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DISTANCE

Future potential traffic scenarios

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Developing Innovative Solutions for Traffic Noise Control in Europe

Partners:

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Author(s) this deliverable:
Matthew Muirhead, TRL

Quality Review:

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<td><strong>Author:</strong></td>
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| Matthew Muirhead | | [Signature]

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<th>Technical Reviewer:</th>
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| Mike Ainge | | [Signature]

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Executive summary

The DISTANCE project is concerned with providing information and guidance to National Road Authorities in Europe with respect to the future management of road traffic noise. It is designed to inform decision makers on topics such as state-of-the-art practical noise mitigation measures, data requirements for future noise mapping and action planning, future potential traffic scenarios and improving public perception, awareness and acceptance of noise mitigation. The aim is to provide information and knowledge which will assist in the planning and implementation of future noise mitigation measures on road networks in Europe.

This work has considered potential changes to road infrastructure and vehicle and tyre technology which may impact traffic noise levels at source. It has found that in the coming years there is likely to be:

- An increase in motorways as a fraction of the road network
- An increase in the use of Intelligent Transport Systems, designed to smooth traffic flow
- An increase in light goods vehicles as a fraction of the fleet
- An increase in the use of durable low-noise road surfaces
- Minimal impact on overall traffic noise from improvements in vehicle and tyre technology
- An increase in the use of electric and hybrid electric cars

None of these factors in isolation are expected to drastically reduce traffic noise but modelling has, with some important limitations, indicated that noticeable reductions in traffic are achievable if infrastructure changes, such as ITS and road surface improvements, are designed to take advantage of ongoing improvements in vehicle and tyre technology and the increasing role of electric vehicles.
1 Introduction

1.1 DISTANCE overview

The DISTANCE project is concerned with providing information and guidance to National Road Authorities (NRAs) with respect to the future management of road traffic noise. It is designed to inform decision makers on topics such as state-of-the-art practical noise mitigation measures, data requirements for future noise mapping and action planning, future potential traffic scenarios and improving public perception, awareness and acceptance of noise mitigation. The aim is to provide information and knowledge which will assist in the planning and implementation of future noise mitigation measures on road networks in Europe.

These primary objectives are addressed in work packages 2-5 of the project. Work package 2 investigates the sort of data that should ideally be provided by the NRAs, above and beyond that which is already collected, in order to produce more robust future strategic noise maps, created using the harmonised environmental noise calculation method CNOSSOS-EU (Kephalopoulos et al., 2012), and action plans, in accordance with the Environmental Noise Directive (2002/49/EC). Research programmes on road surfaces and noise barriers are considered, along with traffic and geospatial data and these sources of information are all linked back to their impact on the resulting quality of noise mapping. Recommendations and priorities for future data capture and modelling refinements are presented.

Noise mitigation measures that provide additional benefits beyond noise reduction may be useful additions to road infrastructure if they can be achieved with relatively little additional expenditure or if whole life costs are favourable. Work package 3 investigates how primary NRA assets such as road surfaces and noise barriers might be enhanced to provide such additional benefits, referred to as ‘secondary functions’. These secondary functions may be categorised as being physical, economic, environmental or social and include applications such as solar power generation and the control of emissions. The work package provides an evaluation of the feasibility and impact of these measures.

This report covers work package 4 which considers the impact on roadside traffic noise of potential changes to national road networks and vehicle fleets. An overview of what this entails and how the report is structured is given in Section 1.2.

Finally, work package 5 provides a critical review of alternative ‘smart’ solutions, including measures based on Intelligent Transport Systems (ITS), which can be used to abate noise from existing roads. These smart solutions include traffic control and management, urban planning and road design and socio-economic actions designed to promote consumer behaviour which results in a quieter environment. The work uses existing information to develop a decision making support tool to aid in identifying suitable measures within the context of available budget, environmental constraints and network restrictions.
1.2 Report structure and scope

Work package 4, presented in this report, concerns the potential impact of various vehicle and network infrastructure developments on the environmental noise exposure next to national network roads.

Traffic composition, fleet size and vehicle developments are discussed in Chapter 2. The future direction of vehicle and tyre technology and vehicle noise type approval regulations are considered along with the growing use of electric and hybrid electric vehicles.

Chapter 3 considers potential changes to road networks in terms of ITS and road surfaces. Given the emphasis on roadside noise, mitigation away from traffic, such as noise barriers, is not considered. This restriction enables the work to include some basic roadside noise calculations, using CNOSSOS-EU, to help quantify the impact of the measures considered.

These calculations are presented in Chapter 4 which explains how the reviewed factors have been incorporated into CNOSSOS-EU and presents results designed to illustrate both the impact of the changes in isolation and in conjunction with each other.

There is an important distinction to make between the manner in which potential changes to traffic and infrastructure are addressed in Chapters 2 and 3 and the manner in which they are addressed in Chapter 4. Chapters 2 and 3 present information on what has happened and, by extension, what may happen whereas Chapter 4 considers what could happen and the impact this would have on road traffic noise.

Approaching calculations in this way helps mitigate, to a certain extent, the inherent uncertainty in predicting future trends and provides the reader with an idea of the noise impact of certain potential changes even if these changes are not predicted to arise. As such no explicit future time frame is specified as being applicable to any of the calculations but an overall time-frame of 10-20 years may be considered loosely appropriate, as predictions further forward than this (for technological advances in particular) carry much greater uncertainty.

Chapter 5 draws together the conclusions, highlighting the potential future developments which will provide the biggest noise reductions.
2 Current and future vehicle fleet

This chapter presents a brief overview of recent changes to the European vehicle fleet both in terms of the amount and composition of traffic and in terms of the vehicle engine and tyre technology of the fleet. This information is, where possible, used to infer potential changes to the fleet in the future.

2.1 Fleet size and composition

New passenger car registrations in the EU have been falling steadily since 2005 (EC, 2014) and this mirrors somewhat the economic conditions of countries in Europe. Southern Europe has seen more of a pronounced decline in sales, a decline of 60% in Spain and 45% in Italy since 2007 (ICCT, 2013). It remains the case that three quarters of all new registrations come from the top five countries – Germany, France, United Kingdom, Italy and Spain. However, the stock of registered cars since 2005 has risen (by around 10% to 246 million in 2012), suggesting that the average age of cars is increasing, and passenger kilometres (pkm) for cars over the same period rose up until 2009 before falling back slightly to 4.6 trillion pkm in 2012 (EC, 2014a).

The stock of goods vehicles has also increased by around 10% between 2005 and 2012 to 34 million while the number of buses and coaches has remained fairly static (EC, 2014a). Despite stock increases, haulage by tonne-kilometres has been slowly but steadily declining since 2005 suggesting either that goods vehicles are being used less or that typical goods vehicles are, on average, getting smaller. This latter assumption is supported by the prediction that light-duty vehicle stock is expected to rise by over 30% by 2030 (ICCT, 2013).

2.2 Vehicle powertrain technology

2.2.1 Electric vehicles

The vast majority of new cars in Europe remain powered by petrol or diesel engines with hybrid and electric cars accounting for around 1% of new registrations, lagging behind both the US and Japan. This area of the market is however both expanding and diversifying; in 2001 only two hybrid models were available in Europe selling around 2,000 cars whereas by 2012 this had risen to over 30 models accounting for around 130,000 sales (ICCT, 2013).

Data collected as part of the CEDR funded FOREVER programme suggested that fully electric cars comprised a negligible amount of the car fleet in 2013 (Muirhead and Kennedy, 2015). Whilst economic incentives in some countries were having a noticeable impact, such as Norway where 13% of all cars sold between January and May 2014 were electric, it was expected that fully electric cars would still only comprise less than 10% of the car fleet in

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1 This rise in light-duty vehicle stock is not reflected in the modelling, presented in Chapter 4, since these vehicles fall into the same CNOSSOS-EU vehicle category as cars. Hence only changes to the fraction of heavy goods vehicles are reflected in the calculations.
2030. Hybrid electric cars were found to make up between 0.5% and 1.5% of the car fleet in 2013 and were expected to grow to comprise 10-25% of the car fleet by 2030. However, these statistics do not consider the distances travelled by the cars and it is likely that most fully electric cars, at least in the near future, will not be covering the distances travelled by their petrol and diesel counterparts.

The impact assessment for the EU proposal for a Directive on the deployment of an alternative fuels infrastructure (EC, 2013) summaries a lot of the published targets and forecasts for the growth in electric vehicle uptake. The overall expectation is for plug-in vehicles to comprise around 7% of new car sales in Europe by 2020.

Although electric Heavy Goods Vehicles (HGVs) have been developed by companies such as EMOSS (www.emoss.biz\textsuperscript{2}) and Smith (www.smithelectric.com\textsuperscript{3}) they form such a small part of the overall market that not only is there essentially no impact on traffic noise on national networks at present any future impact is difficult to predict and likely to be far in the future.

