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

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DISTANCE

Critical guidelines to the effective implementation of alternative "smart" noise mitigation measures

Deliverable 5.1, February 2015

Developing Innovative Solutions for TrAffic Noise Control in Europe

Partners:

BRRC (Belgian Road Research Laboratory) [Belgium]

TRL (Transport Research Laboratory) [UK]

SINTEF [Norway]

ANAS S.p.A. [Italy]

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

DISTANCE: Developing Innovative Solutions for TrAffic Noise Control in Europe

Development of guidelines for the implementation of alternative "smart" noise mitigation measures

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Table of contents

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Executive summary

Conventional traffic noise mitigation measures are based on insulation and absorption techniques. Sound insulation prevents the transmission of noise by the introduction of an acoustical shield whilst sound absorption reduces the amount of energy reflected into the environment, mainly through a dissipating mechanism. These systems are quite consolidated and widely used by NRAs, and include noise barriers, facade insulation, porous asphalt pavements, and other widely known techniques.

There are alternative ways to mitigating noise that are more oriented to reduce noise at the source; this is the case of regulations on low noise vehicles, low noise tyres, urban plans, roadway design, speed control systems, which are measures that try to reduce noise in an unconventional way; moreover, there are some innovative solutions that have been developed recently or that are still at a prototype stage, whose aim is to achieve higher noise reductions compared to other conventional and proven techniques.

The WP 5 deals with these alternative smart noise mitigation measures that are defined as a group of innovative technological solutions, strategies and actions that can be used to mitigating noise in an unconventional and innovative way; many of these unconventional measures, generally, are used to reduce traffic congestion or air pollution and can also be favourably applied to reduce noise as a complementary effect.

Particularly, the WP5 is aimed at developing a schematic procedure to help decision makers in selecting, among the available alternative smart noise mitigation solutions, those specific measures that have proven to be more effective in mitigating noise in relation to the context, expected benefits and costs.
This procedure is based on available information retrieved from a critical literature review accomplished on a wide range of demonstrative or implemented solutions from European and national research and demonstrative projects, and it includes information on their applicability, effectiveness, costs and benefits, as well as other wider benefits in addition to noise mitigation.

Among used and proposed alternative smart noise mitigation solutions, four well-defined categories emerge from the literature review. These categories are:

a) Measures applied to traffic control and management
b) Urban planning and road design measures
c) Socio-economic actions
d) Innovative solutions

The first category addresses those measures acting on mobility and sustainable transport plans. These measures include actions and ITS systems that affect vehicle speed, traffic volume and composition, night-time and daytime traffic modulation, as well as the introduction of limited traffic zones.

The second category addresses those measures acting on urban plans, road design, land use and topographical considerations, and screening techniques. Urban planning concerns the arrangement, appearance and functionality of towns and cities, and in particular the shaping and use of urban public space. A good road design helps to solve traffic and environmental problems, while improving the quality of life of people living near the streets. These measures include solutions such as the introduction of roundabouts, chicanes, cuttings and tunnels, green areas with dense vegetation and trees to separate receivers from roads, the use of new industrial and commercial buildings to screen inhabitants from noise.

The third category addresses those measures acting on noise emissions through socio-economic instruments that direct consumers towards quieter behaviour based on positive or negative incentives and regulations related to the use of noisy devices. Therefore, these actions are not physical instruments as those illustrated in the first and second category, but policies aiming to change traffic conditions and encourage alternative means of transport. To this category belong measures such as the introduction of tolls inside agglomerations based on vehicles type, tax to be applied to vehicles and gasoline, the development of programs to promote a quieter driving style, noise requirements and regulations for road surfaces based on reliable data, actions to be undertaken to reduce noise at the source (noise limits reduction for vehicles and tires, new noise emission testing for road vehicles that better represent typical drivers conditions in real traffic situations, etc.).

The fourth category addresses innovative “smart” noise mitigation measures such as those under development in on-going or recently ended research project or at a prototype stage as well as examples of worked initiatives or demonstration pilot studies. Such measures include solutions like active noise control and sonic crystals.

Data collected from literature are supplemented with information provided by NRA’s through a questionnaire focused on the same thematic domains.

Among all the analysed smart mitigation measures, only eight of them are found to match the interests of NRAs, and to be suitable for high speed roads.

For each selected measure, the report provides a synthetic description, an assessment of technical features, effectiveness, and a qualitative evaluation of costs and benefits. In particular, costs are referred to conventional noise mitigation measures, such as noise barriers, and split into qualitative cost bands.

Noise mitigation measures are also described in terms of their applicability and state of technology readiness. This last feature provides an indication to whether the measure is already available on the market or, if not, the maturity level of the measure in terms of its development/research status.

In order to help NRAs in adopting smart and innovative noise mitigation measures, a schematic procedure is provided. This includes a flow chart to guide users in the decision process, through conditional options based on the context, road type and age, environmental constraints and territorial restrictions, costs and benefits.

The document is produced by ANAS, that is the WP leader, and the Department of Civil and Industrial Engineering at the University of Pisa, its scientific partner, in collaboration with the other WP5 partners, TRL and SINTEF.

Structure of the report

The report consists of a series of paragraphs focused on selected noise mitigation measures, and is broken down into 4 chapters, as follows:

- Chapter 1 introduces the content of the report and the objectives of the deliverable D5.1; moreover, it describes the strategy and techniques used in literature review, the classification of the measures, and how to evaluate the applicability of the measures;
- Chapter 2 presents relevant information on the selected alternative smart mitigation measures; each paragraph provides a short description of the measure, an assessment of its technical features and potential applicability, a qualitative evaluation of costs and benefits, and finally an appraisal of their state of technology readiness and implementation potential.

  The measures selected for the specific interest of NRAs are the following:
  - 2.1: Traffic flow measures: diversion of traffic volumes
  - 2.2: Traffic speed measures
  - 2.3: Effect on noise of future ITS applications
  - 2.4: Junction design
  - 2.5: Traffic tolls
  - 2.6: Tyre noise limits
  - 2.7: New EU vehicle noise limits
  - 2.8: Diffractors
  - 2.9: Helmholtz resonators in pavements
  - 2.10: Poroelastic road surfaces (PERS)
  - 2.11: Soft ground along the road
  - 2.12: Artificial surfaces
  - 2.13: Sonic crystals

- Chapter 3 presents the schematic procedure to implement alternative “smart” noise mitigation measures, and includes a flow chart to support users in finding the most suitable solutions.

- Chapter 4 reports the conclusions and recommendations to NRAs

The Annex A of this report provides a critical review of other alternative smart mitigation measures analysed in the WP5, but that are ineffective or unsuitable to NRAs needs. The review includes data on their application, effectiveness, costs and benefits, and the wider benefits, in addition to noise mitigation, that they offer.

The Annex B reports the questionnaire prepared to collate information from NRAs and its results.

1 Introduction

Work Package No 5 is one of the seven parts in which DISTANCE project is divided. As reported in the first document of the project (“Template for submission – Part A”, May 2013), the objective of the DISTANCE project is to provide the National Road Administrations with comprehensive information/guidance that will help them in planning noise abatement in the future, by addressing the following key issues:

- Data requirements for future noise mapping and action plans;
- Future noise impacts of changes in road traffic;
- Multi-function and smart noise mitigation measures;
- Public awareness and engagement of noise mitigation in relation to action plans.

WP5 fits into the overall project evaluating the third key issue on smart noise mitigation measures. This document will offer NRAs a guideline on the current and future implementation of smart noise mitigation measures, illustrating the state-of-the-art of the most promising measures offering actual or potential environmental benefits.

