference speed of 85 km/h).

In representing this in this methodology the model 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.

Although this concept has been documented (FEHRL, 2006b) there is a very limited amount of data to draw upon, which 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, and to demonstrate how road authorities could create their own data.

4.4.3.2 Noise change due to condition

Silence (2006) was one report that attempted to classify the level of noise change that is expected following a surface change. The report presented an approach on how the noise can change for pavement types of different conditions (based on typical Danish experience). The maximum range of noise change was as high as 9dB. Table 4-5 shows the noise data the report presented for the differences in noise levels for surface of different conditions (assuming a base surface of a good asphalt concrete). There was no empirical basis for this data however; the values were suggested on what might be experienced in an urban environment. If these values were used for different road network (e.g. rural environments) then the user would need to understand the sensitivity of transferring them the data between networks with different characteristics.

Table 4-5: Noise data for different pavement types and conditions (Silence, 2006)

	Condition		
Pavement type	**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

Although the values were not scientifically measured, the layout of the data collection presented the beginnings of an approach for creating the dataset. It can be assumed that at the time of maintenance the surface is changing from one in unacceptable condition to one in good condition. The associated noise data could therefore be used to re-ordered to represent the initial noise change experienced from one surface to another as shown by Table 4-6, which aligns with the surface types used on the Irish network.

Table 4-6: 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	

However, 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).

However, there is no empirical study linked to the values from the Silence report and it therefore lacks evidence behind the data. Also, it only allows for the derivation of the initial change, rather than the constant change value which was also proposed.

4.4.3.3 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 4-5 and Table 4-6 values for the 'noise change over an average lifetime' (Table 4-7) were collated from the FEHRL/Silvia noise report.

Table 4-7: Ranges of average lifetime noise reductions from FEHRL/Silvia report

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	

There are some significant differences between Table 4-6 and Table 4-7 which are theoretically presenting the same data. This demonstrates the importance of checking the provenance of any data. Using data that is measured appropriately (Table 4-7) as opposed to taking very localised, non-scientifically measured data helps build credibility in the outputs generated.

From the ranges in Table 4-7 a single noise change was extracted by selecting the most conservative limit of each range, except where this would lead to a value of 0 being used (i.e. the value closest to 0, but not 0) in order to model a noise benefit for each combination of surfaces. The conservative value from the ranges was chosen so as to limit any over-estimation of noise change benefits (Table 4-8).

However, the data presented in Table 4-8 does not make reference to 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 discussed previously and used for the modelling methodology.

Table 4-8: Average lifetime noise reduction estimated from non-zero, integer lower ranges of Table 4-7

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	

4.4.3.4 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 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 4-8 to produce estimated values for the initial noise reduction (Table 4-9). It was also assumed 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 a slight noise improvement initially.

Table 4-9: 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

4.4.3.5 Constant noise reduction

For the methodology proposed in this research the initial noise reductions needed to be paired with a 'constant change value' (i.e. where no further acoustic degradation occurs) which is reached after a set number of years for each surface type (reflecting the behaviour in Figure 4-3). 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.

The information contained in Figure 4-3 along with other analyses for different vehicles and speeds (FEHRL, 2006b) the number of years until the noise level (or change) plateaued for each surface was estimated (Table 4-10).

Table 4-10: 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

An iterative process was then setup to derive the constant noise change values as described:

1. Apply the initial noise reduction (Table 4-9) 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 4-10);

2. Apply the constant change value *x* for the remainder of the average pavement lifetime (from Nicholls et al, 2010);

3. Average the yearly noise reduction obtained over the life of each pavement;

4. Apply a factor to the average lifetime noise change (Table 4-8) 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 4-7;

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 4-9, 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 4-11).

Table 4-11: 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

4.4.4 Derived data - Trigger rules

Noise 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 if the noise was high enough, 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.

Within the model, noise data alone needs to be capable of triggering a noise-only maintenance treatment. Any rules for noise-only maintenance had 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. Some road authorities have recommended limits for noise, at which point you could argue that a Do Minimum approach would be adopted to mitigate the noise getting any worse. However, a surface is still unlikely to be changed for noise reasons when it remains structurally sound, even if it has lost its nosie benefits but having the options in a PMS allows policies to be tested to understand, for example, the cost of developing a maintenance programme to address only noise issues. Triggering noise schemes could also be more applicable to subsets of the network (i.e. noise sensitive areas) rather than triggering these noise driven maintenance schemes across a whole network.

However, that approach, which uses data on the absolute level of noise in an area 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 in a strategic level model simply because it is unrealistic to expect a road authority to have that level of data 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 number of dwellings over a set noise level exceeded 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.

A noticeable difference in noise (and tolerance by residents) is expected between urban and rural locations and therefore the threshold is separated for the different city and county local authorities.

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 (assuming it meets the default scheme constraints such as minimum length etc.).

4.4.5 Calculating benefits

4.4.5.1 Noise methodology implementation in the model

The noise methodology is used to calculate the benefits or costs of noise for each treatment option, regardless of why the scheme was triggered.

The resultant 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 occurred. This is because the noise resulting from a maintenance intervention can vary in all years of a treatment profile, not just the individual years of the interventions. To truly account for the noise costs or benefits the noise therefore needs calculating for each year of the entire treatment evaluation period.

To aide understanding of the methodology the example in Appendix D: Noise methodology example has been cross-referenced to show the user how the data is built up and used.

1. Determine the number of dwellings in each 5 dB band for the maintenance scheme using the noise input data set (dwellings per km). (see buller 5 in Appendix D);

2. If the noise reducing property of the pavement is being deteriorated, deteriorate the noise data for each year until the first maintenance intervention (see row 2013 in table D1. Note, no deterioration was applied in this example);

3. For each intervention in the treatment evaluation period:

    a) Determine the initial noise change, constant noise change[9] and years until constant noise change values using the old and new pavement surfaces for this intervention (see row 2014 in table D1);

    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 (see row 2013 in table D2);

    c) For each year between the current intervention and the next treatment intervention:

        i. Determine the in-year noise change based on linearly decreasing[9] the initial noise change to the constant noise change from the year of the intervention to the years it takes to reach the constant noise change. Apply the constant noise change for any years beyond the number of years it takes to reach the constant noise change (see rows 2015-2021 in table D1) ;

        ii. Calculate the change in the number of dwellings in each 5 dB band affected by the in-year noise change[10], using the reference dwellings as the base values and assuming that the dwellings are distributed evenly within each 5 dB band (see rows 2015-2021 in table D2, Dwellings changed columns);

        iii. Apply the change in the number of dwellings to the reference dwellings to calculate the number of dwellings that would be in each 5 dB band at the

[9] The constant noise change assumes that at a future point in time the noise property of the surface will plateau and no longer deteriorate or change. Between these periods a linear change for the noise deterioration has been assumed in this methodology. If a different type of relationship is required the methodology can be adapted accordingly. If the surface is not expected to plateau in its noise characteristics, the number of years to the constant change can be set at a high value so that it will never be reached before the next intervention is required.

[10] The in-year noise change is a fixed reduction of noise applied to all identified dwellings associated with the specific maintenance scheme and road chainage

end of that year change (see rows 2015-2021 in table D2, Dwellings in noise band columns);

iv. For each 5 dB band, calculate the noise costs or benefits by multiplying the change in the number of dwellings by the value of moving between the respective 5 dB bands (see rows 2014-2021 in table D3);

v. Sum the noise costs or benefits across each 5 dB band to calculate a total in-year cost or benefit (see rows 2014-2021 in table D3, Total costs column);

4. Repeat step 3 for each new maintenance intervention within the treatment evaluation period (repeat for each of interventions in row 2022, 2030 and 2038 in table D1);

5. Apply discount rates to the noise costs through all years of the analysis to calculation the noise net present value (NPV). The user can specify a noise specific discount rate, although it is recommended that the standard Treasury Green Book values are used (see column NPV in table D3);

6. Include the discounted noise cost in cost calculations as specified by the user during the run configuration (i.e. whether noise costs should be treated as an agency or user cost).

4.4.5.2 Creating specific low-noise maintenance option

As shown in Table 4-2, each treatment type has two Do Something options, one with a low-noise element, the other having standard noise. This allows the model to investigate how the impacts from the Do Something treatment changes when there is a change in the environmental noise 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 how these different surfaces would perform. For example, it has been generally accepted that a low-noise porous asphalt surface will have a lower expected life than a thin surfacing; this improved noise performance of a porous asphalt therefore needs balancing with more frequent maintenance.

A noise deterioration factor is applied to the user specified deterioration rates to reflect the change in performance (durability and life) that is expected for the different noise surfaces.

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. Regardless of the actual values used, the methodology requires these data. Therefore if a road authority wishes to use their own or other data sources (e.g. QUESTIM WP2) that is completely acceptable. The expected life data for the selected surfaces used within this model are shown in Table 4-12.