\textbf{2.2.2 Type approval}

New vehicles need to pass a type-approval noise test irrespective of their powertrain technology and in recent years this test, and the results needed to pass, have gone through a number of changes designed to promote vehicles that are quieter under typical driving conditions.

Under EU vehicle type-approval legislation, Directive 70/157/EEC (EC, 1970) specifies the permissible sound level of vehicles as relating to a noise emission test prescribed in Annex 3 of UNECE Regulation No.51, 02 series of amendments, as amended (UNECE, 2007). The prescribed noise emission test was shown (for example, see Morgan, Nelson and Steven, 2003) as not being representative of real life driving in urban traffic conditions. Therefore, a revised test method was developed (Method B) over a number of years, resulting in a revised ISO 362 (ISO, 2007). Method B is prescribed in Annex 10 of the same UNECE regulation.

The revised method was tested in conjunction with the previous method in order to understand the relative noise emissions from the revised test procedure. The results of this ‘back-to-back’ testing were used to inform appropriate permissible limits for the revised test procedure (Regulation (EU) No. 540/2014).

Despite these changes to the test method and the revised permissible limits the overall impact on traffic noise has been shown to be minimal, see for example (Steven, 2012) and (Muirhead, 2012), since most cars will not have to reduce their noise emissions in order to pass the revised type-approval procedure. Looking to the future, other than the gradual decline of vehicles in the fleet which do not meet these revised type-approval limits, there are unlikely to be many further widespread noise reductions.

Additionally most HGVs will already meet these new noise limits and although there are continued improvements in HGV gearbox and clutch design, which have the potential to

\textsuperscript{2} Accessed 28/05/15
\textsuperscript{3} Accessed 28/05/15
reduce noise under certain acceleration conditions, their impact on typical free-flowing traffic is likely to be negligible.

2.3 Vehicle tyre technology

At steady speeds greater than 40-50 km/h, vehicle powertrain noise has relatively little impact on the overall noise emission from the vehicle and the dominant noise source results from the interaction of the tyres and the road surface. This section provides a brief overview of tyre noise and regulation and road surfaces are discussed in Section 3.2.

Legislation to control tyre noise was introduced in 2001 (Commission of the European Communities, 2001). The Directive established a test method for assessing rolling noise emissions from tyres and set limit values for different types of tyres. Subsequently Regulation (EC) No 661/2009 was introduced to govern tyre noise testing at type approval and outlines revised limit values, which were expected to reduce traffic noise by around 1 dB for medium to high speed roads (Muirhead et. al., 2008). The limits prescribed in Regulation (EC) No 661/2009 are those still in force today.

More recently part of the FOREVER project included an investigation into tyres used on electric cars. This found that electric vehicles make use of low rolling resistance tyres and there is currently no evidence of a trend between the rolling resistance performance and the EU rolling noise labels and even if there were there is no correlation between tyre labelling, which reflects performance at type-approval, and roadside traffic noise (Gasparoni et. al., 2014). Additionally it was found that tyres designed or selected by manufacturers for electric cars have little to no effect on global rolling noise compared to conventional tyres.

Therefore, in looking to the future, it is difficult to see how further noise reductions from tyres, promoted through type-approval testing, can come to have a noticeable impact on traffic noise. Tyre noise depends on a number of factors including the tyre compound, width and tread pattern (and implicitly the age of the tyre), road surface stone size, texture (and implicitly age), vehicle weight, speed and acceleration and surface wetness and weather conditions. Any type approval test on any surface can only account for a small fraction of these factors and will be unlikely to correlate with roadside noise levels in circumstances that differ from the test. Whilst it is appreciated that there different levels of budgets, traffic and weather conditions across Europe steps taken to understand and promote the harmonisation of the most appropriate surfaces, considering factors such as cost, durability and wet grip, would also be an important first step in the right direction in controlling noise and would help considerably in defining a quiet tyre.
3 Current and future road infrastructure

This Chapter provides a brief summary of network infrastructure changes which may impact traffic noise at source\(^4\).

3.1 Road network

Whilst changes in the road network, in terms of road classification, do not necessarily have a direct impact on traffic noise it is useful to briefly consider the extent to which national road networks in Europe are changing since, broadly speaking, this will inform the relative importance of measures effective for motorways, other high speed roads or lower speed roads. For example, measures to reduce powertrain noise would be expected to be most beneficial on low speed roads where rolling noise is not so dominant while motorways may be the only roads with the necessary infrastructure to accommodate certain innovative measures such as variable speed limits.

The length of motorway across the EU has been increasing steadily for a number of years, by over 10% between 2005 and 2011 (EC, 2014), but, as of 2011, still only comprises 20% of all main, national roads\(^5\). This is not counting local and regional roads which cover more total kilometres than the national networks.

If the current trend continues then motorways will become an increasingly important part of most national networks in Europe and, given these roads are most likely to have the infrastructure with which to incorporate Intelligent Transport Systems (ITS), see Section 3.3, this reinforces the importance of technology based traffic management in the coming years.

3.2 Road surfaces

There have been numerous studies on the relevance of the road surface for the noise production of road vehicles, including their acoustic performance over time, e.g. (van Blokland et. al., 2014), (Muirhead et. al., 2010), and depending on the surface traffic noise levels can differ by up to 10 dB (van Blokland et. al., 2014).

Whilst the use of thin surfacing systems, see (Morgan, 2006) for notes on how these may be classified, is increasingly widespread their durability is not always as good as other, generally noisier, road surfaces such as concrete (Muirhead et. al., 2010). As such exposed aggregate concrete surfaces are still used in member states such as the UK and Belgium. On the other hand very quiet surfaces, such as dual-layer porous asphalt, are increasingly used in member states such as the Netherlands (van Blokland et. al., 2014).

The precise future trend of road surface types which are most commonly used is difficult since policy and budget in certain areas in constantly in flux but there is a general desire for

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\(^4\) This therefore excludes noise barriers. For up-to-date information on noise barriers see the output of the CEDR funded QUESTIM programme (Morgan, 2014).

\(^5\) These national roads and motorways likely equate to those roads which fall under the jurisdiction of the NRAs, although this has not been verified.
a reduction in traffic noise to be as part of a surface’s characteristics and this is reflected in the modelling assumptions in this work, see Section 4.2.4.

### 3.3 Intelligent Transport Systems

Intelligent Transport Systems (ITS) are expected to have a major impact on all future transport modes and whilst noise reduction is generally not an explicit aim for ITS applications, it is possible that ITS introduced specifically to provide benefits in one or more other areas, such as safety and efficiency, could have noise implications as a side effect.

This section introduces some examples of ITS which (a) may become more prevalent on national networks in a future time frame of 10-20 years and (b) may have an impact on traffic noise. A full examination of their potential impact on traffic noise has been conducted as part of the DISTANCE programme and is provided here in Appendix B.

Since both powertrain and tyre noise are speed related, it is logical to concentrate on those ITS which will have an effect on vehicle speed. A second effect to consider is that of traffic density; any ITS which affect traffic density will also lead to a change in overall noise generated. Finally tertiary effects such as heavy braking and cornering at excessive speeds create additional short term noise through a combination of increased tyre noise, and tyre and brake squeal. Hence any ITS applications which smooth driving will have a small positive effect on noise.

Various studies, for example the COBRA project (ERA-NET, 2012), have identified a large number of future applications and the most relevant with regard to potential future impacts on traffic noise are:

1. **Traffic information and recommended itinerary with Dynamic Route Guidance (DRG).** This application provides users with a network optimised, dynamic route guidance service. While modern Satnav systems will optimise a route based on current traffic levels, and update the route in response to incidents on the network, this application extends this to include knowledge of what routes other users are planning and will distribute the traffic to make best use of the network.

2. **Various forms of hazard detection, avoidance and mitigation (HD).** This group of applications warns a driver about upcoming hazards on the road network. These could be real hazards (obstacle on road surface, wrong way driver), potential hazards (road works, vulnerable road users) or areas of known increased risk (accident black spots). The warnings, which could be audible, visual or haptic, are presented to the driver in good time to take mitigating action.

3. **In-Vehicle Signage (IVS) and Intelligent Speed Adaptation (ISA).** These applications provide users with in-vehicle information normally displayed on roadside fixed and variable signs. In more advanced systems, the speed of the vehicle is automatically adapted to the current speed limit and conditions.

4. **Insurance and financial services.** This is an area which has already experienced considerable growth, particularly in the Pay-As-You-Drive (PAYD) and Pay-How-You-Drive (PHYD) insurance market. Sensors in the vehicle detect distance driven, types of roads used and driving styles, and the driver’s insurance payments depend on the risk profile identified. Similar technology could be used to implement variable road
charging systems where drivers are charged more for driving at certain times or on certain roads.