1.1 Definition of alternative “smart” noise mitigation measures

Conventional traffic noise mitigation measures are based on insulation and absorption techniques. Sound insulation prevents the transmission of noise by the introduction of acoustical shields, whilst sound absorption reduces the amount of energy reflected into the environment, mainly through a dissipating mechanism. These systems are quite consolidated and widely used by NRAs, and include noise barriers, facade insulation, porous asphalt pavements, and other widely known techniques.

However, there are alternative and unconventional ways to mitigating noise that are more oriented to reduce noise at the source; this is the case of regulations on low noise vehicles and tyres, urban planning, roadway design, and speed control systems. Moreover, there are some innovative solutions that have been developed recently or that are still at a prototype stage, whose aim is to achieve higher noise reductions compared to other conventional and proven techniques.

The WP 5 deals with these alternative smart mitigation measures that can be defined as a series of technological solutions, strategies and actions that can be used to mitigating noise in an unconventional and innovative way; many of these unconventional measures, generally, are used to reduce traffic congestion or air pollution and can also be favourably applied to mitigating noise as a complementary effect.

1.2 Objectives of the deliverable

The WP5 is aimed at developing specific guidelines for selection of smart mitigation measures that have proven to be more effective in mitigating noise in relation to the context (agglomerations, suburban areas), expected benefits and costs; this will be achieved through the development of a schematic procedure and a decision-making support tool that will help decision makers in selecting those specific measures that best fit the NRAs needs.

Moreover, it is intended to provide a comprehensive overview of the most promising noise mitigation measures and to identify those measures potentially suitable to national road networks. The review includes data on their application, effectiveness, costs and benefits, and the wider benefits in addition to noise mitigation that they offer.

1.3 Strategy and description of techniques used

This work package and the deliverable D5.1 are based on a review of the most important examples and applications from European and national research and demonstrative projects, such as:

SILENCE PROJECT: *a three-year (2005-2008) research project co-funded by the European Commission, in which an integrated methodology for the improved control of surface transport noise in urban areas has been developed".*
HOSANNA PROJECT: *a four-year (2009-2013) research project co-funded by the European Commission that suggests cost-effective and environmentally friendly solutions for the reduction of road and rail traffic noise in outdoor environment.*
QCITY PROJECT: *a four-year (2005-2009) research project co-funded by the European Commission which has developed an integrated technology approach for the efficient control of road and rail environmental noise generation at the source at both vehicle and infrastructure level.*
UK NOISE ASSOCIATION RESEARCHES: *documents carried out by a voluntary non-charitable, non-profit making campaigning organization fighting to cut noise in the UK.*
CE DELFT RESEARCHES: *documents carried out by an independent research and consultancy organisation specialised in developing innovative solutions to environmental problems.*
PROJECT LIFE HARMONICA
http://www.noiseineu.eu/fr/33-voir_toutes_les_actions/subpage
EUROPEAN LEGISLATION: *laws that incentive the reduction of noise pollution from road traffic.*

Data collected from the aforementioned projects are reported in standardised worksheets to support a uniform description of noise mitigation measures.

The template is organised in tables, as shown below.

WP5 LITERATURE REVIEW
Template

Noise Abatement Measure (NAM):			
NAM Type:	☐ Traffic Control and Management ☐ Socio-economic Action	☐ Urban Planning and Road Design ☐ Other	
Reference Project Title:			
Project type:	☐ National	☐ European	☐ International
Participating countries:			
Start date (year)		**End date (year):**	
		Duration (months):	
Project character:	☐ Pilot or demonstrative project	☐ Feasibility study	☐ Research & Development

Project content (Summary – NAM description):

Environmental context:				
Context	☐ Agglomeration		☐ Suburban Area	
Road type	☐ Motorway	☐ Main Road	☐ Highway	☐ Secondary Road
Road Age (years)	☐ <=1	☐ 1<age<=5	☐ 5<age<=10	☐ >10
Traffic condition:	ADT[1]	HVP[2]	Main Speed (km/h)	
Environmental constraints and restrictions				

Main results and added value of the solution in terms of noise reduction and costs (qualitative description):			
Implementation expected benefits (qualitatively):			
Implementation expected costs (cost-effectiveness[3]):			
○ Low	○ Medium	○ High	○ Very high
State of the art			
☐ Ready for implementation	☐ Need for some more research	☐ In progress	☐ Inapplicable

List of main references (project homepage, reports, articles, conference proceedings, etc.):

[1] Average Daily Traffic
[2] Heavy Vehicles Percentage
[3] The range could be defined taking into account the method described in the report of CEDR Road Noise 2 "Value for money" to normalise costs and determine the cost-effectiveness of noise mitigation measures i.e. the cost that should be paid to reduce the number of people annoyed by one: low (cost ≤ 500 €); medium (500 €< cost ≤ 2.000 €); high (2.000 €< cost ≤5.000 €); very high (cost> 5.000 €).

The first table contains the name of the noise abatement measure and its category (in the following paragraph categories are listed and explained), the title of the reference project and its links, i.e. project type, participating countries, start and end date.

The second table is dedicated to the project content. In this table the summary and description of the analysed measure is reported.

The third table is focused on the environmental context, road type and age, traffic conditions and notes about environmental constraints and restrictions.

The fourth table is addressed to different features: a qualitative description of the main results and benefit of the solution in terms of noise reduction, costs and benefits, the technology readiness level.

The last table reports the list of the main references, such as project website homepage, reports, articles, conference proceedings, etc.

In order to ease the identification of the potential implementation context of the solution emerged from the literature review, data reported in those tables are then analysed and split in well-defined categories on the basis of their approach in abating noise.

1.4 Classification of the measures

Among used and proposed alternative smart noise mitigation solutions, four well-defined categories emerge from the literature review. These categories are:

a) Measures applied to traffic control and management
b) Road design measures
c) Socio-economic actions
d) Innovative technological solutions

The first category addresses those measures acting on mobility and sustainable transport plans. These measures include actions and ITS systems that affect vehicle speed, traffic volume and composition, night-time and daytime traffic modulation, as well as the introduction of limited traffic zones.

The second category addresses those measures acting on road design, land use, topographical considerations, and screening techniques. A good road design helps to solve traffic and environmental problems, while improving the quality of life of people living close to the streets. These measures include solutions such as the introduction of roundabouts, chicanes, cuttings and tunnels, green areas with dense vegetation and trees to separate receivers from roads, the use of new industrial and commercial buildings to screen inhabitants from noise. Although this second category is not in general suitable to suburban scenarios, an in depth analysis was done to see whether some of the techniques and technologies applied to high volume urban roads might be also applied to suburban major roads and highways.

The third category addresses those measures acting on noise emissions through socio-economic instruments that direct consumers towards quieter behaviour, based on positive or negative incentives and regulations related to the use of noisy devices. Therefore, these actions are not physical instruments as those illustrated in the first and second category, but policies aiming to change traffic conditions and encourage alternative means of transport. To this category belong measures such as the introduction of tolls inside agglomerations based on vehicles type, tax to be applied to vehicles and gasoline, the development of programs to promote a quieter driving style, noise requirements and regulations for road surfaces based on reliable data, actions to be undertaken to reduce noise at the source (noise limits reduction for vehicles and tires, new noise emission testing for road vehicles that better represent typical drivers conditions in real traffic situations, etc.).