Table 4-12: Expected life data (from Nicholls et al, 2010)

Surface Type	Expected Life (yrs)
Thin Surfacing (SMA)	10-16
Porous Asphalt	7-10
Surface Dressing	3-8

In order to replicate the difference in expected lives, the noise deterioration factors are set to enhance the normal rate of deterioration to mirror the results from Nicholls et al. (see Table 4-13).

Table 4-13: 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

This set the low-noise surfaces to deteriorate 1.5 times faster than the standard noise options (where SMA was the standard option) reflecting that the benefits of a low-noise surface are measured against more frequent interventions. The model is therefore able to provide an assessment of how the different whole-life value options compare and what the impacts are on a network.

4.5 Summary

A methodology for integrating noise into a PMS has been described in this chapter. In addition, examples on developing an appropriate dataset are described, although it is expected that datasets should be localised where possible (e.g. referencing the specific pavement surfaces used on a local network).

The current noise mapping data has enough information for use in the methodology but it is expected that significant improvements to this data will come on-stream as the noise mapping further develops. One clear area for improvement with this data is in being able to determine a ‘per km’ noise value for individual sections of a road which is not possible with the current data.

The noise data used to build up the noise datasets for this methodology (e.g. noise change values) were documented so that when new noise data becomes available it can be substituted into the process to create more up-to-date noise datasets.

The developed methodology aimed to take account of the competing factors with the different noise surfaces, such as shorter expected lives associated with low-noise surfaces. This ability was incorporated into the methodology and means that a greater range of realistic options can be investigated.

The types of questions that can be investigated using this methodology are:

- What are the implications on a road maintenance programme between the different choices of noise surface available?

- If low-noise surfaces are selected at times of maintenance what are the implications on developing a maintenance programme?

- What are the longer-term effects (e.g. the timing and number of future interventions) when choosing low-noise surfaces for maintenance?

The noise methodology developed can help a road authority develop a greater understanding of the impacts from these types of questions, especially when compared to a more traditional approach that doesn't include externalities alongside the direct works costs when developing a maintenance programme. It should be noted that it is incorrect to expect a PMS to provide one definitive answer. Instead it allows highway authorities to investigate a range of different scenarios (e.g. modelling different policies) which then provide them with a range of likely outcomes. The modelled maintenance programmes use notional schemes and therefore detailed consultations with engineers will be required to translate the PMS data into a more complete maintenance programme. And although the principles of whole-life costing attempt to assess the scheme benefits and costs over a longer period (e.g. 30-60 years), the immediate programme period (i.e. 1-4 years) is the period of most importance to a road authority and they would be expected to undertake revised analyses each year and adapt the programme accordingly as more recent condition data, costs, deterioration relationships etc. become available to the model.

It is important to recalibrate any model on an ad-hoc basis as relevant data are made available and this is also true of the noise methodologies developed.

The next chapter that follows uses the developed noise methodology (implemented in a base pavement maintenance model) to create a case study to investigate the types of scenarios that can be analysed.

5 Case study

This chapter documents the application of the noise methodology to one road on the Irish national network using data specific to Ireland. The case study reported in this chapter uses a pavement whole-life value model developed as part of other research, into which the noise methodology was incorporated.

Sections 4.1 and 5.1 provide a description of the deterministic model developed and used for this research. However, the data use and interpretation of the outputs from the case study are the important elements for the reader, as well as the process to go through, so that this, or similar methods can be implemented in different models or PMSs in use by a road authority.

5.1 Data

The case study required data specific to the Irish national network and the reference data used in the model (e.g. unit rates, noise costs) were all set using Irish defaults where applicable or otherwise tailored for use on the Irish network.

The condition data was obtained from NRA, Ireland in May 2013 and provided condition parameter data for skid resistance (termed SCRIM[11]), longitudinal profile, rut depth and texture depth for 2011 and 2012.

The network definition (e.g. routes, lengths) and inventory information (e.g. carriageway width, surface type) had not changed from a 2010 dataset and was therefore used as the source for all non-condition data.

5.2 Base model

The base model (i.e. the model into which the wider impact of noise was incorporated into) allows comparison of maintenance appraisals across a selected network by assessing both the initial works and additional delay cost of each option and the future whole-life costs. The model was developed on that basis and uses the data accordingly to allow maintenance strategies to be created and compared.

The structure of the modelling process is shown in Figure 5-1. The network database and reference database linked into the workspace are used as the input 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.

[11] SCRIM is the Sideway-force Coefficient Routine Investigation Machine is used to measure the skid resistance of the surface of a road.

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' is about collating the specific network data needed for the run chosen (e.g. the correct sections, condition parameters etc.). 'Data Ageing' compensates for survey data not potentially all being available in the same year 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 the 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); or

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.

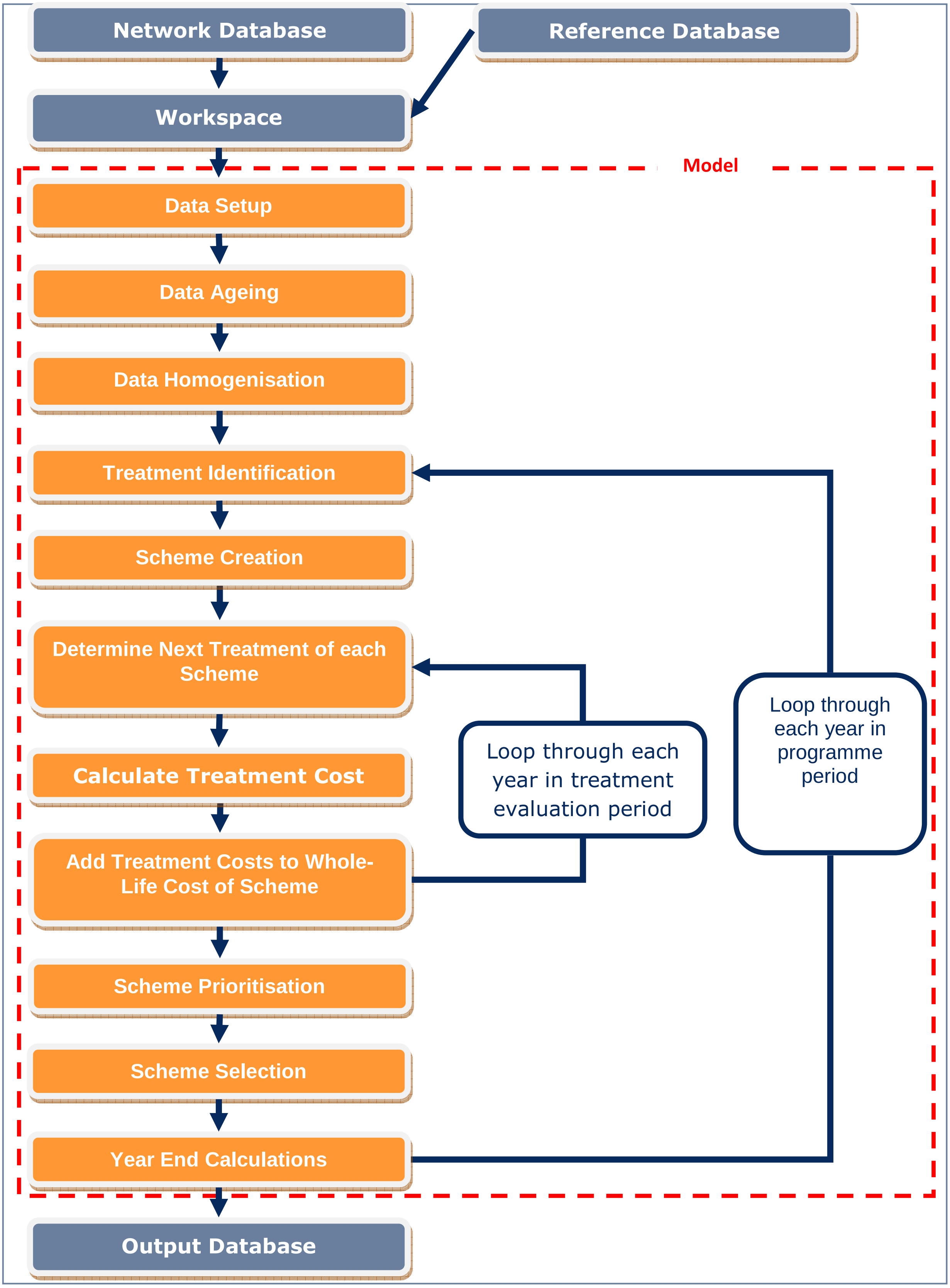


Figure 5-1: Modelling processes

5.2.1 *Model capabilities*

The main modelling processes are listed in this section to provide a further summary of how the model operates and what its capabilities are.

- The model allows users to set-up an analysis for any subset of the network;
- Data selection (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 minimum scheme lengths;
- Schemes are created by appropriately joining up the lengths needing treatment. This may mean some lengths of the network remain untreated until they grow to be 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).