5. **Eco-Driver Support.** Electronic systems can control engines more effectively than people but overall fuel consumption and emissions still depend on the driver’s right foot. In this application the infrastructure reports upstream traffic and geographic features to the vehicle so that the driver can be recommended a strategy for minimising emissions and fuel consumption without affecting journey time and the engine can be kept in its optimal operational zone.

6. **Dynamic Traffic Management (DTM).** Using similar information to the Dynamic Route Guidance application, the road authority dynamically manages the network, for example by using variable speed limits and hard shoulder running. The information can be relayed to in-vehicle systems through IVS and ISA applications. Smoother running traffic tends to reduce the incidence of accidents.

7. **Platooning and Autonomous Vehicles.** Vehicles following each other closely and travelling at a constant speed maximise use of the road and reduce emissions. In platooning, vehicles are electronically linked using V2V communications to form a platoon or convoy. The lead vehicle sets the speed of the platoon, with following vehicles automatically maintaining the speed and position in the platoon. The following vehicles are therefore autonomous. The autonomous concept can then be extended to vehicles operating autonomously outside of platoons.

8. **Active Noise Cancellation (ANC).** While not normally considered an ITS application, ANC is a technology which directly addresses the noise produced by vehicles. ANC is a technique where sound is created which is directly in phase opposition to unwanted noise, thereby reducing the unwanted noise.

Overall the biggest impact on traffic noise from ITS is likely to come from those applications which reduce overall traffic speeds and promote smoother driving and this is reflected in Chapter 4, in which ITS are modelled through changes to traffic speed and acceleration.
4 Impact on the traffic noise environment

This chapter takes the vehicle and road infrastructure information from Chapter 3 and interprets these factors in terms of variables, such as mean traffic speed for cars and road surface type, which may be modelled using CNOSSOS-EU. Changes to these variables are considered in isolation first, so that their relative impact on traffic noise may be judged without too many confounding factors, before an example of a future roadside noise environment is investigated to illustrate how changes to these factors may be brought together to provide noticeable reductions in noise exposure.

4.1 Scope of calculations

In order to provide an overview of the potential impact of future vehicle and infrastructure changes on the traffic noise environment it is important to have a clear understanding of the key parameters determining traffic noise, including identifying those which can be clearly accounted for given available data and modelling restrictions, and how they interact.

The approach adopted focuses on determining appropriate parameters for the calculation of roadside noise levels and evaluating each in turn. Given the wide variation in traffic noise environment between different road types in different member states absolute noise levels pertaining to specific locations are not the focus of the calculations. The emphasis is instead on providing an understanding of the extent to which traffic noise would be altered if certain changes occurred. As such a baseline model, loosely reflecting current road infrastructure and vehicle technology, is created and changes to noise levels brought about by illustrative changes to various important factors are considered relative to this baseline.

Following this a potential future scenario is considered which combines the impact of various measures. It is important to note however that this scenario is just one of many possible directions in which the future traffic environment might change and merely serves as an example of what could happen in 10-20 years’ time rather than what will happen.

Modelling is carried out using CNOSSOS-EU, including the correction factors for electric vehicles derived in the FOREVER programme\(^6\), to provide octave levels for the rolling and propulsion noise components of all vehicles\(^7\) in the traffic stream. These levels are then combined to provide indicative changes to hourly average noise levels, \(L_{Aeq,1h}\), at the roadside.

Section 4.2 discusses the key parameters in the modelling and provides justification for some of the modelling assumptions. Section 4.3 collates this information to outline the matrix of scenarios considered, see Table 4.1. This matrix consists of a present day baseline model

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\(^6\) Only electric cars are considered in the modelling. Electric trucks are not considered since (a) further measurement programmes are required before robust correction factors can be determined (b) they constitute such small fraction of the fleet as to have negligible impact at present and (c) data on the future uptake of electric power within the HGV fleet are very difficult to come by.

\(^7\) CNOSSOS-EU vehicle category 1 consists of cars and vans under 3.5 tonnes, category 2 twin-axle goods vehicles over 3.5 tonnes, category 3 vehicles over 3.5 tonnes with three or more axles and category 4 motorbikes. The full definition of the CNOSSOS-EU vehicle categories is provided in Appendix A.
from which each of the identified parameters is altered in turn followed by an example future scenario. Section 4.4 presents the results of the modelling, in terms of $L_{Aeq,1h}$ roadside noise levels, and explains the causes of the observed differences.

### 4.2 Key modelling factors

#### 4.2.1 Road categories (vehicle composition and speed)

Changes to vehicles and networks will alter the noise environment by different amounts depending upon the make-up of the traffic stream. Therefore the decision as to what sorts of traffic streams to consider is a fundamental topic to address before the impact of various changes can be classified.

The modelling considers a variety of road categories from motorways to local, minor roads and also the impact of changes to congested motorways. By doing this it is considered that a variety of traffic compositions and speeds can be considered and the reader can get an appreciation of how these factors influence changes to overall traffic noise. For example, it is to be expected that the relative noise benefit from a switch to electric cars will be greatest on roads with a small fraction of HGVs and low mean traffic speed. Higher levels of HGVs will mask the noise from the cars and higher traffic speeds will increase the dominance of the rolling noise component which, as discussed in Section 4.2.7, is unlikely to change significantly with the introduction of more electric cars.

The data pertaining to the breakdown of traffic by road category are the same as was used for within the FOREVER programme (Muirhead and Kennedy, 2015) which themselves came from UK Department for Transport statistics cross-referenced with data for other member states, such as France and Austria, provided by other partners on the FOREVER consortium; this information is used as a starting point for the modelling of the different road categories.

#### 4.2.2 Traffic

The nature of typical traffic, in terms of vehicle numbers and percentage HGVs, will largely be governed by the type of road and local factors and, as such, modelling based on an estimated European average is not very informative. The road type is controlled in the modelling as discussed in Section 4.2.1 and the model incorporates some potential variations on these data to give an idea of the noise impact of changing traffic levels and composition.

As discussed in Section 2.1, overall traffic in Europe has been declining in recent years and there has not been any dramatic change in the proportion of traffic comprised of HGVs. Nevertheless, as an example of the relative robustness of traffic noise to changes in these factors, an indication of the noise impact of a 2%/yr increase in traffic, over a 20 year period, and a 50% increase or decrease in HGV traffic is included within the roadside noise calculations. For the future baseline scenario no change in traffic volume or composition is assumed.
4.2.3 Speed

As with traffic volume and composition, traffic speed is a key parameter controlled for through the modelling of various road types. Future variations to traffic speed are modelled in terms of an increase to the speed limit on motorways for cars, as has been proposed in the UK for example\(^8\), and the impact of ITS in smoothing traffic on a congested motorway.

This follows the analysis into the effect of future ITS on vehicle noise emissions, see Appendix B, which, whilst not identifying any applications which would have a significant effect on noise, did conclude that the biggest effect is likely to come from those applications which reduce overall traffic speeds and promote smoother driving. For the future baseline scenario just the traffic smoothing is modelled.

4.2.4 Road surface data

The road surface information used in the modelling is crucial in so much as it is the key parameter influencing rolling noise which is itself the dominant noise source at most speeds. Additionally, the quieter the road surface the less dominant the rolling noise and therefore the greater the chance of detecting the propulsion noise reduction achieved from switching to electric cars.

There exist a wide range of road surface types on European roads and there is a large body of literature on their acoustic performance, for example (van Blokland et. al., 2014) and (Muirhead et. al., 2010). These surface performance characteristics are not the primary focus for this work and therefore it is considered prudent to use the default road surface of CNOSSOS-EU, a Stone Mastic Asphalt / Dense Asphalt Concrete surface with an 11mm chip size (SMA/DAC 0/11), for modelling the current baseline.

The alternate road surfaces modelled are SMA 0/6, reflecting the advancement of thin surfacing systems with relatively small chip sizes, twin-layer porous asphalt, reflecting the ultra-low noise surfaces in member states such as the Netherlands, and exposed aggregate concrete, reflecting the existing and proposed use of such a durable road surface in countries such as the UK and Belgium. For the future baseline scenario it is assumed the drive towards quieter road surfaces continues and correction factors for a SMA 0/6 are used.

The corrections factors used for these road surfaces are those derived for the HARMONOISE source model (Peeters and van Blokland, 2007) which forms the basis for the CNOSSOS-EU source model. It is important to highlight that (a) other correction factors for these surfaces exist (van Blokland et. al., 2014) and would give different results and (b) it is well-known that the acoustic properties of road surfaces degrade with age (Muirhead et. al., 2010) and this is not modelled here. This latter restriction is the equivalent of the modelling assuming that the road surfaces in the alternate scenarios have been laid within the last 12 months.