The fourth category is dedicated to innovative smart mitigation measures, for which not everything is fully developed yet. To this category belong noise mitigation technological solutions under development in on-going or recently ended research project or at a prototype stage as well as examples of worked initiatives or demonstration pilot studies. Such measures include solutions like active noise control and sonic crystals. The collection of data on innovative solutions was based not only on literature review, but also on information retrieved from the other partners of the project (TRL, SINTEF) and from CEDR member consultation (see Annex B).

1.5 Applicability of the measures

Being the DISTANCE project oriented to the needs of NRAs, the major interest of the research is focused on the suburban context, and in particular on high-speed roads.
However, in order to check if some of the solutions usually applied in urban contexts can be transferred to the suburban environment, the literature review is extended to urban noise mitigation measures as well, but this deliverable contains only measures that fit such requirements. Measures that are typical of urban contexts are reported in the Annex A to provide a wider overview of available smart mitigation measures.
The applicability of the measures is analysed in terms of costs and benefits, by using a qualitative approach, based on the information retrieved from literature and experiences of the consortium members. In particular, costs are referred to conventional noise mitigation measures, such as noise barriers, and split into four qualitative cost bands. The reference cost of conventional noise barriers is based on the information provided by the CEDR Members of the Project Group Road Noise in the document “Value for Money” (Milford et al, 2013). An average cost of 400 €/m^2 is considered (derived from the average cost of 1.600 €/m for a 4 m high noise barrier; the same report records that the annual cost for noise barrier maintenance is 77 €/m), including the foundation costs.

Using this as the benchmark, the following cost bands are defined within this Work Package:

- *Cost band '-'*: The measure is expected to be less expensive than an average noise barrier.
- *Cost band '='*: The measure is expected to be comparable in costs to an average noise barrier.
- *Cost band '+':* The measure is expected to be more expensive than an average noise barrier.
- *Cost band '++':* The noise measure is expected to be considerably more expensive than an average noise barrier.

Noise mitigation measures are also described in terms of their applicability and state of technology readiness. This feature provides an indication to whether the measure is already available on the market or, if not, the maturity level of the measure in terms of its development/research status.

The same 4-point feasibility scale introduced in the WP3 is used, as follows:

Technical feasibility	Description
1	Initial identification of new concept knowledge and/or technology
2	Demonstration of prototype measure in the laboratory/trial conditions
3	Initial demonstration of measure on public roads
4	Concept routinely available on the commercial market

2 State-of-the-art of selected smart noise mitigation measures

Among used and proposed alternative smart noise mitigation solutions, four well-defined categories emerge from the literature review. These categories are:

a) Measures applied to traffic control and management
b) Road design measures
c) Socio-economic actions
d) Innovative technological solutions

Traffic management techniques include measures on traffic flow, traffic composition and speed; they represent an alternative and efficient solution to reduce noise at the source, making all receivers being positively affected and benefiting from the mitigation effects. A steady traffic flow without accelerations and decelerations helps to reduce noise, as does speed reductions, reductions in the percentage of heavy vehicles and in overall traffic levels. However, none of these approaches provide solutions to noise problems when used individually, as the effect of each of them is usually limited to a few decibels (dB), but combining various traffic flow measures with measures aiming at roads, vehicles and tyres, it should be possible to achieve substantial noise reductions [Project SILENCE, 2005-2008]. Nowadays, the availability of advanced ITS systems (satellite navigation systems and smart communication devices [CVIS, HOTSPOT and COOPERS projects, 2010]), suggests also to start testing the possibility of implementing other techniques, such as the application of dynamic speed control, rerouting, ramp metering, etc. to assess their potential effectiveness in abating noise at a lower cost.
Among the reviewed measures, only those related to the diversion of traffic volumes and to the reduction of traffic speeds are considered to be suitable for NRAs and are reported in the paragraphs 2.1 and 2.2. Moreover, considering the relevance of future ITS application, another paragraph (2.3) is added to highlight their potential application as noise abatement measures.

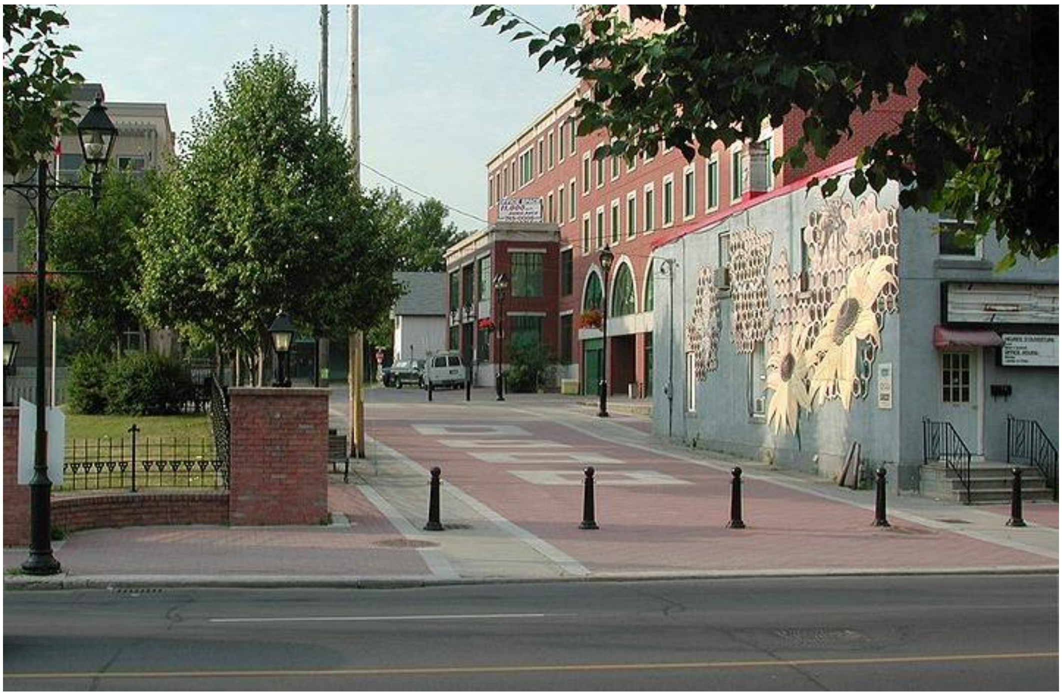
Road design measures are based on the concept that preventing noise situations is the most effective way to avoid disturbance. This is much easier in new constructions than in existing situations, where noise can be controlled also with urban planning initiatives, such as roads and cities layout, public transport, orientation of buildings and soft mobility services (bicycle, skating, etc.). These measures can be mainly used in urban environment, but some of them can also be transposed into suburban contexts. This is the case, for example, for screening buildings hosting commercial activities and roundabouts.
Among the reviewed measures, only that related to design of road junctions is considered relevant for NRAs and is reported in the paragraph 2.4.

Measures aiming at reducing noise by socio-economic actions are mainly based on regulations and policies, such as taxes on noisy vehicles, subsidies to buy low noisy vehicles, traffic tolls, taxes on kilometres travelled, public transport enhancement, eco driving, regional incentives to reduce noise, tyre noise limits, new EU vehicle noise limits.
The potential effect of socio economic-actions is huge from the National Roads Administrations perspective, as they redistribute the cost of noise reduction also to the

private sector (e.g. vehicle and tyre producers) and the road user. For society at large, it is important for road authorities to stimulate road vehicles and tyres to become quieter, as reducing vehicles noise is the most cost effective solution.
Considering this, among the reviewed measures, only those related to traffic tolls, tyre noise limits and new EU vehicle noise limits are considered of particular interest for NRAs and are reported in the paragraphs 2.5, 2.6 and 2.7.