The output databases present information in a set of tables. Outputs from different analyses allow a range of identified scenarios to be compared and used to inform decision making.

5.3 Case study setup

The case study was based on investigating maintenance programmes under different scenarios for a single road, the N4. The N4 runs from Dublin in the east to Sligo in the west (see Figure 5-2 and Figure 5-3) and is the longest national primary route at approximately 208 km. The standard of the road varies significantly along its length, from a tolled motorway section near Dublin to single-carriageway sections either side of Longford (almost halfway along the route).

The variety associated with this strategic corridor is further reflected in the inventory and condition data (see Figure 5-4 to Figure 5-10).

Figure 5-2: N4 location in Ireland

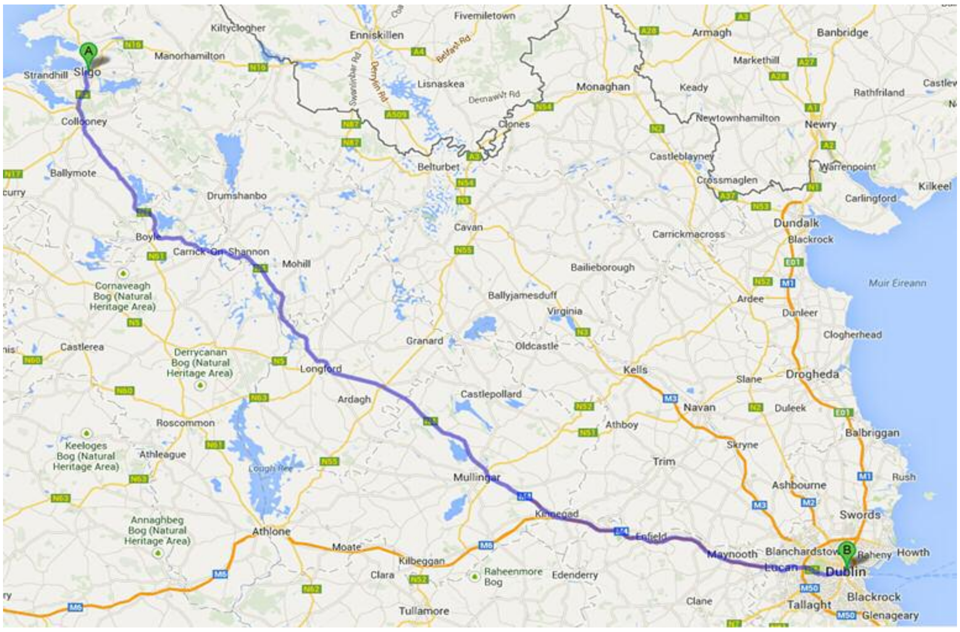


Figure 5-3: N4

Table 5-1: N4 road types

Start Chainage (km)	End Chainage (km)	County	Carriageway type
0	12.069	Sligo	Dual
12.069	32.511	Sligo	Single
32.511	34.267	Sligo	Single
34.267	34.865	Sligo	Single
34.865	38.544	Roscommon	Single
38.544	54.042	Letrim	Single
54.042	67.993	Letrim	Single
67.993	75.503	Letrim	Dual
75.503	75.509	Letrim	Single
75.509	107.58	Longford	Single
107.58	126.74	Westmeath	Single
126.74	138.575	Westmeath	Dual
138.575	147.44	Westmeath	Motorway
147.44	154.622	Meath	Motorway
154.622	162.219	Kilda	Motorway
162.219	169.823	Meath	Motorway
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

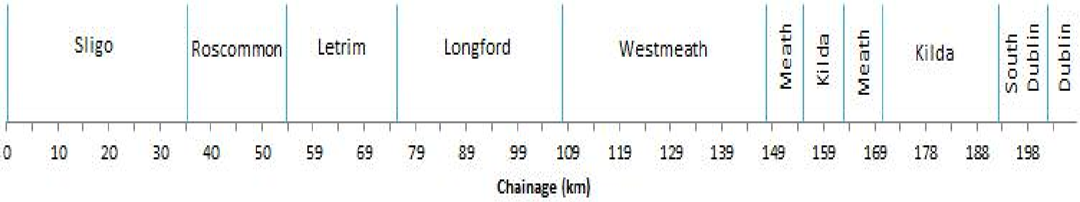


Figure 5-4: Counties along the route of the N4 (aligned with Figure 5-5 to Figure 5-10)

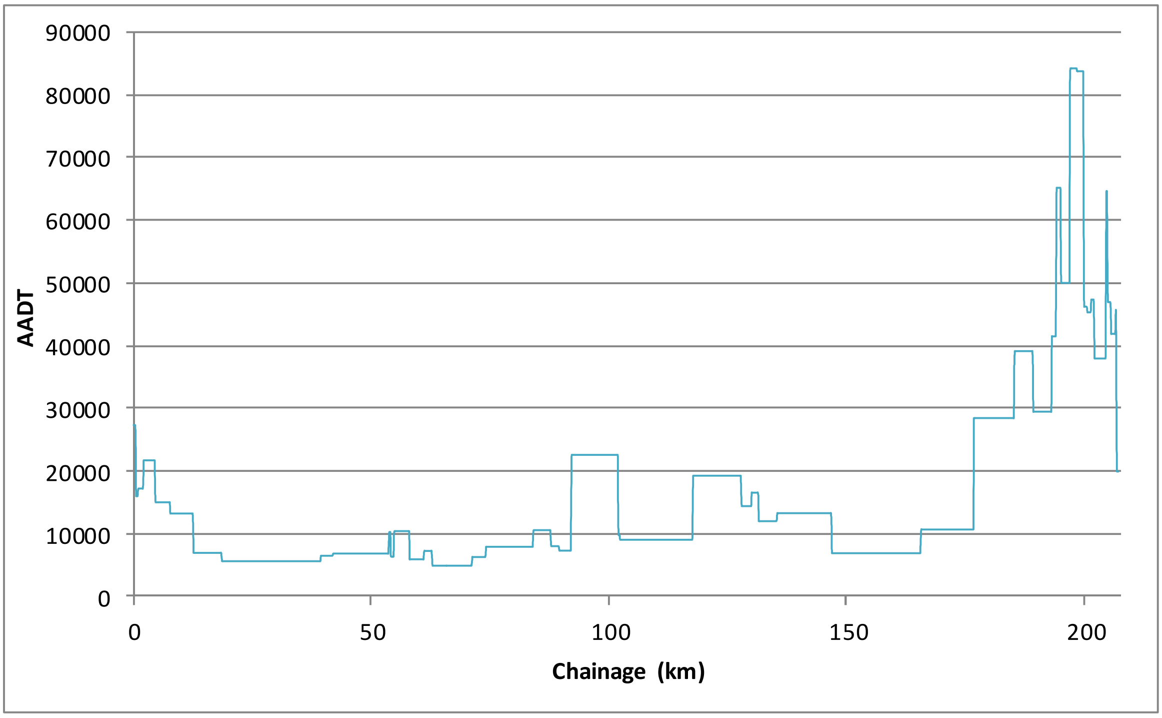


Figure 5-5: N4 traffic (all charts start with Sligo at 0 km chainage)

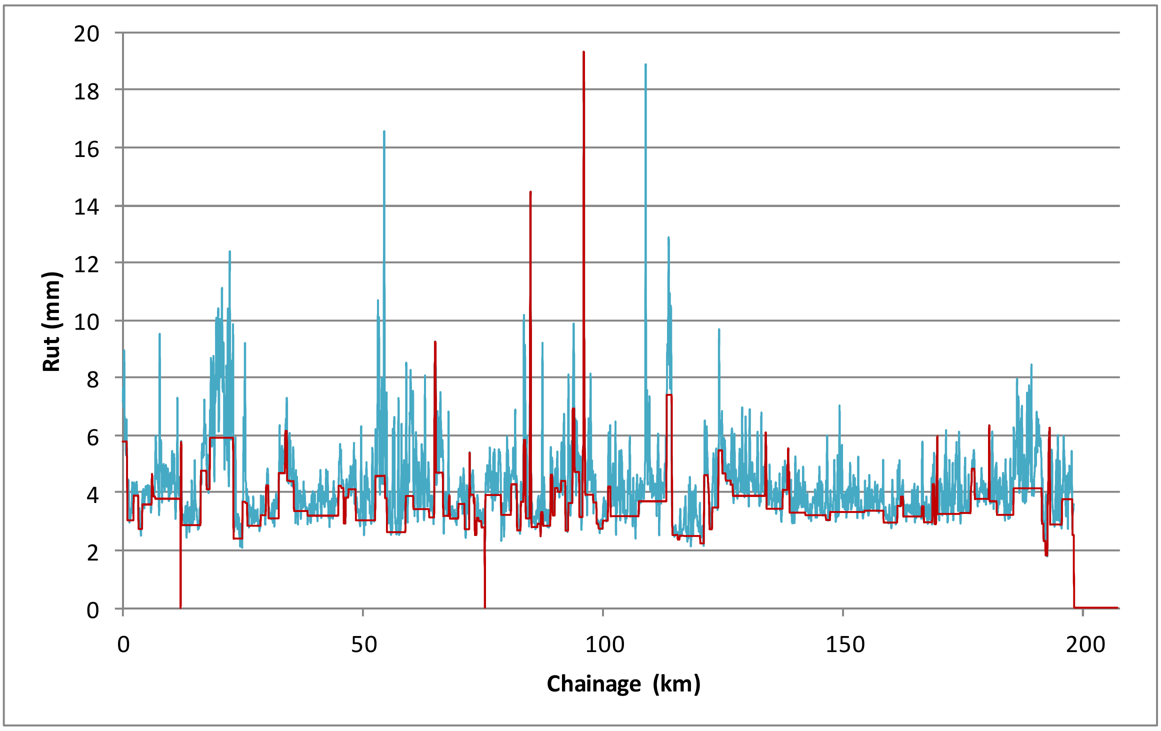


Figure 5-6: N4 rut depth (for the condition parameters, the blue line represents the individual data records, whilst the red line represents the homogenised data)