\(^8\) [http://www.express.co.uk/news/uk/554114/Speed-limit-motorways-raised-80mph](http://www.express.co.uk/news/uk/554114/Speed-limit-motorways-raised-80mph), accessed 28/05/15
4.2.5 Studded tyres

The CNOSSOS-EU model allows the modelling of studded tyres for cars and these correction factors are used to explore the difference to the traffic noise this would make for the different road categories. The future baseline scenario does not assume studded tyres are used.

4.2.6 Acceleration

The only present baseline scenario under which acceleration is modelled is the congested motorway and these acceleration terms are removed in modelling the smoothing impact of future ITS.

To give an idea of the potential impact of acceleration on traffic noise each road type is modelled with these acceleration terms put back in. The effect is to increase the contribution of powertrain noise relative to rolling noise for the vehicles. No acceleration terms are used in modelling the future scenario.

4.2.7 Tyre composition

The rolling noise component in CNOSSOS-EU is based upon the work carried out in the HARMONOISE programme (Peeters and van Blokland, 2007). Vehicle and tyre noise measurements taken to support this model predate Regulation (EC) No 661/2009, see Section 2.3. Previous work, for example (Muirhead, 2008), concluded that rolling noise for cars and trucks on typical surfaces, such as the default road surface for CNOSSOS-EU, would be reduced by around 2 and 1.5 dB respectively.

This analysis was factored to reflect the fact that noise benefits determined on a smooth ISO surface will not be fully realised on typical roads but nevertheless contrasts with the findings of the FOREVER project, see Section 2.3, which investigated quiet tyres for electric cars and recommended no further correction to the CNOSSOS-EU rolling noise component. However the FOREVER work did acknowledge its limited scope of testing and reveal that some benefit achieved at type approval can be realised on certain roads despite the definition of quieter tyres being far from clear cut.

The rolling noise reductions of 2 and 1.5 dB for cars and trucks are used here in the future scenario to reflect the fact that some progress will have been made since the year 2000 but that little further tangible improvement is expected beyond the measures taken to meet Regulation (EC) No 661/2009.

4.2.8 Vehicle noise

As discussed in Section 2.2.2 there has been a lot of work carried out on changes to the type approval regulations governing vehicle noise, changes not accounted for in the CNOSSOS-EU model. Given the associated limit values have only recently been finalised (EC, 2014b) the impact of these revisions is not included in the baseline scenario but is modelled as a

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9 These reductions are not applied in the baseline scenario since (a) not all tyres will yet meet these limits and (b) the calculations are intended to quantify the impact of such reductions.
factor and incorporated into the future scenario to reflect a general trend for slightly quieter engines at steady speeds or under gentle acceleration.

Additionally, the propulsion noise corrections to CNOSSOS-EU for electric cars, as proposed by the FOREVER project, are included as a modelled factor. In the future scenario the fraction of electric cars, see Section 2.2.1, is taken to be 25%\textsuperscript{10}.

4.2.9 Agglomerations

Work carried out on assessing the impact of changes to the type approval regulations for tyres (Muirhead \textit{et. al.}, 2008) looked at the distribution of dwellings in agglomerations within England and found that the vast majority of residents (approximately 98%) in such urban conurbations lived next to low speed, minor roads.

It is therefore not really appropriate to include agglomerations in the modelling matrix since (a) the results would be near identical to those for minor roads (b) the low level of traffic on some of these roads may well make the noise from individual vehicles a more appropriate metric and (c) most of these minor roads are unlikely to be part of the national network and the responsibility of the NRA.

As such the impact on agglomerations may be considered within the context of the existing modelling matrix, see Section 4.3, rather than treated as a separate calculation.

Additionally, further geospatial analysis of the proximity of dwellings to various road types, for areas considered representative of the whole country (i.e. including rural areas outside of agglomerations), estimated that between 64 and 96% of dwellings had minor roads as their closest source of traffic noise. In this case the remaining dwellings were estimated to be approximately evenly split between having dominant traffic noise from roads with a speed limit of 50-80km/h and roads with a speed limit over 80km/h.

Therefore, when considering entire member states, a more complex mix of road types needs to be considered. This analysis is largely outside the scope of this work package but relevant comments are made in discussing the results of the modelling.

4.3 Matrix of scenarios

The aim of the modelling is to provide an idea of the impact changes to key parameters will have on traffic noise and to define the boundaries within which potential changes to the traffic noise environment under a number of local scenarios may be envisaged. This is considered more informative than selecting specific data on fleet compositions for pre-determined years which would necessarily contain both an element of uncertainty and a limited range of applicability.

\textsuperscript{10}This is a somewhat optimistic figure, arguably more reflective of the future proportion of hybrid electric cars (which would likely be running in petrol mode at the speeds used within the modelling), but, as highlighted in Section 4.1, the emphasis of the calculations is on showing what impact such changes could have were they to be achieved rather than on trying to select one figure to represent the whole of the EU.
The modelled scenarios are summarised in Table 4.1; Scenario 1 is the ‘baseline scenario’ and the final scenario, Scenario 14, is the ‘future scenario’. Scenarios 2-13 reflect changes to a particular modelling parameter in isolation so that its impact can be assessed.

Roadside noise levels, expressed as $L_{A_{eq,1h}}$, are calculated for the following road types:

- Motorways (free-flowing, 90-110 km/h)
- Motorways (congested, 50 km/h)
- Major, national trunk roads (70-77 km/h)
- Principal local roads (54-56 km/h)
- Minor local roads (49-50 km/h).

Where a range of speeds is listed this reflects the different mean speeds of the different vehicle categories.

The fleet composition for the baseline scenario, in terms of the fraction of twin axle and 3+ axle trucks (CNOSSOS-EU category 2 and category 3), is taken from UK national statistics, cross-referenced with data from other member states, such as France, collated as part of the FOREVER programme. A summary of these statistics is presented as part of Table 4.1 in terms of a range of percentages for HGVs covering all road types, from minor roads (lowest percentage HGV) to motorways (highest percentage HGV).

The remaining terms in the baseline calculation assume steady flow, except in the case of a congested motorway where a small acceleration term\(^{11}\) is introduced to reflect the variable speed of vehicle in traffic jams, and adopt CNOSSOS-EU default values for road surface, tyre noise and engine noise.

Scenario 2 examines the impact of a 50% increase in traffic volume, reflecting a 2%/year increase over 20 years. It is important to note that the emphasis is on the difference in noise level between the baseline scenario and alternate scenarios and not absolute levels. The traffic volumes used in the calculation are therefore nominal and by definition (other than Scenario 2) have no impact on the relative noise levels reported.

Scenarios 3 and 4 model a 50% increase and decrease in the fraction of HGV traffic respectively. Although existing data imply the fraction of HGV traffic may be expected to fall slightly, see Section 2.1, no major changes, of the order of 50% for example, are expected in general across Europe. However these large changes are always possible on individual roads and these scenarios are designed to reflect this and illustrate a form of worst case and best case scenario for changes in HGV movement.

Scenario 5 models potential changes to motorway regulations. For free-flowing motorways the impact on traffic noise of a 10 mph (16 km/h) increase in the speed limit is considered and for congested motorways the impact of ITS being able to smooth the flow is considered by removing the modelled acceleration term. The calculations for the other road types are unaffected in this scenario.

Alternate road surfaces are considered in Scenarios 6-8. They are designed to show the potential impact of improvements in thin surfaces (SMA 0/6, Scenario 6), ultra-low noise

\(^{11}\) In CNOSSOS-EU this is the term derived from acceleration away from a roundabout which is less severe than the correction term derived from acceleration away from a junction.
surfaces (twin-layer porous asphalt, Scenario 7) and popular durable road surfaces (exposed aggregate concrete, Scenario 8). As stated in Section 4.2.4 the correction terms are those reported in HARMONOISE and, as with any corrections used, can only be considered representative of the performance of the road surface rather than a definitive measure.

Scenario 9 models the impact of studded tyres. This can only be modelled for cars in CNOSSOS-EU and here is modelled for all cars to provide an upper bound for the potential impact on noise of their use.

In Scenario 10 a small acceleration term\textsuperscript{12}, as applicable to the congested motorway, is applied to all road types to give an idea of the noise impact of vehicle changing speed. This may also be viewed in terms of increasing the relative importance of engine noise in the calculation as this is modelled to increase under acceleration.

Scenario 11 is designed to reflect the impact on roadside traffic noise of quieter tyres, whereby the entire fleet is equipped with tyres meeting Regulation (EC) No 661/2009. From 2016 all new and replacement tyres will be expected to meet these regulations.