The review of innovative smart mitigation measures was focused on the most interesting and potentially implementable solutions, such as sonic crystals, active noise control, diffractors, Helmholtz resonators embedded in pavements, poroelastic road surfaces (PERS), artificial surfaces and soft ground along the road.
Some of the investigated solutions have shown a great potential, like sonic crystal barriers and PERS whilst others, at least at the current status of technology (e.g. active noise control) seem quite inapplicable. Particularly, sonic crystal noise barriers are much more optically transparent, permeable to the wind than traditional acoustic road barriers and aesthetically appealing. Likewise PERS show a huge noise reduction potential up to 12 dB, but with an unacceptable durability.
Other interesting solutions, such as diffractors at the road side have shown appreciable results, even though with some important drawbacks, like cost, safety and construction constraints.
Conversely, the potential of Active Noise Control (ANC) systems seems quite negative, and their use appears to be ineffective and costly in open environment. Also artificial surfaces and the replacement of hard ground with soft ground have shown low potential at the time being and seem not to be ready for implementation on a large scale; finally, Helmoltz resonators embedded into the road pavement seem efficient in reducing noise as twin layer porous pavements.
Among the reviewed innovative measures, Diffractors, Helmholtz resonators in pavements, Poroelastic road surfaces (PERS), Soft ground along the road, Artificial surfaces and sonic crystals are considered of interest for NRAs. Their description is reported in the paragraphs from 2.8 to 2.13

2.1 Diversion of traffic volumes



2.1.1. Description

Traffic flow measures help improve traffic flow, traffic safety and/or a neighborhood's environment. The latter may include noise considerations, but it is seldom the main issue when establishing traffic calming and similar initiatives that may reduce traffic volumes on streets and dwelling areas.
Measures aimed at reducing the traffic volume are a way of reducing noise. On minor roads this may be an effective measure if traffic can be moved to major roads (rerouting), where the traffic increase can be neglected.
On major roads reductions in traffic volumes are rarely feasible solutions to noise problems. In specific cases it may be possible through building a by-pass around a town or an area.

2.1.2. Noise reduction

Changing traffic volumes affects noise levels. Given that the traffic composition, speed and driving patterns are unchanged, the logarithmic nature of the dB scale means that a 50% reduction of the traffic volume results in a 3 dB(A) reduction in noise levels, regardless of the absolute number of vehicles, providing that speed, traffic composition and driving pattern is unchanged (Table 1-1).
A reduction in traffic volumes on a road will often lead to increasing speeds of the remaining vehicles, unless measures are taken to keep the speed down. Increased speed will work against the reduction in noise caused by the reduced traffic level. If traffic flows more freely,

there is also a change in driving pattern. Decreases in the number of accelerations and decelerations are likely to result in lower noise levels. However, more room for driving may also lead to harder accelerations, which will increase noise.

Table 1-1 - Noise level reduction as a function of traffic volume (L. Ellebjerg, 2005)

Reduction in traffic volume %	Reduction in noise (L_{Aeq}) dB
10	0.5
20	1.0
30	1.6
40	2.2
50	3.0
75	6.0

2.1.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☐ Motorway	☐ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☑ Old Construction	

The reduction of traffic volumes is a measure that is mainly applicable on minor roads or for certain (smaller) areas, where measures may be used to move the traffic onto major roads.
On major roads, however, reductions in traffic volumes are rarely feasible solutions to noise problems. Large numbers of vehicles would have to be removed in order to result in any significant level of noise reduction. This may be possible in specific cases, for instance through building a by-pass, which may lead large amounts of traffic – and often most of the heavy traffic – around an urban area instead of inside it.

2.1.4. Implementation expected costs and benefits

Generally, measures that influence the amount of traffic are unlikely to significantly influence the noise levels on an overall area level unless these measures lead to dramatic changes. Thus, such measures are not generally applicable as means of noise abatement, but they may have an effect on minor roads or certain smaller areas where a variety of measures may be used to move the traffic onto major roads.
Traffic volumes reduction related benefits include less congestion, and consequently a decrement in travel time and in stops.

Implementation expected costs			
☑ Less expensive	☐ Comparable	☐ More expensive	○ Not available

Technical feasibility			
☐ 1	☐ 2	☐ 3	☑ 4

2.2 Traffic speed measures

2.2.1. Description

Traffic speed measures are usually implemented to improve traffic safety and noise emissions. Noise emissions can be lowered reducing traffic speed. Cutting speeds is the most immediate, the most cost-effective and most equitable way of reducing traffic noise (Mitchell, 2009).
Speed reduction can be applied on certain roads or for complete areas (common are 30 km/h zones) and can be achieved mainly with static or dynamic speed limit signs and active traffic control systems.

2.2.2. Noise reduction

Table 2-1 Noise level reduction versus traffic speed (L. Ellebjerg, 2005; M. Berengier, 2007)

Reduction in actual driving speed (Km/h)	Noise reduction (LAE, dB) Light vehicles	Noise reduction (LAE, dB) Heavy vehicles
130 to 120	1.0	-
120 to 110	1.1	-
110 to 100	1.2	-
100 to 90	1.3	1.0
90 to 80	1.5	1.1
80 to 70	1.7	1.2
70 to 60	1.9	1.4
60 to 50	2.3	1.7
50 to 40	2.8	2.1
40 to 30	3.6	2.7

Noise abatement up to 3 dB(A) can be achieved depending on speed reductions. Reducing speed on urban motorways from 130 km/h to 100 km/h would cut noise by up to 50%. On higher speed roads, the effect of 10 km/h reduction is less and also depends on the proportion of heavy vehicles using the road. For roads with speeds between 60 to 110 km/h and with 10% of heavy vehicles, reducing speeds by 10 km/h will reduce noise by 1-2 dB(A). With minor heavy vehicle percentages, higher noise reduction can be achieved. This measure has been applied successfully on Paris ring road (http://www.noiseineu.eu/fr/).

Reducing speed limits, through posting new or changing existing static speed limit signs, has little or no effect on actual driving speeds, while interactive speed signs have shown to be more effective because of increased drivers' awareness. (R. Annecke, 2008). Reducing speed on a motorway through signs is only effective to a certain degree. Speed limits that are considered too low by users are disrespected. Results indicate that speed reductions up to 15-20 km/h may be achieved at locations where speeds are already relatively high compared with the speed limits.

The use of lower speed limits for noise reduction is more effective if combined with physical measures, Automatic Traffic Control (ATC) or massive enforcement by police. In these cases, realistic speed reductions may result in noise reductions (LAeq) of 1-3 dB(A), depending on speed and road type (whether it is a motorway or an urban road). ATC results in lower speeds, but it may also lead to uneven driving patterns, where drivers decelerate at the camera boxes and accelerate between them. This may lead to increased noise and/or annoyance due to accelerations and decelerations. When control is based on the medium travel speed along a road section, it is more effective in encouraging a steady, slower speed; both of these impacts reduce noise level and eliminate noise peaks.

2.2.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☑ Motorway	☑ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☑ Old Construction	

Lowering traffic speed increases travel time and consequently social costs.