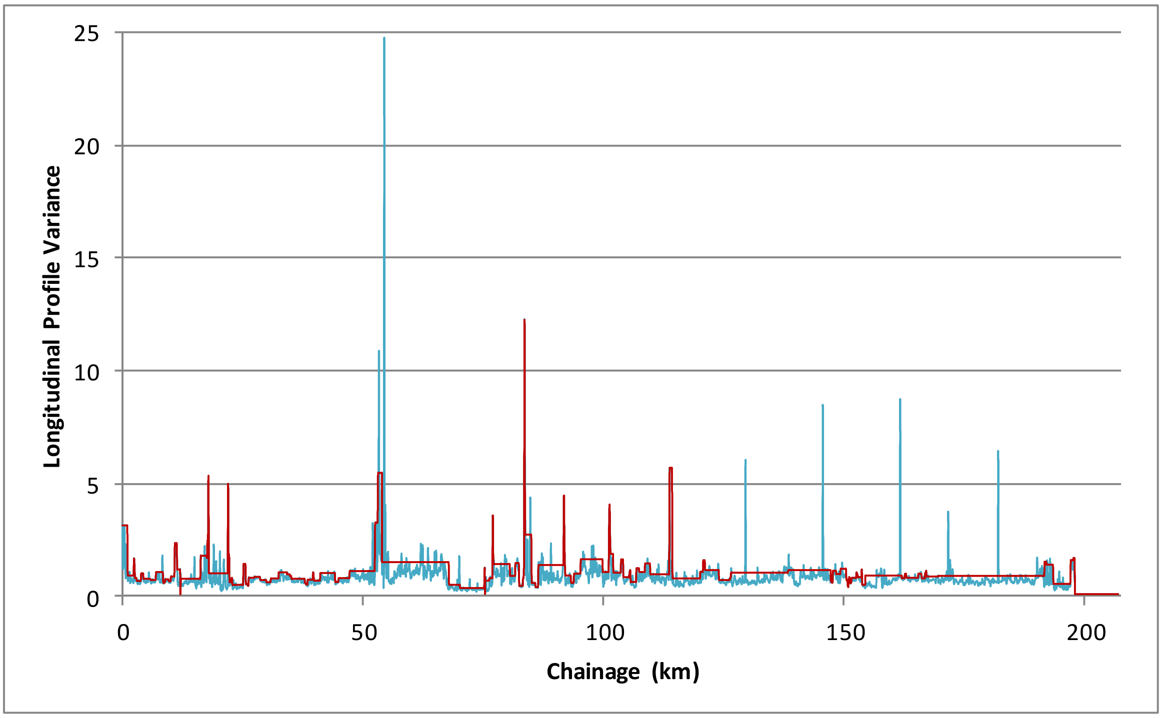


Figure 5-7: N4 longitudinal profile variance

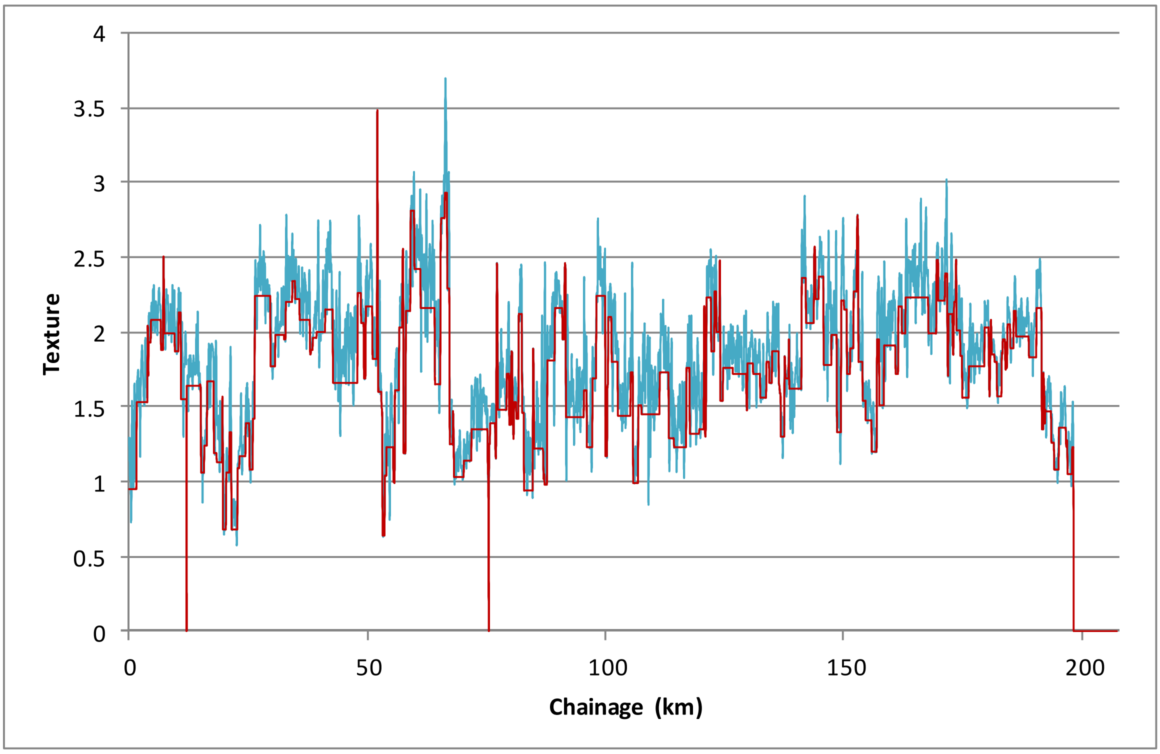


Figure 5-8: N4 texture

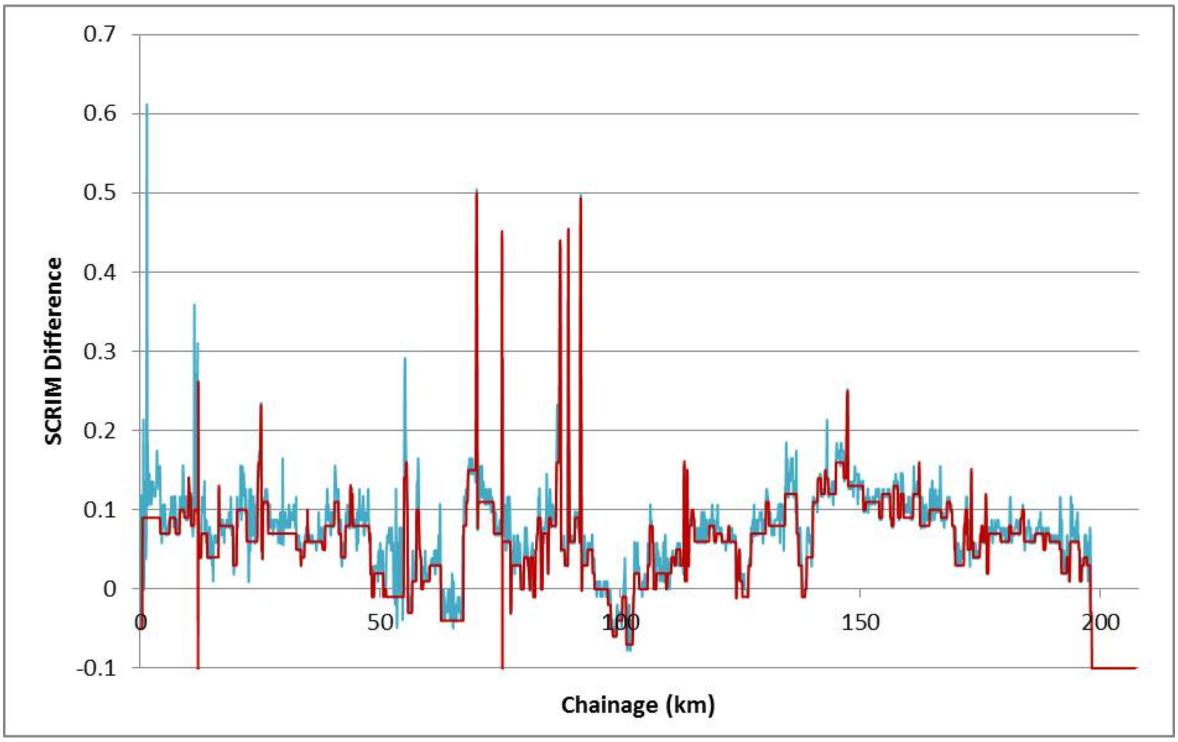


Figure 5-9: N4 SCRIM

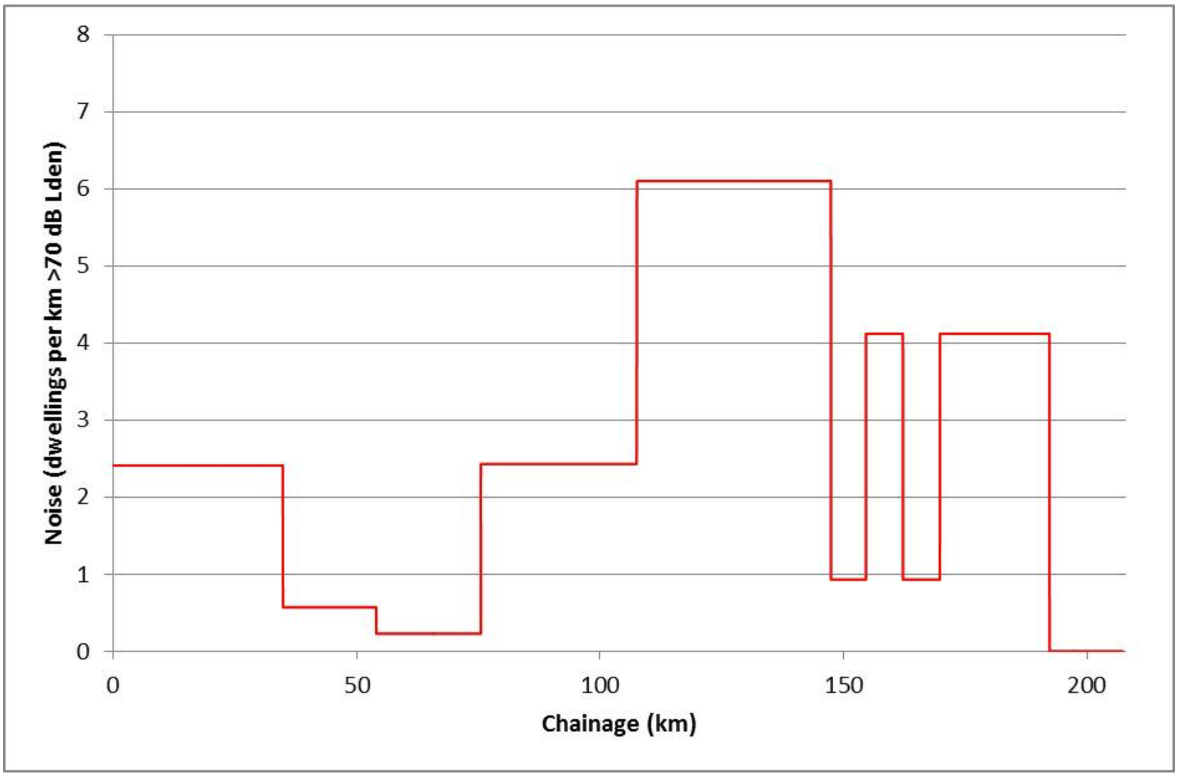


Figure 5-10: N4 noise

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 standard ring-road 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.

5.3.1 N4 analysis setup

For the N4 case studies the start year was set as 2013 and the programme period was set to 1 year (i.e. deriving a maintenance programme for 2013). The treatment evaluation period (for assessing the future maintenance needs of each scheme) was set to 30 years. The discount rate used for all cost elements was 3.5%. All scenarios used the linear method for calculating residual value at the end of the analysis.

For every scheme[12] identified, the model could 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 Do Minimum option is configured to treat only those defects that have passed safety thresholds and therefore represents the maintenance needed to keep the network in a safe condition. The Do Something option represents a maintenance scheme that addresses general intervention thresholds, not just minimum safety thresholds, and therefore results in a maintenance scheme that adds more value back into the pavement. There were no constraints (e.g. budgetary) imposed on the analysis, thereby simulating an unconstrained maintenance budget.

5.4 Case study results

5.4.1 Base model analysis

The functionality of the base whole-life cost model (i.e. works costs and user delay costs without the addition of a noise parameter) was used to undertake an initial analysis on the N4. The summary outputs from the analysis were:

- Identified schemes: 33 (see Table 5-2);
- Selected schemes: 16;
- Number of selected Do Minimum schemes: 14 out of 16;

[12] Scheme here refers to a continuous length along a route that is selected for treatment

- Length of selected schemes: 27.1km.

These selected schemes came from a total number of 33 identified schemes based on the treatment thresholds and scheme creation criteria. For any scheme, the entire length does not need treating at each intervention, with the length requiring treatment being determined from the condition data and associated thresholds.

Table 5-2: Scheme lengths identified and selected

Scheme No	Direction[13]	Do Something Start Chainage[14] (km)	Do Something End Chainage[14] (km)	Do Something Scheme Length (km)	Treatment Option Selected[15]	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

[13] EB = Eastbound; WB = Westbound.
[14] 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).
[15] DS = Do Something; DM = Do Minimum.

Scheme No	Direction[13]	Do Something Start Chainage[14] (km)	Do Something End Chainage[14] (km)	Do Something Scheme Length (km)	Treatment Option Selected[15]	Selected Year 1 Treatment Length (km)
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