Scenario 12 calculates the noise impact of all cars being fully electric and therefore, given the other parameters, reflects an upper bound on the noise benefit that may be expected from a move to electric cars. As inferred in Section 2.2.1 the percentage of electric vehicles refers to cars only; no change is modelled to HGVs.

The impact of changes to the propulsion noise of standard petrol and diesel vehicles prompted by the introduction of EC Regulation No. 51.03 is modelled in Scenario 13. Note that, as rolling noise dominates over engine noise in most of the scenarios modelled, this impact is relatively minor.

Finally Scenario 14 is designed to reflect a potential future road layout comprising of a low noise thin surface, some ITS smoothing the flow and quieter cars, 25\% of which are electric, with quiet tyres. It is important to emphasize that this is just one possible future scenario amongst many and actual future changes to the noise environment are sensitive to not only all the parameters modelled but also mitigation measures not modelled, such as noise barriers. This is discussed further in Section 4.4 and Chapter 5.

\textsuperscript{12} In CNOSSOS-EU these terms reflect measurements taken from acceleration away from a roundabout and not under congested motorway conditions and this limitation is highlighted in the discussion of the results.
Table 4.1: Modelling matrix

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Flow (veh/hr)</th>
<th>%HGV</th>
<th>Speed (km/h)</th>
<th>Surface</th>
<th>Stud. Tyre</th>
<th>Acc.</th>
<th>Tyre noise</th>
<th>Engine noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>0/11</td>
<td>No</td>
<td>No</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>2</td>
<td>7500</td>
<td>2-13</td>
<td>49-110</td>
<td>0/11</td>
<td>No</td>
<td>No</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>3</td>
<td>5000</td>
<td>3-20</td>
<td>49-110</td>
<td>0/11</td>
<td>No</td>
<td>No</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>4</td>
<td>5000</td>
<td>1-7</td>
<td>49-110</td>
<td>0/11</td>
<td>No</td>
<td>No</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>5</td>
<td>5000</td>
<td>2-13</td>
<td>128°</td>
<td>0/11</td>
<td>No</td>
<td>Smooth</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>6</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>SMA 0/6</td>
<td>No</td>
<td>No</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>7</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>PA°</td>
<td>No</td>
<td>No</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>8</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>EAC°</td>
<td>No</td>
<td>No</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>9</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>0/11</td>
<td>Yes</td>
<td>No</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>10</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>0/11</td>
<td>Yes</td>
<td>No</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>11</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>0/11</td>
<td>No</td>
<td>No</td>
<td>-2/-1.5</td>
<td>100% EC⁴</td>
</tr>
<tr>
<td>12</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>0/11</td>
<td>No</td>
<td>No</td>
<td>0/0</td>
<td>-1/-2</td>
</tr>
<tr>
<td>13</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>0/11</td>
<td>No</td>
<td>No</td>
<td>0/0</td>
<td>-1/-2</td>
</tr>
<tr>
<td>14</td>
<td>5000</td>
<td>2-13</td>
<td>49-110</td>
<td>SMA 0/6</td>
<td>No</td>
<td>Smooth</td>
<td>-2/-1.5</td>
<td>25% EC, -1/-2</td>
</tr>
</tbody>
</table>

¹Vehicle and road type dependent ²dB reductions for cars/HGVs ³DAC/SMA 0/11 (CNOSOS-EU default surface) ⁴Except for congested motorway ⁵Free-flow speed of cars on motorway ⁶Steady flow for congested motorway ⁷Porous Asphalt ⁸Exposed Aggregate Concrete ⁹For cars only ¹⁰Electric cars (correction from FOREVER)

4.4 Results and discussion

The results of the modelling, in terms of the difference in $L_{Aeq,1h}$ between the baseline scenario and the alternate scenarios, are presented in Table 4.2. A dash (‘-‘) mark in the table highlights that the conditions of that calculation are identical to that of the baseline. These results are discussed in turn in the following paragraphs.

The results from Scenario 2 merely reflect the well-known fact that traffic noise is proportional to $10\log_{10}$ of the flow or, put another way, that a 25% increase or a 20% decrease in traffic is required to change the traffic noise by 1 dB.

Scenarios 3 and 4 highlight that large changes in the fraction of HGV traffic have minimal impact on the overall traffic noise under steady flow conditions. Under acceleration, HGV powertrain noise is relatively high and at low speeds in particular this can be a dominant noise source in the traffic, hence the larger differences calculated under congested traffic conditions. It is also worth noting that the noise annoyance of accelerating HGVs at low speed is generally perceived in terms of individual vehicles rather than as an increase in longer term exposure.
Table 4.2: Differences in $L_{A_{eq,1h}}$ between baseline and modelled scenarios

<table>
<thead>
<tr>
<th>Scenario (description)</th>
<th>Motorway (free-flow)</th>
<th>Motorway (congested)</th>
<th>Trunk</th>
<th>Principal</th>
<th>Minor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (baseline)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2 (+50%flow)</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>3 (+50%HGV)</td>
<td>0.4</td>
<td>1.5</td>
<td>0.3</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>4 (-50%HGV)</td>
<td>-0.4</td>
<td>-2.2</td>
<td>-0.3</td>
<td>-0.3</td>
<td>-0.1</td>
</tr>
<tr>
<td>5 (speed/ITS)</td>
<td>1.1</td>
<td>-3.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6 (SMA 0/6)</td>
<td>-2.1</td>
<td>-0.1</td>
<td>-1.6</td>
<td>-1.0</td>
<td>-0.9</td>
</tr>
<tr>
<td>7 (PA)</td>
<td>-5.9</td>
<td>-4.6</td>
<td>-5.0</td>
<td>-4.3</td>
<td>-3.9</td>
</tr>
<tr>
<td>8 (EAC)</td>
<td>1.2</td>
<td>0.1</td>
<td>1.1</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>9 (stud. tyres)</td>
<td>1.2</td>
<td>0.4</td>
<td>1.7</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>10 (acceleration)</td>
<td>-0.2</td>
<td>-</td>
<td>-0.1</td>
<td>0.7</td>
<td>-0.4</td>
</tr>
<tr>
<td>11 (quiet tyres)</td>
<td>-1.5</td>
<td>-0.2</td>
<td>-1.5</td>
<td>-1.3</td>
<td>-1.4</td>
</tr>
<tr>
<td>12 (electric cars)</td>
<td>-0.3</td>
<td>-0.4</td>
<td>-0.4</td>
<td>-0.6</td>
<td>-0.8</td>
</tr>
<tr>
<td>13 (quieter cars)</td>
<td>-0.2</td>
<td>-1.6</td>
<td>-0.3</td>
<td>-0.3</td>
<td>-0.3</td>
</tr>
<tr>
<td>14 (future scenario)</td>
<td>-3.6</td>
<td>-4.6</td>
<td>-3.1</td>
<td>-2.4</td>
<td>-2.5</td>
</tr>
</tbody>
</table>

Scenario 5 presents two results: the first indicates that an increase in traffic noise of around 1 dB may be expected if cars on a free-flowing motorway are allowed to travel 16 km/h quicker and the second highlights the potential noise benefit of smoothing congested traffic. This latter result in particular should be treated with some caution since (a) it has not been verified that the chosen acceleration correction, derived from vehicle accelerating away from roundabouts, is an accurate reflection of the variable speed of vehicles in congested traffic and (b) it may well be the case in practice that ITS designed to smooth the traffic also increases the mean speed of the traffic, improving the flow of vehicles but negating some of the noise reduction.

Some examples of the impact the road surface can have on traffic noise are highlighted in Scenarios 6-8. The first two road surfaces, SMA 0/6 and porous asphalt, reduce rolling noise relative to the CNOSSOS-EU reference surface and are therefore most effective in reducing traffic noise on higher speed roads where rolling noise is the dominant source. In general quiet road surfaces are arguably the most effective way in which to reduce traffic noise and have been studied extensively. In particular the results of Scenario 8, for exposed aggregate concrete, need to be considered in context since, while they show an increase in noise relative to the CNOSSOS-EU reference surface the surface is still quieter than other types of road surface such as Hot Rolled Asphalt (HRA) and brushed concrete. Also these results do not reflect the acoustic performance of these surfaces over time and EAC has been shown to be more durable in this regard than certain thin surfaces (Muirhead et al, 2010).

The impact on traffic noise of having all cars equipped with studded tyres is shown in the results for Scenario 9. These results reflect the fact that the relative increase in rolling noise, compared to standard tyres, is higher at lower speeds and that the lower speed roads also have a higher proportion of cars in the traffic stream.
The acceleration terms in CNOSSOS-EU increase the propulsion noise of all vehicles but also decrease the rolling noise, especially for cars (Kephalopoulos et al., 2012). This results in the slightly counter-intuitive numbers presented in Table 4.2. For minor roads, where there are very few HGVs, the reduced rolling noise component for cars results in an overall reduction in traffic noise. For principal roads the increase in HGV numbers increases the overall traffic noise relative to smooth flow as accelerating HGVs are modelled as definitively noisier under acceleration at these speeds. For the high speed roads, such as motorways, the dominance of rolling noise for cars (which are themselves travelling at higher speeds than the HGVs) results in an overall relative reduction in traffic noise despite the increase in proportion of HGVs on these roads.