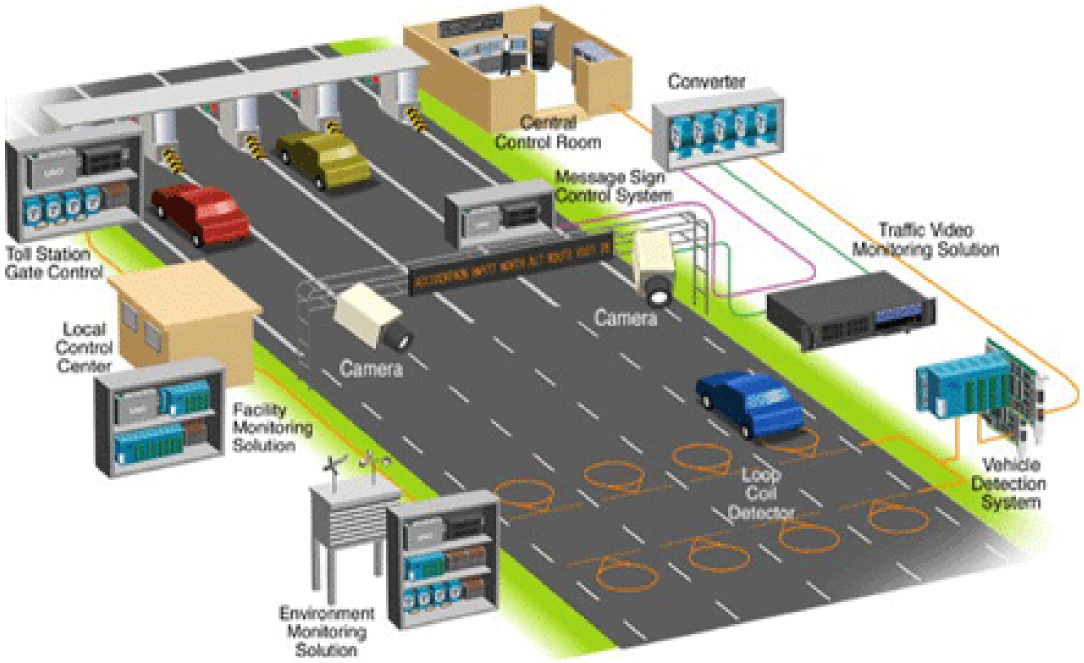
2.2.4. Implementation expected costs and benefits

In general, reducing traffic speed contributes not only to noise mitigation, but also to road safety, less fuel consumption and improved air quality.

Implementation expected costs			
☑ Less expensive	☐ Comparable	☐ More expensive	○ Not available

Technical feasibility			
☐ 1	☐ 2	☐ 3	☑ 4

2.3 Future ITS applications



2.3.1. Description

Several ITS applications currently used for safety, environmental or efficiency reasons are reported in terms of their influence on traffic speed, density, acceleration/deceleration and harsh braking/cornering to estimate their potential effect on noise emissions (Phil Morgan, 2014). The list of ITS applications is the following:

a) **Traffic information and recommended itinerary with Dynamic Route Guidance (DRG)**
b) **Various forms of hazard detection, avoidance and mitigation (HD)**
c) **In-Vehicle Signage (IVS) and Intelligent Speed Adaptation (ISA)**
d) **Automatic Crash Notification (ACN)**
e) **Decentralized Floating Vehicle Data (FVD)**
f) **Insurance and financial services**
g) **Tracking and Tracing of hazardous and valuable goods (T&T)**
h) **Eco-Driving Support**
i) **Dynamic Traffic Management (DTM)**
j) **Platooning and Autonomous Vehicles (PAV)**

a) 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. The following effects are observed for this application:

- influence on vehicle speeds - No, as long as traffic density is not increased beyond the carrying capacity of the road.
- Influence on traffic density – Potential influence; as 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. On the other hand, traffic can also be rerouted from minor congested roads to major roads, with positive effects on local communities.
- Influence on acceleration/deceleration – Unlikely;
- Influence on heavy braking and cornering - 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. When moving traffic from minor congested roads to major roads, noise emissions can be reduced locally with negligible impact on receivers located along major roads.

b) 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. The following effects are observed for this application:

- influence on vehicle speeds - This is unlikely to have a significant effect on average vehicle speeds
- Influence on traffic density – No, other than in the vicinity of serious incidents.
- Influence on acceleration/deceleration – 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
- Influence on heavy braking and cornering - Yes, emergency braking should be reduced in the vicinity of hazards.

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

c) 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. The following effects are observed for this application:

- Influence on vehicle speeds - Yes, drivers are more likely to obey speed limits, both through increased awareness due to IVS, and by automatic speed limiting by ISA.
- Influence on traffic density - There may be a minimal effect by 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.
- Influence on acceleration/deceleration - There may be a minimal effect due to the vehicle fleet maintaining a more uniform speed, reducing noise.
- Influence on heavy braking and cornering - 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. However, a recent study on the effects of voluntary ISA adherence to existing speed limits recognized beneficial impacts in urban areas where ISA could reduce harsh acceleration and the incidence of speeding when roads are not congested.

d) 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. The following effects are observed for this application:

- Influence on vehicle speeds - No
- Influence on traffic density – No
- Influence on acceleration/deceleration - No
- Influence on heavy braking and cornering - 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.

e) 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. Equipping a proportion of vehicles with tracking devices, which regularly report their location and speed, can provide more comprehensive data. 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. Satnav providers like TomTom already use this technique. The following effects are observed for this application:

- Influence on vehicle speeds - No

- Influence on 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.
- Influence on 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.
- Influence on 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 an application that directly affects driver behaviour. However the improved understanding of traffic conditions that this application enables may have an indirect effect on noise.

f) Insurance and financial services
This is an area 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. The following effects are observed for this application:

- Influence on vehicle speeds - PHYD insurance has the potential to reduce traffic speeds
- Influence on traffic density – Unlikely.
- Influence on acceleration/deceleration - PHYD insurance tends to penalise those who accelerate and brake heavily, so this could have an effect.
- Influence on 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.

g) 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. The following effects are observed for this application:

- Influence on vehicle speeds - No
- Influence on traffic density - No
- Influence on acceleration/deceleration - No
- Influence on heavy braking and cornering - No

This application is unlikely to have any effect on noise.

h) 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 to 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. The following effects are observed for this application:

- Influence on vehicle speeds -Yes, it will encourage slower driving
- Influence on traffic density - No
- Influence on acceleration/deceleration - Yes, it will encourage smoother driving, minimising the amount of braking.
- Influence on 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 that 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.

i) 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. The following effects are observed for this application:

Influence on vehicle speeds -Yes, variable speed limits are an important part of DTM.

Influence on traffic density - 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.

Influence on acceleration/deceleration - Yes, this should decrease due to smoother running

Influence on heavy braking and cornering - 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.

j) 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. The following effects are observed for this application:

Influence on vehicle speeds -Yes, vehicles will stay within posted limits.

Influence on traffic density - Potentially yes, particularly platooning which will lead to an increase in traffic density.

Influence on acceleration/deceleration -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.

Influence on heavy braking and cornering -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. However, the reduced frequency of accelerations and decelerations could probably decrease noise emissions.

2.3.2. Noise reduction

ITS applications are mainly used for safety, capacity and environmental reasons, to smooth traffic, reduce congestion, improve air quality and provide assistance in case of accidents. At the time being such applications are not in general used to mitigate noise, but in case they would be used, they could give many positive effects related to the aforementioned aspects. Consequently, the effectiveness of these measures depends on the variable affected (speed, traffic volume and composition, etc.).