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

This analysis represents the type of analysis that is most commonly undertaken by road agencies currently, prioritising on the whole-life costs of the works whilst also minimising delays to road users.

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 being 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 schemes[16] (i.e. all 33 schemes) the Do Something option was checked to see if it:

1. Was above a set economic indicator[17];
2. Gave a cost saving for the whole-life period compared to the Do Minimum; and
3. Remained under any budget cap if the Do Something had a greater first year cost than the Do Minimum.

[16] 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.
[17] The economic indicator was set at -10 to still allow Do Something schemes to be considered that did not offer an immediate benefit of being economically viable. Do Something schemes with an economic indicator less than -10 were not considered.

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.
The resulting cost outputs for the whole programme are shown in Table 5-3.

Table 5-3: Cost outputs from initial analysis

	Works Costs (€K)	Maintenance Delay Costs (€K)	Total Agency Costs (€K)
Year 1	1,409	40	1,449
Year 1 (scheme min[18])	17	0	17
Year 1 (scheme max[19])	197	2	199
Year 1 (avg per scheme[20])	88	3	91
Year 1 (per km[21])	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

The works costs (see Table 5-3) are over 95% of the total agency costs, demonstrating the marginal impact that delay costs had in this analysis. The whole-life costs of the works costs are about 4 times larger than the year 1 works costs, reflecting on average about 4 maintenance interventions within the whole-life cost period for each of the schemes selected in year 1.

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 5-4.

18 The minimum scheme cost from all selected schemes
19 The maximum scheme costs from all selected schemes
20 The average scheme cost per scheme for all selected schemes
21 The average scheme cost per kilometre for all selected schemes

Table 5-4: Condition outputs from initial analysis

	Proportion of network (%)
Length not exceeding thresholds for any condition parameter	87.4
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	12.4
Length exceeding Do Minimum thresholds (but for any condition parameter	0.1

5.4.2 Adding noise costs to the scheme costs

When noise was added into the whole-life calculations, the results from the equivalent run are shown below (see Table 5-5). The results below show the same run (i.e. choosing between a Do Minimum and the one standard Do Something as the only viable option) but with the noise costs included alongside the other costs, all of which are used in the economic indicator calculations.

The summary outputs from the analysis were:

- Identified schemes: 33 (see Table 5-2);
- Selected schemes: 13;
- Number of selected Do Minimum schemes: 12 out of 13;
- Length of selected schemes: 25.8km.