How accurate this model is under these circumstances however is open to question; the acceleration terms were derived from vehicles moving away from roundabouts, not accelerating on high speed roads. Therefore these results should be treated with caution and perhaps are best viewed as illustrating that variable speeds within the traffic will be most noticeable, from a noise perspective, in situations where there are relatively low speeds and a large fraction of the traffic is made up of HGVs. This is the case for the congested motorway model and the results of Scenario 5 show that a noticeable noise reduction is potentially possible from ensuring smooth flow under these circumstances.

Scenario 11 reflects previous work, for example (Muirhead et al, 2008), which has estimated the benefits to traffic noise of Regulation (EC) No 661/2009 to be around 1.5 dB. This impact is reduced when traffic is congested and engine noise becomes more prominent but is otherwise fairly consistent across road types. The reduction in rolling noise may be expected to have greater impact on the high speed roads but this countered by the fact that the impact is less for HGVs and the proportion of these vehicles on the higher speed roads is greater.

A detailed look at the impact of electric cars on traffic noise was carried out as part of the FOREVER programme and Scenario 12 reflects these results, in indicating that, even if all cars were to be fully electric, the overall impact on traffic noise is likely to be less than 1 dB.

Similarly Scenario 13 shows that the impact of quieter conventional petrol and diesel engines is very minimal for free-flowing traffic. However, the work carried out on UNECE Regulation 51 does highlight some benefit for traffic under acceleration.

Finally Scenario 14 provides an example of one way in which a noticeable difference (generally considered to around 3 dB) in traffic noise may be achieved in the future. These benefits come from a combination of ITS, a quieter road surface, quieter tyres, quieter conventional engines and electric cars. It highlights that all these factors need to be worked on to really drive down traffic noise in the future and that there is no one system or technology that will provide a large reduction in traffic noise on its own. The largest reduction in traffic noise is generally achieved from quieter road surfaces but this is an expensive measure, especially if the quieter road surface is also considered less durable (i.e. would need replacing sooner than a surface which, when new, is less quiet).

These benefits generally arise from reductions in rolling noise and therefore are largest on high speed roads where rolling noise is the dominant noise source. However, most of the potential noise reductions can also be achieved on lower speed roads as, even at 50 km/h, rolling noise is still the loudest noise source for cars.
There are some more complex details which the calculation does not consider. For example, the estimated benefit of Regulation (EC) No 661/2009 is based on work which takes into account the relationship between tyre noise on an ISO surface and tyre noise on ‘typical’ road surfaces in the UK, such as HRA and SMA 0/14, and these relationships are not adjusted to reflect an equivalent relationship with SMA 0/6. Other factors, such as the fact electric cars may have narrower (and therefore quieter) tyres, are also not modelled although these would be expected to have little impact on the overall hourly noise level of the traffic.
5 Conclusions

This work has considered potential changes to road infrastructure and vehicle and tyre technology which may impact traffic noise levels in Europe in the future. It has found that in the coming years there is likely to be:

- An increase in motorways as a fraction of the road network
- An increase in the use of Intelligent Transport Systems, designed to smooth traffic flow
- An increase in light goods vehicles as a fraction of the fleet
- An increase in the use of durable low-noise road surfaces
- Minimal impact on overall traffic noise from improvements in vehicle and tyre technology
- An increase in the use of electric and hybrid electric cars.

None of these factors in isolation are expected to drastically reduce traffic noise but modelling has, with some important limitations, indicated that noticeable reductions in traffic are achievable if infrastructure changes, such as ITS and road surface improvements, are designed to take advantage of ongoing improvements in vehicle and tyre technology and the increasing role of electric vehicles.

One area for further research is the impact of ITS on traffic noise. In general ITS has the effect of smoothing traffic flow thereby reducing the acceleration and deceleration of vehicles and, as explained in Section 4.4, the acceleration terms in CNOSSOS-EU have not been derived or validated under these conditions.
References


## Appendix A: CNOSSOS-EU vehicle categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
<th>Description</th>
<th>Vehicle category in EC whole vehicle type approval&lt;sup&gt;(1)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light motor vehicles</td>
<td>Passenger cars, delivery vans ≤ 3.5 tons, SUV’s&lt;sup&gt;(2)&lt;/sup&gt;, MPV’s&lt;sup&gt;(3)&lt;/sup&gt; including trailers and caravans</td>
<td>M1 and N1</td>
</tr>
<tr>
<td>2</td>
<td>Medium heavy vehicles</td>
<td>Medium heavy vehicles, delivery vans &gt; 3.5 tons, buses, touring cars, etc. with two axles and twin tyre mounting on rear axle</td>
<td>M2, M3 and N2, N3</td>
</tr>
<tr>
<td>3</td>
<td>Heavy vehicles</td>
<td>Heavy duty vehicles, touring cars, buses, with three or more axles</td>
<td>M2 and N2 with trailer, M3 and N3</td>
</tr>
<tr>
<td>4</td>
<td>Powered two-wheelers</td>
<td>4a mopeds, tricycles or quads ≤ 50 cc</td>
<td>L1, L2, L6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4b motorcycles, tricycles or quads &gt; 50 cc</td>
<td>L3, L4, L5, L7</td>
</tr>
<tr>
<td>5</td>
<td>Open category</td>
<td>To be defined according to the needs in the future</td>
<td>N/A</td>
</tr>
</tbody>
</table>


<sup>(2)</sup> SPORT UTILITY VEHICLES

<sup>(3)</sup> MULTI-PURPOSE VEHICLES
Appendix B: Influence of ITS on reducing traffic noise

Introduction

The DISTANCE project is investigating future road noise issues. As Intelligent Transport Systems (ITS) are expected to have a major impact on all future transport modes, it is logical to investigate whether any of the future ITS applications will have an impact on the noise emitted by vehicles. This note will investigate which ITS systems are expected to become common in the next 10-20 years and what effect (if any) they will have on traffic noise.

First we need to ensure that we understand the sources of vehicle noise. The overwhelming majority of noise from road vehicles comes from two sources, namely mechanical noise (exhaust, drivetrain, ancillaries etc.) and tyre/road noise. The former predominates at low speed (below 30-60 kph, depending on vehicle type) while the latter predominates above these speeds. Mechanical noise makes a greater contribution while vehicles are accelerating, although this effect is probably negligible for cars and becoming increasingly so for modern heavy vehicles. Since both mechanical and tyre noise are speed related, it is logical to concentrate on those ITS systems which will have an effect on vehicle speed.

A second effect to consider is that of traffic density. Everything else being equal, each doubling of traffic density will lead to a 3db increase in vehicle noise, so any ITS systems which affect traffic density will also lead to a change in overall noise generated.

Finally we must also consider some tertiary effects; heavy braking and cornering at excessive speeds create additional short term noise through a combination of increased tyre noise, and tyre and brake squeal. Hence any ITS applications which smooth driving will have a small positive effect on noise.

So in summary, the questions we will ask for each ITS application identified are:
- Will this application affect vehicle speeds?
- Will this application affect traffic density?
- Will this application affect acceleration/deceleration?
- Will this application influence incidences of heavy braking and cornering?

Any ITS application which results in a positive answer to any of the above questions may then have an effect on traffic noise.

Identification of future ITS applications

Noise reduction is generally not an explicit aim for ITS applications. The PIARC handbook (PIARC, 2004) on Intelligent Transport Systems does not list noise reduction as a specific benefit of ITS.

The handbook lists the benefits of ITS in six categories:
- Safety benefits
- Efficiency benefits
- Productivity and cost reduction benefits
- Environmental benefits
• Benefits to people with mobility difficulties
• Benefits to local communities

Noise fits most comfortably into the *environmental benefits* and *benefits to local communities* categories.

The US Department of Transport (DoT, 2014) also maintains an extensive list of ITS applications.

Other than Active Noise Cancellation (which is not really considered an ITS application) as used in some luxury cars, no ITS applications have been identified which are specifically designed to reduce noise. However, it is possible that ITS introduced specifically to provide benefits in one or more of the other categories could have noise implications as a side effect. Research on future ITS systems has tended to concentrate on cooperative ITS as this is seen as the area with most potential benefits, so this is the area in which most information is available.