2.3.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☑ Motorway	☑ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☐ Old Construction	

Drawbacks
ITS applications disadvantages depend on the parameters they are affecting: traffic speed, volume and composition (see previous paragraphs).
If they influence traffic speed, the main drawback can be attributed to time delays. Lowering traffic speed increases travel time and consequently social costs. In case of in car-enforcement without proper information, safety issues may also arise as a consequence of the driver losing vehicle control.
If ITS applications affect traffic volume and composition, vehicles are often turned out to run at higher speed as a consequence of reduced congestion, unless measures are taken to keep the speed down. Increased speed will work against noise mitigation caused by the reduced traffic level. If traffic flows more freely, there is also a change in driving pattern. Decreases in the number of accelerations and decelerations are likely to result in lower noise levels. However, more room for driving may also lead to harder accelerations, which will increase the noise emissions.

2.3.4. Implementation expected costs and benefits

Implementation costs are not relevant for ITS applications in case they are used to control and manage the traffic.
On the contrary, if an ITS is applied with the main aim of mitigating traffic noise, infrastructure costs should be considered. Such costs depend on the complexity of the system, and they can be reasonably lower or higher than costs of traditional mitigation measures.

Implementation expected costs			
☑ Less expensive	☑ Comparable	☑ More expensive	○ Not available

In the following table the main advantages and disadvantages of ITS applications are summarised.

Table 3-1 Main advantages and disadvantages of ITS applications.

Application	Speed	Density	Acceleration/ Deceleration	Harsh braking/ cornering	Noise Implications
DRG (Dynamic Route Guidance)	0	+	0	0	Possible increase due to more traffic on minor roads
HD (Hazard Detection)	0	0	-	-	Slight reduction in noise due to less harsh braking
IVS/ISA (In Vehicle Signage/Intelligent Speed Adaptation)	-	0	-	-	Slight reduction due to lower speeds and smoother driving, including less emergency braking
ACN (Automatic Crash Notification)	0	0	0	0	No direct effect
FVD (Decentralized Floating Vehicle Data)	0	0	0	0	No direct effect
Insurance and financial services	-	0	-	-	Slight reduction due to smoother driving being encouraged. Unknown effect due to some roads being avoided
T&T (Tracking and Tracing of hazardous and valuable goods)	0	0	0	0	No direct effect
Eco-driving	-	0	-	-	Slight reduction due to smoother driving, less acceleration/braking
DTM (Dynamic Traffic Management)	-	+	-	0	Reduction due to speed, increase due to density
PAV (Platooning and Autonomous Vehicles)	-	+	-	-	Reduction due to speed, increase due to density

0 = none; - = reduce; + = increase

Green	Reduce noise
Yellow	None effect on noise
Red	Increase noise

Technical feasibility			
☐ 1	☐ 2	☑ 3	☐ 4

2.4 Junction design

2.4.1. Description

The design of a junction – roundabouts, ordinary intersections with or without traffic lights – has influence on traffic noise emissions. Many European surveys document the effect of replacing ordinary intersections with roundabouts. Any noise reductions at roundabouts, compared with crossings, are likely to depend upon the traffic and the layout of both the intersection and the roundabout (M. Kloth, 2008).

2.4.2. Noise reduction

How these parameters influence the noise generated is unclear. Mini-roundabouts – small paved or painted circles in the center of intersections – are used as traffic calming measures to reduce speed. The little evidence found on the noise effects of mini-roundabouts indicate that these, when properly designed, may lead to noise reductions due to reductions in speed as well as to more even driving patterns. Based on this, the potential seems to be a noise reduction (LAeq) of up to 4 dB(A).
Results from surveys indicate that roundabouts without overrun areas may reduce noise levels (LAeq) by up to 4 dB(A) compared to ordinary intersections.

2.4.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☐ Motorway	☑ Main Road	☐ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☑ Old Construction	

Roundabouts with smaller diameters are often built with overrun areas with paving stones at the center in order to allow large trucks to pass the roundabout. If cars use these areas to drive through the roundabouts at high speed, this may generate high impulsive-like noise levels, which may increase the annoyance experienced by those living next to the roundabout. The influence of the roundabout design on noise emission needs further clarification.

2.4.4. Implementation expected costs and benefits

An Australian study refers to the benefit of roundabouts in terms of annoyance. Noise from roundabouts appears to create less community annoyance than other traffic calming devices. If roundabouts create a steadier driving pattern than ordinary intersections, this might contribute to the objectives of air quality protection too.

Implementation expected costs			
◉ Less expensive	○ Comparable	○ More expensive	○ Not available

Technical feasibility			
☐ 1	☐ 2	☐ 3	☑ 4

2.5 Traffic tolls

2.5.1. Description

Traffic tolls are typical instruments that have been implemented inside urban areas to help local authorities to reduce the number of vehicles coming into inner cities and change travelers' means of transport and behavior; they are used as a transport demand management tool to try to reduce traffic congestion and air pollution.
The QCITY project reports the case of the city of Stockholm, where fees are applied to enter and exit the city center (Sundbergh, 2007; Eliasson, 2006). The fees vary from 20 SEK in peak hours, to 10 SEK in off peak hours, with a maximum fee per day of 60 SEK (1 SEK is approximately 0.1 €).
In other cases, traffic tolls are used as a form of road pricing typically implemented to help recovering the cost of road construction and maintenance, which amounts to a form of taxation.

2.5.2. Noise reduction

The QCITY project shows that the impact on traffic volumes is relatively large close to the city center, with an overall noise reduction of 1 dB(A) up to 2 dB(A) (Ström, 2009). Although noise mitigation effects due to traffic tolls are not so striking, the decrease in traffic and congestion leads to a significant reduction in the perception of annoyance.

2.5.3. Environmental context and constraints

Traffic tolls might be applied everywhere. Traffic tolls were levied traditionally for a specific access (e.g. city) or for a specific infrastructure (e.g. roads, bridges). However, the evolution in technology made it possible to implement traffic-tolling policies based on different charging concepts, which are designed to suit different requirements regarding purpose of the charge, charging policy, tariff class differentiation etc.
The main charging policies normally used are the following:
Time Based Charges and Access Fees: In a time-based charging regime, a road user has to pay for a given period of time in which he may use the associated infrastructure.
Motorway and other Infrastructure Tolling: The term tolling is used for charging a well-defined special and comparatively costly infrastructure, like a bridge, a tunnel, a mountain pass, a motorway concession or the whole motorway network of a country.
Distance or Area Charging: In a distance or area charging system concept, vehicles are charged per total distance driven in a defined area.

Context	[x] Agglomeration		[x] Suburban Area	
Road type	[x] Motorway	[x] Main Road	[ ] Highway	[ ] Secondary Road
Road Age (years)	[x] New Construction	[x] Renovated	[x] Old Construction	

2.5.4. Implementation expected costs and benefits

One of the main benefit that comes from traffic tolls is the diversion of traffic towards more sustainable means of transport. In the case study of Stockholm, an increase of about 4% of people who travel by bus, bicycle and walking instead of car was reported. Altogether travel time was decreased by 3% and the reduction of person hours in car was 9%.
This measure is less expensive than traditional noise mitigation measures if charging infrastructures are available, otherwise investment costs could be high. In the first case the costs would be limited to some adjustment, such as new road signs. However, it should also be taken in mind that in both cases costs would be repaid by road users tolls.

Implementation expected costs			
(•) Less expensive	( ) Comparable	( ) More expensive	( ) Not available

Technical feasibility			
[ ] 1	[ ] 2	[ ] 3	[x] 4

Traffic toll systems have been criticized for some drawbacks:

– they require vehicles to stop or slow down (except open road tolling), and this can determine an increase of noise close to the toll station.
– collection costs can absorb up to one-third of revenues.
– where the tolled roads are less congested than the parallel "free" roads, the traffic diversion resulting from the tolls increases congestion on the road system and reduces its usefulness.