Although the selected schemes came from the same 33 identified schemes as in the initial analysis the actual schemes selected and the options chosen may not have necessarily been the same, hence why in the table below the year 1 works costs are less than in the previous analysis. The reason why different schemes might get selected is that when noise costs are included it changes the economic calculations and economic indicator used to priorities the scheme and determine if it represents an economic return on the investment. With some schemes that were previously close to the cusp of the economic cut-off, the inclusion of noise costs into the analysis can have the effect of changing the whole-life costs, and when compared to the base case (i.e. the Do Minimum) this can have the effect of making schemes that were previously economically viable no longer viable, or vice-versa.

Table 5-5: Cost outputs from initial 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

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 extent when noise costs were added, but the actual treatment in year 1 has not significantly increased. 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.

For all schemes, in year 1 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 schemes generated an overall total noise saving[22] and the noise savings were a significant proportion of the total scheme costs. Noise therefore had a greater effect on the total scheme costs than carbon.

At the end of the analysis (i.e. after one year) the resultant condition is shown in Table 5-6. There was a small increase in the good condition lengths as a result of adding noise.

[22] One scheme did not generate any noise costs because there was no noise data.

Table 5-6: Condition outputs from initial analysis including noise costs

	Proportion of network (%)
Length not exceeding thresholds 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 (but for any condition parameter	0.1

5.4.3 Allowing the selection of a specific noise treatment option

In addition to including the costs of noise, a specific Do Something option was created that was tailored to reflect specific low-noise maintenance.

The tailoring of this Do Something option (e.g. by material choice, bitumen content, deterioration rate etc.) meant that as well as a Do Minimum and the standard Do Something option to select from, an additional low-noise Do Something option was available for the model to select from for each scheme. The low-noise Do Something option was tailored to provide enhanced noise characteristics (i.e. greater noise reductions) but with a trade-off of higher works costs and an increased deterioration rate.

When this additional maintenance option was introduced into an analysis on the N4 the following results were generated. The summary outputs from the analysis were:

- Selected schemes: 14;
- Number of selected Do Minimum schemes: 12 out of 14;
- Length of selected schemes: 25.5km.

Table 5-7: Costs when choosing between a Do Minimum and two Do Something options

	Works Costs (€K)	Delay Costs (€K)	Noise Costs (€K)	Total Agency Costs (€K)
Year 1	1,350	29	60	1,439
Year 1 (scheme min)	30	1	-7	24
Year 1 (scheme max)	181	7	19	208
Year 1 (avg per scheme)	96	2	4	103
Year 1 (per km)	53	1	2	56
All years WLC	6,700	140	-2,237	4,602
All years WLC (scheme min)	126	5	-90	40
All years WLC (scheme max)	734	34	-49	718
All years WLC (avg per scheme)	479	10	-160	328
All years WLC (per km)	262	5	-88	180

Compared with Table 5-5 when noise costs were included in the initial analysis (but without any specific noise treatment) there was not a significant difference in the output schemes and costs when a specific noise Do Something option was made available as a treatment option.

13 of the schemes were identical with the previous 13 schemes. The additional 14th scheme was a noise Do Something option that was not viable as a standard Do Something.

Although the overall costs were not significantly different, the additional 14th noise Do Something treatment had a total whole-life cost noise benefit equal to -€100k per km. This represents an 18% increase in the noise benefit compared to the average of -€85k per km for all schemes and more importantly, its economic indicator was an order of magnitude greater than the other standard Do Something. If the same pattern was found across a network then for an agency operating with a constrained budget it would be noise Do Something options that became prioritised above many of the standard Do Something options. Therefore, under constrained budgets the noise savings (per km) would likely be higher than for this unconstrained budget.

This is important for road authorities. By considering more cost elements in their analyses (i.e. noise) it could actually allow them to justify scheme selections that would otherwise not get approved but which offer wider benefits to society.

It is important to remember though that in these analyses the costs for noise were attributed to be agency costs. 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.

At the end of the analysis (i.e. after one year) the resultant condition is shown in Table 5-8.

Table 5-8: Condition outputs when choosing between a Do Minimum and two Do Something options

	Proportion of network (%)
Length not exceeding thresholds for any condition parameter	87.6
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	12.1
Length exceeding Do Minimum thresholds (but for any condition parameter	0.3

5.4.4 Forcing a choice between the Do Minimum and a low-noise Do Something

In this scenario only one Do Something option is available for the model along with the Do Minimum. Instead of being the standard Do Something, the Do Something option available was the low-noise alternative that represented the divergence (in noise characteristics) from the standard Do Something option. The summary outputs from the analysis were:

- Selected schemes: 13;
- Number of selected Do Minimum schemes: 12 out of 13;
- Length of selected schemes: 22.6km.

The cost results from this analysis are in Table 5-9.

Table 5-9: Costs when choosing between a Do Minimum and a low-noise Do Something option

	Works Costs (€K)	Delay Costs (€K)	Noise Costs (€K)	Total Agency Costs (€K)
Year 1	1,186	24	54	1,264
Year 1 (scheme min)	30	1	-7	24
Year 1 (scheme max)	181	7	19	208
Year 1 (avg per scheme)	91	2	4	97
Year 1 (per km)	52	1	2	56
All years WLC	5,966	106	-2,188	3,884
All years WLC (scheme min)	126	5	-90	40
All years WLC (scheme max)	491	6	27	525
All years WLC (avg per scheme)	459	8	-168	299
All years WLC (per km)	264	5	-97	172

When the model was given the choice of only selecting either a Do Minimum option or a low-noise Do Something it resulted in a 3km (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 £172k, 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 (on a per km whole-life cost basis) were the greatest of any analysis, amounting to an equivalent of over one-third of the works costs, therefore offsetting a large proportion of the agencies direct spend on maintenance. Such significant noise savings would be expected from any schemes that choose this Do Something option as it is always going to result in a low-noise treatment, and therefore most likely generate the largest noise savings.

The works costs across the whole-life period were similar with the previous analyses that included noise costs, and much larger than the initial analysis with only works and delay costs. These higher works costs are expected because the 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 meaning more frequent interventions are required.

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.

At the end of the analysis (i.e. after one year) the resultant condition is shown in Table 5-10.

Table 5-10: Condition outputs when choosing between a Do Minimum and a low-noise Do Something option

	Proportion of network (%)
Length not exceeding thresholds for any condition parameter	86.9
Length exceeding Do Something thresholds (but not Do Minimum thresholds) for any condition parameter	12.8
Length exceeding Do Minimum thresholds (but for any condition parameter	0.3

5.5 Summary

This case study on the N4 has shown how the model outputs and maintenance programmes are affected by inclusion of the externalities of noise emissions from maintenance.

When costs for 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 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 noise costs meant the total agency costs increased by approximately 7% in the first year. The works costs over the whole-life cost period increased by almost 25% but the addition of noise (generating significant cost savings over the whole-life cost period) meant that the total agency costs actually fell by approximately 15%. This reduction in overall scheme costs is based on all cost elements being attributed as agency costs over the whole-life period.

When an additional specific low-noise Do Something maintenance option was included as an available treatment it resulted in significant environmental benefits across the whole-life period. The noise savings increased (to be approximately one-third 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 the noise Do Something option which outweighed any initial benefits. However, it served to demonstrate the importance of taking a whole-life approach to valuing the environmental externalities of noise.

The condition of the network after the one year analysis was fairly consistent across all scenarios. The best condition was a result of the scenario where noise costs were included alongside the works and delay costs, and the worst condition was a result of allowing the model to choose from only the Do Minimum and the specific low-noise Do Something option. This drop in condition is reflected in a decrease in maintenance and although the drop in maintenance lengths was 10%, the worsening of condition was not of the same scale, a reflection that not all of the treated lengths are in a poor condition at the time of treatment.

A future enhancement to these case studies would be to conduct analyses over longer programme periods (i.e. greater than one year), especially when considering the increased deterioration and therefore more frequent interventions required from the low-noise Do Something.

This page is intentionally left blank

6 References

Ausejo, M., Tabacchi, M., Recuero, M., Asensio, C., Pagan, R & Pavon, I. (2011). Design of a Noise Action Plan based on a Road Traffic Noise Map. *Acta Acustica united with Acustica*, Vol 97(3), pp.492-502

Bickel, P., Friedrich, R., Link, H., Stewart, L. & Nash, C. (2006). Introducing Environmental Externalities into Transport Pricing: Measurement and Implications. *Transport Reviews*, Vol 26(4), pp.389-415

Bishop, M. (2004). *Economics A-Z terms beginning with E, The Economist* [online] [Accessed 3rd November 2012]. Available from World Wide Web: http://www.bettertransport.org.uk/local_campaigning/online_guides/roads/understand_process/value_for_money

Boiteux, M. (n.d.) *Transport: investment choices and nuisance costs, Task Force Report – Chairman Marcel Boiteux*

Bourke, K., Ramdas, V., Singh, S., Green, A., Crudington, A. & Mootanah, D. (2005). *Achieving Whole Life Value in infrastructure and buildings.* Bracknell, BRE

Bowskill, G. & Abell, R. (1994). Whole life costing of road pavements – the way ahead. *Paper for the 7th international symposium on concrete roads*, Vienna, October 1994. TRL

Brandt, S. & Maennig, W. (2011). Road noise exposure and residential property prices: Evidence from Hamburg. *Transportation Research* Part D, 16, pp.23-30

British Standards Institution. (2000). *BS EN ISO 15686-1:2000. Buildings and constructed assets – Service life planning – Part 1: General principles.*

Chandler, J., Phillips, S., Roe, P. & Viner, H. (2003). *Quieter concrete roads: construction, texture, skid resistance and noise.* TRL, TRL576

Clark C and Stansfeld SA (2007). The Effect of Transportation Noise on Health and Cognitive Development: A Review of Recent Evidence. *International Juornal of Comparative Psychology*, Vol. 20, pp145-158.