Various studies have identified a large number of future cooperative applications. For example, the COBRA project (ERA-NET, 2012) identified a long list of 50 future cooperative applications. There is however a significant overlap between many of these applications, and others are somewhat speculative. To reduce the amount of analysis required in evaluating applications, a number of studies have identified the most likely future ITS using a combination of technology readiness, likely costs and benefits and market pull.

The COBRA project (ERA-NET, 2012) used the results from a number of previous projects, namely *Defining the required infrastructure supporting Cooperative Systems* (SMART2010/0063, 2011), *New Services Enabled by the Connected Car* (SMART2010/0063, 2011), and *Proposal for first priority EasyWay cooperative services* (EasyWay 2010) and *Cooperative Vehicle Highway Systems: Implications for the Highways Agency*, written by TRL for the Highways Agency (unpublished but used with permission) to produce a consensus list of the highest priority cooperative ITS services identified in the projects. These are the first 19 applications listed in the table below in priority order where the first service is the highest priority. Note that while this is a list based on the results of the studies mentioned, choosing a different set of source literature is likely to result in a slightly different set of priorities. The remaining applications listed are those which have become more prominent recently and may have an impact on noise emissions.

<table>
<thead>
<tr>
<th>No.</th>
<th>Application Description</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traffic information and recommended itinerary</td>
<td>Efficiency</td>
</tr>
<tr>
<td>2</td>
<td>Traffic jam ahead warning</td>
<td>Safety</td>
</tr>
<tr>
<td>3</td>
<td>Hazardous location notification</td>
<td>Safety</td>
</tr>
<tr>
<td>4</td>
<td>Road works warning</td>
<td>Safety</td>
</tr>
<tr>
<td>5</td>
<td>In-vehicle signage</td>
<td>Safety</td>
</tr>
<tr>
<td>6</td>
<td>Enhanced route guidance</td>
<td>Efficiency</td>
</tr>
<tr>
<td>7</td>
<td>Intelligent Speed Adaptation</td>
<td>Safety</td>
</tr>
<tr>
<td>8</td>
<td>Automatic access control / parking management incl. ITP</td>
<td>Efficiency</td>
</tr>
<tr>
<td>9</td>
<td>Obstacle on driving surface warning</td>
<td>Safety</td>
</tr>
<tr>
<td>10</td>
<td>Decentralized floating vehicle data</td>
<td>Data Collection</td>
</tr>
<tr>
<td>11</td>
<td>Automatic Crash Notification (eCall)</td>
<td>Safety</td>
</tr>
</tbody>
</table>
From the above list, several groups of applications stand out:

1. Traffic information and recommended itinerary with dynamically updated route guidance (1, 6 and 8)
2. Various forms of hazard detection, avoidance and mitigation (2, 3, 4, 9, 12, 13, 14, 15 and 18).
3. In-vehicle signage and intelligent speed adaptation (5 and 7)

As the applications in each group will have a similar effect on driver behaviour, we can therefore reduce the number of applications to be considered to the following:

<table>
<thead>
<tr>
<th>No.</th>
<th>Application Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traffic information and recommended itinerary with Dynamic Route Guidance (DRG)</td>
</tr>
<tr>
<td>2</td>
<td>Various forms of hazard detection, avoidance and mitigation (HD)</td>
</tr>
<tr>
<td>3</td>
<td>In-Vehicle Signage (IVS) and Intelligent Speed Adaptation (ISA)</td>
</tr>
<tr>
<td>4</td>
<td>Automatic Crash Notification (ACN)</td>
</tr>
<tr>
<td>5</td>
<td>Decentralized Floating Vehicle Data (FVD)</td>
</tr>
<tr>
<td>6</td>
<td>Insurance and financial services</td>
</tr>
<tr>
<td>7</td>
<td>Tracking and Tracing of hazardous and valuable goods (T&amp;T)</td>
</tr>
<tr>
<td>8</td>
<td>Eco-Driving Support</td>
</tr>
<tr>
<td>9</td>
<td>Dynamic Traffic Management (DTM)</td>
</tr>
<tr>
<td>10</td>
<td>Platooning and Autonomous Vehicles (PAV)</td>
</tr>
<tr>
<td>11</td>
<td>Active Noise Cancellation</td>
</tr>
</tbody>
</table>

**Analysis of effect on noise of future ITS applications**

In this section we consider each of the (groups of) applications listed above, evaluate whether they will have an effect on traffic speed, density, acceleration/deceleration and harsh braking/cornering, and hence consider if the application will have any net effect on noise emissions.

1. Traffic information and recommended itinerary with Dynamic Route Guidance (DRG).

This application provides users with a network optimised, dynamic route guidance service. While modern Satnav systems will optimise a route based on current traffic levels, and update the route in response to incidents on the network, this application extends this to include knowledge of what routes other users are planning and will distribute the traffic to make best use of the network.
Will this application affect vehicle speeds?
  o No, as long as traffic density is not increased beyond the carrying capacity of the road.

Will this application affect traffic density?
  o Potentially yes; the aim of the application is to make journey times more reliable by making better use of available infrastructure. This means that some vehicles which would normally use heavily trafficked roads may be diverted onto quieter local roads, thereby increasing the density on smaller roads. The effect is likely to be minimal as highway authorities are unlikely to countenance the diversion of large amounts of traffic from motorways to less safe trunk roads.

Will this application affect acceleration/deceleration?
  o Unlikely

Will this application influence incidences of heavy braking and cornering?
  o Unlikely

There may be a slight net increase in noise due to the increased density of traffic. A more important source of additional noise is the diversion of traffic off heavily trafficked trunk routes onto local roads, leading to a significant increase in noise for local communities. If this application is managed by road authorities, this is unlikely to be an issue as they would like to keep traffic on safer motorways as much as possible.

2: Various forms of hazard detection, avoidance and mitigation (HD).

This group of applications warns a driver about upcoming hazards on the road network. These could be real hazards (obstacle on road surface, wrong way driver), potential hazards (road works, vulnerable road users) or areas of known increased risk (accident black spots). The warnings, which could be audible, visual or haptic, are presented to the driver in good time to take mitigating action.

Will this application affect vehicle speeds?
  o This is unlikely to have a significant effect on average vehicle speeds

Will this application affect traffic density?
  o No, other than in the vicinity of serious incidents.

Will this application affect acceleration/deceleration?
  o Yes, vehicles will be warned in advance of hazards ahead, giving them the chance to reduce speeds more gradually. It is unlikely to have an effect on acceleration.

Will this application influence incidences of heavy braking and cornering?
  o Yes, emergency braking should be reduced in the vicinity of hazards.

This set of applications is unlikely to have a significant effect on noise.

3: In-Vehicle Signage (IVS) and Intelligent Speed Adaptation (ISA).

These applications provide users with in-vehicle information normally displayed on roadside fixed and variable signs. In more advanced systems, the speed of the vehicle is automatically adapted to the current speed limit and conditions.
Will this application affect vehicle speeds?
  o Yes, drivers are more likely to obey speed limits, both through increased awareness due to IVS, and by automatic speed limiting by ISA.

Will this application affect traffic density?
  o There may be a minimal effect through to better utilisation of the road network due to more uniform speeds of the vehicles using the road. An increase in traffic will result in an increase in noise, whereas smoother driving will lead to a decrease in noise. There is unlikely to be a net effect.

Will this application affect acceleration/deceleration?
  o There may be a minimal effect due to the vehicle fleet maintaining a more uniform speed, reducing noise.

Will this application influence incidences of heavy braking and cornering?
  o As above, there may be a minimal effect due to the vehicle fleet maintaining a more uniform speed. Advanced ISA systems could also reduce cornering speeds.

These applications are unlikely to have a significant effect on noise; if there is an effect it will most likely be a slight drop in overall noise. The biggest effect is likely to be in areas where vehicles tend to use excessive speed where ISA will reduce speeds to the posted limit.

4: Automatic Crash Notification (ACN).

This is an application which automatically notifies the emergency services in the event of a crash (normally as detected by airbag actuation). The application sends a Minimum Set of Data (MSD) containing details of the vehicle and its location to a public service access point. The MSD allows the emergency services to be aware of the vehicle type, fuel type and location of the crash, allowing for a timelier and appropriate response. In Europe, this service will be mandated through the pan-European eCall service in the near future.

Will this application affect vehicle speeds?
  o No

Will this application affect traffic density?
  o No

Will this application affect acceleration/deceleration?
  o No

Will this application influence incidences of heavy braking and cornering?
  o No

Note that while ACN will not have an effect on noise sources directly, once an accident occurs it becomes a hazard, and timely notification of an accident will bring the benefits of hazard detection into play earlier.

5: Decentralized Floating Vehicle Data (FVD).