2.6 Tyre noise limits

2.6.1. Description

Tires have a great impact on road traffic noise. Depending on the speed and gear, tire/road noise can cause higher noise levels than the noise produced from the power train. Differences in noise properties between different tires indicate that there could be an important potential to mitigate noise from tires in a cost effective way.
Noise from tires can be reduced by increasing the stiffness of the tire carcass (for instance, increasing the number of the ply sheets, adding reinforcement rubber, and using steel ply materials) and providing a different tread design in shape, arrangement, and size (for instance, by using the circumferential-oriented grooves, reducing the hardness of tread rubber, changing the length(s), the angle and width of the grooves, reducing isolated voids in the tread design).

2.6.2. Noise reduction

Rolling noise can be reduced up to 2 dB(A) with an acceptable cost for society by improving tyre performance (Milford et Al., 2013).

2.6.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☑ Motorway	☑ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☑ Old Construction	

This measure is ineffective when the tire/road noise is equal to the power unit noise. This condition occurs when light vehicles speed is less than 30-40 km/h and when heavy vehicles speed is less than 60-70 km/h.

2.6.4. Implementation expected costs and benefits

The potential effect of this measure is huge from the NRAs perspective, as tyre producers and road users, who are equally responsible for producing noise, can share the costs.
Furthermore, improved tire noise limits would mean a benefit for NRAs and people affected by noise more than any other measures, as they will drastically reduce noise emissions at the source, without additional costs for road owners and managers.
As stated in the report Value for Money in Road Traffic Noise Abatement, carried out by CEDR (Milford et Al., 2013), rolling noise can be reduced up to 2 dB(A) with an acceptable cost for society by improving tires performance. The analysis was based on the calculation of how much extra cost one could accept on tires compared to other noise abatement measures. The calculation was made referring to a selected number of noise measures and for 1 and 2 dB(A) tire noise reduction. The results of these calculations (see table 1.0) show the increase in tire price that society can accept to reach the same reduction in noise annoyance as thin layer asphalt, façade insulation, porous single and double layer asphalt or noise barriers.

Table 6-1 Tyre price increase to equal the cost of other noise measures – Source: Value for Money in Road Traffic Noise Abatement, CEDR March 2013

	TYRES - 1 dB REDUCTION		TYRES - 2 dB REDUCTION	
Measure to be equalized	Extra cost for Tyre (EUR)	Percent increase in Tyre price	Extra cost for Tyre (EUR)	Percent increase in Tyre price
Vehicle 3.1 dB	0.5	0.6%	0.9	1%
Thin Layer asphalt	3.7	5%	7.3	9%
Pourus single layer asphalt	5.8	7%	11.3	14%
Façade insulation	10.7	13%	21.0	26%
Pourus double layer asphalt	25.7	32%	50.2	63%
Noise barrier	113	141%	221.3	227%

Implementation expected costs			
(•) Less expensive	( ) Comparable	( ) More expensive	( ) Not available

The potential implementation of this measure mostly depends on the availability of tire producers to invest in the design and development of new low noise tires and on the users possibility of buying more expensive tires. This is a solution that needs a strong support from the European Community and National Governments.

Technical feasibility			
☐ 1	☐ 2	☐ 3	☑ 4

2.7 New European vehicle noise limits

Vehicle category	Description of vehicle category	Limit values expressed in dB (A)		
		Step 1	Step 2	Step 3
M	PASSENGER VEHICLES			
M_1	power to mass ratio≤ 120 kW/1 000 kg	72	70	68
M_1	120 kW/1 000 kg < power to mass ratio	73	71	69
M_1	160 kW/1 000 kg < power to mass ratio	75	73	71
M_1	power to mass ratio> 200 kW/1 000 kg	75	74	72
M_2	mass ≤ 2 500 kg	72	70	69
M_2	2500 kg < mass≤ 3 500 kg	74	72	71
M_2	3500 kg < mass ≤ 5000 kg; rated engine power ≤ 135 kW	75	73	72
M_2	3500 kg < mass ≤ 5 000 kg; rated engine power > 135 kW	75	74	72
M_3	rated engine power ≤ 150 kW	76	74	73
M_3	150 kW <rated engine power ≤ 250 kW	78	77	76
M_3	rated engine power > 250 kW	80	78	77
N	FREIGHT VEHICLES			
N_1	mass ≤ 2 500 kg	72	71	69
N_1	2 500 kg < mass ≤ 3 500 kg	74	73	71
N_2	rated engine power ≤ 135 kW	77	75	74
N_2	rated engine power > 135 kW	78	76	75
N_3	rated engine power ≤ 150 kW	79	77	76
N_3	150 kW < rated engine power ≤ 250kW	81	79	77
N_3	rated engine power> 250 kW	82	81	79

Source: ANNEX III “Limit Values” - Regulation (EU) No 540/2014

2.7.1. Description

Vehicle noise emissions are defined by the Regulation (EU) n° 540/2014 of the European Parliament and of the Council of 16 April 2014.
In this regulation new noise emission limits are introduced in three steps that come into force after 2 years, 6-8 years and 10-12 years respectively after the publication of the directive. In the first step noise emission limits are applied only to new vehicles and vary in a range between 72-80 dB(A) for passenger vehicles and 72-82 dB(A) for heavy vehicles.
In the second step, lower noise emission limits, ranging from 70-78 dB(A) for passenger vehicles and 71-81 dB(A) for heavy vehicles, will be applied starting from July 1, 2020.
In the third step, noise emissions limits will be further reduced to 68-77 dB(A) for passenger vehicles and 69-79 dB(A) for heavy vehicles. This last step will come into force starting from July 1, 2024.

2.7.2. Noise reduction

Noise abatements are expected up to 3-4 dB(A).

2.7.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☑ Motorway	☑ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☑ Old Construction	

2.7.4. Implementation expected costs and benefits

According to Transport and Environment (2012), the costs of reducing car noise are € 20 per car per dB(A) reduction and those for reducing noise limits for trucks and buses is about € 250 per vehicle per dB(A) reduction, which would be passed to the consumer in a 1% increase in the purchase price for Step 2, or 1.5 % price increase for Step 3.
By adopting the proposed Step 3 limit values, 2 dB(A) below Step 2 in all vehicles classes, the number of people "highly annoyed" by traffic noise will be reduced by 39 %, and the number of people "highly sleep disturbed" will be reduced by 29 %. Cutting the number of people exposed to high road noise levels will contribute € 89 billion of the accumulated savings to 2030 from the proposed Step 3 limit value. In addition, increased property prices in quieter areas are valued at € 229 billion for Step 3.
The Step 3 standards also halve the need for noise barriers and reduce the need for noise insulation by a quarter in the long-term, saving € 8 billion in public expenditure.
Based on the results achieved from the cost-benefit analysis accomplished according to the EC methods, it can be stated that tighter noise limits can affect noise impacts positively. As for Step 2, benefits of € 275 billion far outweigh the costs of € 7 billion related to noise limits reduction, with a benefit-cost ratio of 39:1. As for Step 3, it is foreseen that benefits of € 326 billion, compared to costs of € 10 billion, give a benefit-cost ratio of 32:1.

Implementation expected costs			
◉ Less expensive	○ Comparable	○ More expensive	○ Not available

2.7.5. Implementation potential and technical feasibility

The implementation of this measure should lead to a significant abatement of sound pressure levels and costs for NRAs. Further improvements are still achievable, but their feasibility mostly depends on the availability of vehicles producers to invest in the design and development of new more silent cars.