Dale, S. J. (1993). Introduction to life cycle costing. In: J. Bull, (ed). *Life Cycle Costing for Construction*, Glasgow: Blackie Academic and Professional, pp.1-22.

DfT. (2012a). *The Noise Sub-objective: TAG Unit 3.3.2.* London: Department for Transport.

ERF. (2006). *The Socio-Economic Benefits of Roads in Europe*. Brussels, Belgium: European Union Road Federation.

European Commission. (2000). *A Study on the Economic Valuation of Environmental Externalities from Landfill Disposal and Incineration of Waste* [pdf]. [Accessed 24th October 2012]. European Commission, DG Environment. Available from World Wide Web: http://ec.europa.eu/environment/waste/studies/pdf/econ_eva_landfill_report.pdf

European Commission (2002). Directive 2002/49/EC of the European Parliament and of the Council relating to the assessment and management of environmental noise. *Official Journal of the European Commission*, L189/12. Brussels, Belgium: Commission of the European Communities.

European Commission (n.d.). *EU policy-making – counting the hidden costs* [online] [Accessed 24th October 2012]. Available from World Wide Web: http://ec.europa.eu/research/environment/print.cfm?file=/comm/research/environment/newsanddoc/article_1444_en.htm

FEHRL (2006a). *Study SI2.408210 Tyre/Road Noise Volume 1: Final Report.* Brussels.

FEHRL. (2006b). *Guidance manual for the implementation of low-noise road surfaces* (Report 2006/02), [pdf]. FEHRL, Belgium. [Accessed 10th April 2013]. Available from the World Wide Web: http://www.trl.co.uk/silvia/Silvia/pdf/silvia_guidance_manual.pdf

Flanagan, R. & Norman, G. (1983). *Life Cycle Costing for Construction.* London: RICS

Flintsh, G. and Kuttesch, J. (2002). Engineering economic analysis tools for pavement maintenance. management. In: *Proceedings of the 3rd International Conference Bituminous Mixtures and Pavements*, Nov 02, Greece, Vol 2, pp.669-679

Hofstetter, P. and Muller-Wenk, R. (2005). Monetization of health damages from road noise with implications for monetizing health impacts in life cycle assessment. *Journal of Cleaner Production*, 13, pp.1235-1245

Hooper, R., Armitage, R., Gallagher, A. and Osorio, T. (2009). *Whole-life infrastructure asset management: good practice guide for civil infrastructure.* London: CIRIA

Hormandinger, G. and Lucas, N. (1996). Is clean enough? The influence of environmental externalities on markets for fuel cells in transport, *Transportation Research Part D: Transport and Environment*, Vol 1, Issue 1, pp.63-78

ISO (1997). ISO 11819-1. *Acoustics - Method for measuring the influence of road surfaces on traffic noise - Part 1: The Statistical Pass-by method.* Geneva, Switzerland: International organisation for standardisation.

ISO (2000). ISO 11819-2. *Acoustics — Measurement of the influence of road surfaces on traffic noise — Part 2: The close-proximity method*. Geneva, Switzerland: International Organisation for Standardisation.

Kent Highway Services. (2008). *Quiet Surface Prioritisation Methodology* [online]. [Accessed 4th November 2012]. Available from World Wide Web: http://tdc-mg-dmz.thanet.gov.uk/documents/s2779/Queit%20Surfacing%20Prioritisation%20Methodology.html?CT=2

Kephalopoulos, S., Paviotti, M. and Anfosso-Lédée, F. (2012). *Common Noise Assessment Methods in Europe (CNOSSOS-EU).* Luxembourg: Publications Office of the European Union.

Kirk, S. and Dell'Isola, A. (1995). *Life Cycle Costing for Design Professional* (Second Edition). McGraw-Hill

Kruitwagen, S., Udo, J. and Janssen, L. (n.d.) *Noise annoyance in the Netherlands: an empirical valuation study* [pdf]. [Accessed 4th November 2012]. Available from World Wide Web: http://www.webmeets.com/files/papers/ERE/WC3/644/Kruitwagen%20Kyoto%20063101.pdf

Lake, I., Bateman, I., Day, B. and Lovett, A. (2000). *Assigning a monetary value to noise reduction benefits; an example from the UK* [online]. [Accessed 4th November 2012]. Available from World Wide Web: http://www.iccr-international.org/trans-talk/docs/ws2-lake.pdf

Litman, T. (2009). *Transportation Cost and Benefit Analysis – Techniques, Estimates and Implications: Noise*, Second Edition [pdf]. [Accessed 4th November 2012]. Available from World Wide Web: http://www.vtpi.org/tca/tca0511.pdf

Morgan, P. A. (2008). *IPG Research Report. Innovative mitigation measures for road traffic noise* (DVS-2008-18). Delft, The Netherlands: Rijkswaterstaat Dienst Verkeer en Scheepvaart

Morgan, P. A. (2014). *Assessing the acoustic durability of noise barriers on NRA road networks.* (QUESTIM Deliverable D4.1) [online]. Available from World Wide Web: www.questim.org

Morgan, P. A. and Nelson, P. (2000). *Selection of EU computation methods for road and rail transport noise* (PR/SE/116/00). Crowthorne: Transport Research Laboratory.

Muirhead, M., Morris, L. and Stait, R.E. (2010). *The performance of quieter surfaces over time.* (PPR485). Crowthorne: Transport Research Laboratory.

Muller-Wenk, R. & Hofstetter, P. (2003). *Monetization of the health impact due to traffic noise.* Berne, Switzerland: Swiss Agency for the Environment, Forests and Landscape SAEFL.

Nelson, J. (2007) *Hedonic Property Value Studies of Transportation Noise: Aircraft and Road Traffic*, in Brananzini, A. et al, Hedonic Methods in Housing Markets: Pricing Environmental Amenities and Segregation, Springer

Nicholls, J., Carswell, I., Wayman, M. & Reid, J. (2010). *Increasing the environmental sustainability of asphalt* (INS007). Crowthorne: Transport Research Laboratory.

Nijland, H. & Wee, B. (2008). Noise valuation in ex-ante evaluations of major road and railroad projects. *European Journal of Transport and Infrastructure Research*, Issue 8(3), pp.216-226

Noise & Vibration Worldwide. (2004). Noise and Property Values. *Noise and Vibration Worldwide*, 35(3), pp.9-12

OGC. (2007). *Whole-life costing and cost management: Achieving Excellence in Construction Procurement Guide.* London: OGC

Padmos, C., Morgan, P., Abbott, P., van Blokland, G., Roovers, M. S., Bartolomaeus, W. and Anfosso-Lédée, F. (2005). *Classification scheme and CoP method* (SILVIA Project Report SILVIA-DWW-025-014-WP2-151005) [online]. Available from: www.trl.co.uk/silvia

Robinson, R., Danielson, U. & Snaith, M. (1998). *Road Maintenance Management.* Great Britain: MacMillan.

Silence (2006). *Report on noise-related parameters of existing pavement monitoring systems and possibility of integrating acoustic parameters*, Silence report F.D8, European Commission.

Sinhal, R., Abell, R. and Ramdas, V. (2001). Use of whole life costs in network level assessments of road maintenance budgets. *Proceedings of the 5th International Conference on Managing Pavements*, Seattle

van Blokland, G., Tollenaar C., van Loon R. (2014a). *Acoustic aging of road surfaces.* (QUESTIM Deliverable D2.2) [online]. Available from World Wide Web: www.questim.org van Blokland, G., Morgan P., Beckenbauer T., Kuosmanen A. (2014b). *Half Period report.* (QUESTIM Deliverable D1.1) [online]. Available from World Wide Web: www.questim.org

Veisten, K. and Akhtar, J. (2011). Cost-benefit analysis of low-noise pavements: dust into the calculations. *International Journal of Pavement Engineering*, Vol 12 (1), pp.75-86.

World Bank. (2008). *HDM-4 Road User Effects* [online]. [Accessed 14th August 2009]. Available from the World Wide Web : http://siteresources.worldbank.org/INTROADSHIGHWAYS/Resources/338993-1115667319236/1095944-1229373148786/08HDM-4RoadUserEffects2008-10-22.ppt

World Health Organisation (2011). *Burden of disease from environmental noise.* Copenhagen, Denmark: WHO.