Managing ever more heavily utilised road space requires the road manager to have an accurate view of current traffic conditions. This is currently mostly achieved through the use of in-road sensors, like MIDAS loops. These are only used on motorways, so do not provide information on other road types. They are also expensive to install and maintain. More comprehensive data can be provided by equipping a proportion of vehicles with tracking
devices which regularly report their location and speed. As long as enough vehicles are equipped, it will be possible to build up an accurate and up to date view of current traffic conditions, including density, speed and detection of incidents. This technique is already used by satnav providers like TomTom.

- Will this application affect vehicle speeds?
  - No
- Will this application affect traffic density?
  - Not directly, but the improved knowledge of traffic behaviour on the road network could lead to improved utilisation of the network, which in turn could affect traffic density.
- Will this application affect acceleration/deceleration?
  - Not directly, but FVD has the potential to reduce the time to detecting an incident, which could then allow the hazard detection application to be deployed earlier.
- Will this application influence incidences of heavy braking and cornering?
  - No

While an important future ITS application, this is not believed to have any direct positive or negative noise implications as it is a data collection service, rather than one which directly affects driver behaviour. However the improved understanding of traffic conditions that this application enables may have an indirect effect on noise.

6: Insurance and financial services

This is an area already experience considerable growth, particularly in the Pay-As-You-Drive (PAYD) and Pay-How-You-Drive (PHYD) insurance market. Sensors in the vehicle detect distance driven, types of roads used and driving styles, and the driver’s insurance payments depend on the risk profile identified. Similar technology could be used to implement variable road charging systems where drivers are charged more for driving at certain times or on certain roads.

- Will this application affect vehicle speeds?
  - PHYD insurance has the potential to reduce traffic speeds
- Will this application affect traffic density?
  - unlikely
- Will this application affect acceleration/deceleration?
  - PHYD insurance tends to penalise those who accelerate and brake heavily, so this could have an effect
- Will this application influence incidences of heavy braking and cornering?
  - PHYD insurance tends to penalise those who drive corner, accelerate and brake heavily, so this could have an effect

As these applications reward drivers for smoother driving, they may result in a small reduction in overall noise.

7: Tracking and tracing of hazardous and valuable goods
Logistics companies are already tracking their truck fleets for fleet management purposes. Specific high-values vehicles can be tracked and the information shared with law enforcement agencies.

This application will provide Safety, Productivity and Cost Reduction benefits. It is not believed the application will have any noise implications.

- Will this application affect vehicle speeds?
  - No
- Will this application affect traffic density?
  - No
- Will this application affect acceleration/deceleration?
  - No
- Will this application influence incidences of heavy braking and cornering?
  - No

This application is unlikely to have any effect on noise.

8: Eco-Driving Support

Electronic systems can control engines more effectively than people but overall fuel consumption and emissions still depend on the driver’s right foot. In this application the infrastructure reports upstream traffic and geographic features to the vehicle so that the driver can be recommended a strategy for minimising emissions and fuel consumption without affecting journey time and the engine can be kept in its optimal operational zone. This application will provide benefits in the Environmental category.

- Will this application affect vehicle speeds?
  - Yes, it will encourage slower driving
- Will this application affect traffic density?
  - No
- Will this application affect acceleration/deceleration?
  - Yes, it will encourage smoother driving, minimising the amount of braking.
- Will this application influence incidences of heavy braking and cornering?
  - Yes, again through encouraging smoother driving. It will not affect instances of emergency braking.

For any vehicle, the most significant effects on fuel economy are due to speed and harsh acceleration/braking. As speed is the most important contributor to vehicle noise at most driving/cruising speeds, any application which specifically targets speed will have an effect on noise emissions. Therefore this application will most likely reduce noise, particularly in areas where speeds tend to be excessive.

9: Dynamic Traffic Management (DTM)

Using similar information to the Dynamic Route Guidance application, the road authority dynamically manages the network, for example by using variable speed limits and hard shoulder running. The information can be relayed to in-vehicle systems through IVS and ISA applications. Smoother running traffic tends to reduce the incidence of accidents.
Will this application affect vehicle speeds?
  o Yes, variable speed limits are an important part of DTM.

Will this application affect traffic density?
  o Yes; the aim of the application is to make journey times more reliable by making better use of available infrastructure, and improving use of existing infrastructure by using it more efficiently, for example by making use of the hard shoulder during peak hours.

Will this application affect acceleration/deceleration?
  o Yes, this should decrease due to smoother running

Will this application influence incidences of heavy braking and cornering?
  o Unlikely

DTM is unlikely to have a net effect on noise. As traffic densities increase, variable speed limit systems will reduce speeds to smooth traffic flow, hence the increased noise due to increased densities will be cancelled out by reduced traffic speeds.

10: Platooning and Autonomous Vehicles

Vehicles following each other closely and travelling at a constant speed maximise use of the road and reduce emissions. In platooning, vehicles are electronically linked using V2V communications to form a platoon or convoy. The lead vehicle sets the speed of the platoon, with following vehicles automatically maintaining the speed and position in the platoon. The following vehicles are therefore autonomous. The autonomous concept can then be extended to vehicle operating autonomously outside of platoons.

Will this application affect vehicle speeds?
  o Yes, vehicles will stay within posted limits.

Will this application affect traffic density?
  o Potentially yes, particularly platooning which will lead to an increase in traffic density.

Will this application affect acceleration/deceleration?
  o Yes, autonomous vehicles will be programmed to accelerate as efficiently as possible. By being more aware of their surroundings, deceleration will be gentler and planned further ahead.

Will this application influence incidences of heavy braking and cornering?
  o Yes as autonomous vehicles are more aware of their surroundings and will be able to react to potential hazards earlier and less harshly.

As with DTM, there is unlikely to be a net effect on noise emissions as increased traffic density is likely to be cancelled out by reduced traffic speeds.

11: Active Noise Cancellation (ANC)

While not normally considered an ITS application, ANC is a technology which directly addresses the noise produced by vehicles. ANC is a technique where sound is created which is directly in phase opposition to unwanted noise, thereby reducing the unwanted noise. A number of different ANC technologies exists, including:
• Interior noise reduction, making the vehicle quieter for occupants. This also has the potential for reducing the amount of sound deadening material fitted into the vehicle, reducing costs and improving fuel economy. This technology already exists in some luxury cars.

• Exterior noise reduction, using active cancellation to reduce exhaust noise. This has the potential to use smaller, lighter exhausts with lower back-pressure to improve fuel economy while reducing noise emissions. The current research into this technology is focussing mainly on weight reduction and performance improvement, rather than noise reduction.

Regarding the effect on sources of noise:
• Will this application affect vehicle speeds?
  o No.
• Will this application affect traffic density?
  o No.
• Will this application affect acceleration/deceleration?
  o No.
• Will this application influence incidences of heavy braking and cornering?
  o No.

Interior Noise Reduction only addresses interior noise and will have a minimal effect on exterior noise. It is possible that the increased comfort factor will lead to an increase in vehicle speeds, but this is unlikely.

Exterior noise reduction could have an effect on noise emissions, but as noted most current research is replacing existing noise mitigation measures rather than producing a net decrease in noise.

In theory it may be possible to use ANC to reduce drive-by tyre noise, but no significant research has been identified into this area.

The above analysis is summarised in the table below.
## Affects:*

<table>
<thead>
<tr>
<th>Application</th>
<th>Speed</th>
<th>Density</th>
<th>Acceleration/Deceleration</th>
<th>Harsh braking/Cornering</th>
<th>Noise Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRG</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>Possible increase due to more traffic on minor roads</td>
</tr>
<tr>
<td>HD</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Slight reduction in noise due to less harsh braking</td>
</tr>
<tr>
<td>IVS/ISA</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Slight reduction due to lower speeds and smoother driving, including less emergency braking</td>
</tr>
<tr>
<td>ACN</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No direct effect</td>
</tr>
<tr>
<td>FVD</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No direct effect</td>
</tr>
<tr>
<td>Insurance</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Slight reduction due to smoother driving being encouraged. Unknown effect due to some roads being avoided</td>
</tr>
<tr>
<td>T&amp;T</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>Eco-driving</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Slight reduction due to smoother driving, less acceleration/braking</td>
</tr>
<tr>
<td>DTM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>0</td>
<td>Reduction due to speed, increase due to density</td>
</tr>
<tr>
<td>PAV</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>Reduction due to speed, increase due to density</td>
</tr>
<tr>
<td>ANC</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Noise reduction by design</td>
</tr>
</tbody>
</table>

* 0=none, -=reduce, +=increase

## Conclusions

The analysis into the effect of future ITS on vehicle noise emissions has not identified any applications which will have a significant effect on noise. The biggest effect is likely to come from those applications which reduce overall traffic speeds and promote smoother driving.

No applications have been identified which will increase speeds. While some applications will result in an increase in traffic density, these tend to be accompanied by a decrease in traffic speeds, giving no net increase in noise emissions.
References