Appendix A: Reviewed systems

- AgileAssets Suite, Agile Assets Inc
- Asset Manager, FHWA, AASHTO and Cambridge Systematics
- ATLAS, Exor (now part of Bentley)
- CONFIRM, MapInfo
- dTIMS, Deighton Associates
- HDM-4, World Bank
- HIMA, Harfan
- HIMS, HIMS Ltd
- HMS-2, HMS Ltd
- Insight Enterprise, Symology Ltd
- Integrated Asset Management System, WDM Ltd
- MARCHpms, Yotta Ltd
- Maximo, IBM
- MicroPaver, American Public Works Association
- Optram, Bentley
- PARMMS, PARMMS Software Solutions
- PMS, Dynatest
- RDM, TRL
- RoadAsyst and BridgeAsyst, Pitt and Sherry
- Road Manager, Vanasse Hangen Brustlin Inc
- RoSyPMS, Grontmij and CarlBro
- Total Infrastructure Management System (TIMS), Alberta Infrastucture and Transportation, Canada
- WiLCO, SEAMS

This page is intentionally left blank

Appendix B: Pavement Management Systems and noise: Information request

The 'Quietness and Economics Stimulate Infrastructure Management' (QUESTIM) project, awarded under the CEDR Transnational Road Research Programme Call 2012, is, within Work Package 5, addressing the topic of integrating strategic noise management into the operation and maintenance of national road networks.

Noise from road traffic and road pavements is the environmental issue that is most acknowledged by highway authorities, being recognised as not just an annoyance but also a health impact. Also since the implementation of the Environmental Noise Directive (END)[23] there has been a renewed emphasis on long term noise management from major sources within EU member states, such as that from road traffic using the Strategic Road Network.

One of the tasks under the QUESTIM project is to review existing cost-benefit models and Pavement Management Systems (PMS) and understand what commonality exists between them. We are also interested in how they currently deal with noise or how noise might be able to be incorporated in the future.

To provide the evidence base for this task we are seeking information which provides evidence on current use of PMS, with a specific emphasis on the environmental issue of noise. However, we are aware that in recent years there have been studies asking similar questions on the topic of PMS and the environment and so we do not want to repeat these requests.

To that extent we have used previous reports[24] and compiled a brief summary of what we believe to be the current position which can be found at the end of this request. We would be grateful if you could read through the brief summary provided and either provide a response based on your experiences or pass on to the relevant person within your organisation who may have such experience. Some questions have been suggested as prompts for the response.

If you are able to help by providing a response to the supporting background information please send the information or details of how to obtain the information (e.g. web-link) to Matthew Muirhead (mmuirhead@trl.co.uk, +44(0)1344 770609) or Thomas Buckland (tbuckland@trl.co.uk, +44(0)1344 770455) before 26th July 2013.

Please do not withhold information because the contribution is thought to be limited to describing only some of the impacts of a PMS. Any information, or contact details of others who can provide information, will be valuable in preparing our report. If you are unable to provide any information it would be helpful if you could let us know so that we do not bother

[23] European Union Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise, vol. L., 2002, pp12-16

[24] Deliverable 4.1 – Report on environmental components: Strategies for the effective integration of environmental parameters into asset management systems, Holistic Evaluation of Road Assessment, 2012

you again for this request, but we hope you are able to contribute and thank you in advance for your assistance.

Details on the evidence being sought

There are a vast range of systems available for a road authority to choose from. Some PMS function simply as data storage systems while others include analysis components for predicting and costing future road maintenance needs (the later more commonly being known as pavement cost models).

Traditionally the only indirect costs included in pavement cost models have been the cost of delays experienced by road users. However, the more recent focus for these systems and models is to include data on externalities[25] and make use of that data within their analyses. This is particularly true for environmental issues (e.g. carbon, noise).

Noise is the environmental issue that has generated the greatest momentum within road maintenance assessment. Although there is still a lack of a consistent assessment of noise, the published noise maps demonstrate that road authorities are delivering the requirements of the END. However, the noise maps do not contribute into any formal assessment or prioritisation of maintenance needs and limited use is made of them once they are produced.

Scheme level environmental parameters have been incorporated into scheme assessments but often only on a qualitative (not quantitative) basis. Some authorities quantify noise (e.g. Scotland) but very few actually cost that noise. When noise is costed it tends to be at the detailed design stage rather than the more high-level modelling.

At a network (or strategic) level there is a current lack of a system which integrates noise data with road inventory and condition data and although noise data is stored within some systems (e.g. UK Highways Agency PMS) it is not used in calculating the costs and benefits of road maintenance.

Although there is a lot of detailed research on noise assessment and abatement, strategic assessments still do not integrate noise alongside the direct costs of maintenance. We would like to build on this position to understand the most appropriate ways in which noise can be considered within the framework of strategic cost-benefit tools as well as providing a cost-effective way in which to give a broad overview of scheme options in order to lead to a fuller appraisal of road maintenance options.

Some suggested questions to help guide your response are listed below:

- Do you agree with the summary above?
- Does the road authority in your country operate a PMS? Does it use a cost model to help manage the maintenance needs on the network? Does the model include noise?
- Is noise currently considered within maintenance planning? – either in deciding where schemes should happen, or in determining the costs and benefits of schemes.

[25] An externality affects the wider society, who were not directly involved in the initial act but who are affected by its outcomes (i.e. delays, emissions or noise from roadworks).

- Is noise indirectly considered in your maintenance planning via the consideration of low noise surfaces or noise barriers?
- How do you feel noise should be incorporated into strategic maintenance models?

This page is intentionally left blank

Appendix C: WebTAG Noise cost data

Table C.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	
66	67	82.84		
67	68	86.21		

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)
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[26]		
82	83	127.24		
83	84	127.24		
84	85	127.24		318.1

[26] The research used to derive these costs assumed a constant monetary value for noise changes above 81 dB.

Appendix D: Noise methodology example

This example of the noise implementation data uses for following input data:

1. Maintenance interventions occur in 2014, 2022, 2030 and 2038;
2. The initial surface is a surface dressing and a new thin surfacing is applied in all interventions;
3. The noise change values are as set in Table 13;
4. The noise scheme was assumed to be in county Kildare, using initial noise input data from Table 20;
5. The maintenance scheme was assumed to be 200m in length meaning the starting number of dwellings in the scheme were:
   a. 55-59 dB: 294;
   b. 60-64 dB: 195;
   c. 65-69 dB: 186;
   d. 70-74 dB: 49; and
   e. 75+ dB: 1.
6. The noise costs were as in Table 5;
7. The discount rate was 3.5%;

Table D.1: Noise change for surfaces in worked example

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[27]	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
2033		TS	-1	0	5	-0.4
2034		TS	-1	0	5	-0.2
2035		TS	-1	0	5	0.0
2036		TS	-1	0	5	0.0
2037		TS	-1	0	5	0.0
2038	TS	TS	-1	0	5	-1.0
2039		TS	-1	0	5	-0.8
2040		TS	-1	0	5	-0.6
2041		TS	-1	0	5	-0.4
2042		TS	-1	0	5	-0.2

[27] The maintenance years are shaded

Table D.2: Noise dwellings and dwelling changes for worked example

Year	In-year change (dB)	Dwellings in noise band					Dwellings changed from reference dwellings[28]				
		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
2033	-0.4	240	185	110	23	0	20	15	9	2	0
2034	-0.2	243	188	114	24	0	10	8	5	1	0
2035	0.0	245	191	118	25	0	0	0	0	0	0
2036	0.0	245	191	118	25	0	0	0	0	0	0
2037	0.0	245	191	118	25	0	0	0	0	0	0
2038	-1.0	234	176	99	20	0	49	38	24	5	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

[28] The reference years (years immediately prior to maintenance) are shaded dark. Lighter shading indicates the years using that reference data for deriving dropped dwellings for that 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: The dwelling calculations are round to the nearest whole dwelling and therefore rounding differences may be apparent in some of the example calculations.

Table D.3: Noise costs for worked example

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
2033	-0.4	4,795	5,208	4,118	1,060	21	15,202	7,640
2034	-0.2	2,398	2,604	2,059	530	11	7,601	3,691
2035	0.0	0	0	0	0	0	0	0
2036	0.0	0	0	0	0	0	0	0
2037	0.0	0	0	0	0	0	0	0
2038	-1.0	11,988	13,019	10,294	2,651	54	38,005	16,082
2039	-0.8	9,590	10,415	8,235	2,121	43	30,404	12,430
2040	-0.6	7,193	7,812	6,176	1,590	32	22,803	9,008
2041	-0.4	4,795	5,208	4,118	1,060	21	15,202	5,802
2042	-0.2	2,398	2,604	2,059	530	11	7,601	2,803