Technical feasibility			
☐ 1	☐ 2	☐ 3	☑ 4

2.8 Diffractors

2.8.1. Description

Diffractors are concrete plane elements that are usually inserted at the same level of the road surface, along the carriage margins. Instead of absorbing, diffractors bend sound waves in an upward direction. Sound moves in horizontal waves and each molecule pushes the others, bending them up. Through this deflection, the annoyance near the path is significantly reduced (Wijnant. Y.H.).

In addition, diffractors can coexist, and thus complement, existing noise-reducing measures such as noise road surfaces and noise barriers. The first trial version was built with long slots, on the right side of the new N314 near Hummelo, in The Netherlands, in October 2013 (www.utwente.nl**)**. The operation was satisfactory in terms of noise reduction, but the perspective of drivers, and in particular of motorcyclist, was not pleasant because the grooves of diffractors were considered dangerous. As a consequence, two alternative solutions were designed. The first one was made with holes in a concrete slab, and the second one looked more or less like the original grooves. According to motorcyclists, the version with round holes was better because the engine remained manageable and good brakes were guaranteed. An ingenious drainage system ensured that the resonators didn't overflow. Instead, the longitudinal grooves created an effect similar to the milled asphalt so that it was more difficult to maintain control of the motorbike.

2.8.2. Noise reduction

The noise measurements carried out have shown positive results and a noise reduction of about 4 dB(A) at a speed of 100 km/h has been observed. The system doesn't differ so much, in terms of noise reduction, from silent coatings on the asphalt.

2.8.3. Environmental context and constraints

Context	☐ Agglomeration		☑ Suburban Area	
Road type	☐ Motorway	☐ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☐ Old Construction	

Diffractors are applicable only along highways, for safety reason. However they are incompatible with road safety barriers, therefore their use is not suitable in cuttings and on embankments. Moreover, this measure is effective only on low receivers located alongside the road, while noise reduction is negligible at buildings upper floors and on far lanes.

2.8.4. Implementation expected costs and benefits

Costs are similar to concrete slabs, around €/m 150.

Implementation expected costs			
☑ Less expensive	☐ Comparable	☐ More expensive	○ Not available

Technical feasibility			
☐ 1	☐ 2	☑ 3	☐ 4

2.9 Helmholtz resonators in pavements

2.9.1. Description

In order to improve the absorption characteristics of porous asphalt, buried Helmholtz resonators can be added to create a more broad-band absorbing road surface opportunely tuned to abate low frequency components. Resonators are made of polymer concrete that seems to be the best choice in terms of mechanical, thermal and chemical resistance (Forssén J, Hosanna project deliverable 4.6, 2013).
Resonators are grouped in arrays that are glued to the bedding layer of the porous asphalt with bitumen. Each array is laid down with a defined spacing so that the covering porous asphalt can reach the bedding layer and the resonators can communicate with the external air via the void matrix of the porous asphalt (Forssén J, 2013).
A first track of porous asphalt with resonators on a public road was laid down in Summer 2008 as a demonstrator of a German project (Quiet road traffic 2). The test track was then investigated in the Hosanna project (Forssén J., 2013)

2.9.2. Noise reduction

Measurements carried out in the Hosanna project show that, in far field measurements, sound pressure level of the porous asphalt with resonators is about 3 dB(A) lower than the reference porous asphalt. The level difference in the near field measurements was however smaller (only 1 dB(A)). This means, that the main effect of the resonators is expected to be due to the propagation over the porous asphalt with buried resonators.
Based on more recent measurements, the open porous asphalt twin layer with Helmholtz resonator seems not more efficient with respect to noise reduction than a twin layer of open porous asphalt without resonators. These are the results of SPB measurements carried out on two test sections build at the same time (Summer 2008) and measured at the same time (June 2013).

On the first section, that is a Twin 0/8 + 0/11 the following SPB levels are recorded: passenger cars at 120 km/h 76.0 dB(A); heavy trucks at 88 km/h 80.7 dB(A)
On the second section, that is a Twin 0/8 + 0/11 with Helmholtz Resonators, the following SPB levels are recoded: passenger cars at 120 km/h 75.8 dB(A); heavy trucks at 88 km/h 80.7 dB(A) (Dr.-Ing. Wolfram Bartolomaeus, *internal communication*). Generally one can conclude that Helmholtz resonators in the sub layer of a porous pavement are an expensive concept with little or no effect on the noise reduction.

2.9.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☑ Motorway	☑ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☐ Renovated	☐ Old Construction	

Road age: Helmholtz resonators modify the pavement structure and the different resistance of these elements glued into porous asphalt influences the design of layer thickness. So they are suitable for new roads that could be designed evaluating the difference between this measure and traditional porous pavements.

2.9.4. Implementation expected costs and benefits

No information about costs is available. We can estimate that at the time being implementation costs are high. On the other hand, a drop in the cost can be estimated if the measure is applied on a large scale.
As for benefits, the advantages associated to the implementation of twin layers with resonator, in practice, are the same of twin layers alone and of other recognized low noise pavements, i.e. a widespread effect of noise reduction on the whole impacted area.

Implementation expected costs			
☐ Less expensive	☑ Comparable	☐ More expensive	○ Not available

Technical feasibility			
☐ 1	☐ 2	☑ 3	☐ 4

2.10 Poroelastic road surfaces (PERS)

2.10.1. Description

The poroelastic road surface (PERS) is a non-conventional pavement, consisting mainly of rubber particles (virgin rubber or recycled, e.g. from tires) bound with an elastic resin, generally polyurethane. Other ingredients may be added to enhance the properties of the pavement, such as natural or artificial aggregate and additives to improve durability, to speed up the polymerization and so on. It does not contain any bitumen and should not be confused with rubberized asphalt (Ejsmont, J. 2014).
In the reference work about poroelastic pavements (PERSUADE Project), PERS is defined as follows: “A poroelastic road surface (PERS) is a wearing course for roads with a very high content of interconnecting voids so as to facilitate the passage of water and air through it, while at the same time the surface is elastic due to use of rubber (or other elastic products) as a main aggregate. The design air void content is at least 20 % by volume and the design rubber content is at least 20 % by weight”. In practice air void content in PERS can easily exceed 30 - 35 %, which is higher than the typical value for porous asphalt (20 - 25 %).
The first full scale test section was built on a national road at Kalvehave in Denmark, in 2013; a second full scale test section was constructed on 2014 at the same location (Bendtsen, H., 2013, 2014). In Belgium, the construction of a first 15 m long try-out test section took place in September 2013, and in November 2013 a second trial was performed with the same mix used in Kalvehave. As a second step in Belgium, the construction of a larger scale test section took place on a not too busy country road in Herzele in September 2014 (Goubert, L. 2014).

2.10.2. Noise reduction

Noise reductions of up to 10 - 12 dB(A) have been measured on PERS, while the quietest conventional low noise pavement, two layers porous asphalt, rarely yields a reduction exceeding 7 dB(A). In general, the effect of noise reduction becomes significant when mechanical impedance approximates the elasticity of the tyre.

2.10.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☐ Motorway	☐ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☐ Old Construction	

Road age: Poroelastic surfaces modify the entire pavement structure and the fatigue behaviour of the structure could be different from a traditional porous pavement. So they are optimal for new roads but also good for a renovated road; for example, in combination with existing paving blocks this surface combines the noise reducing qualities of the poroelastic material with the possibility to manufacture a large part of the road pavement off site and thus avoiding problems with poor adhesion.

2.10.4. Implementation expected costs and benefits

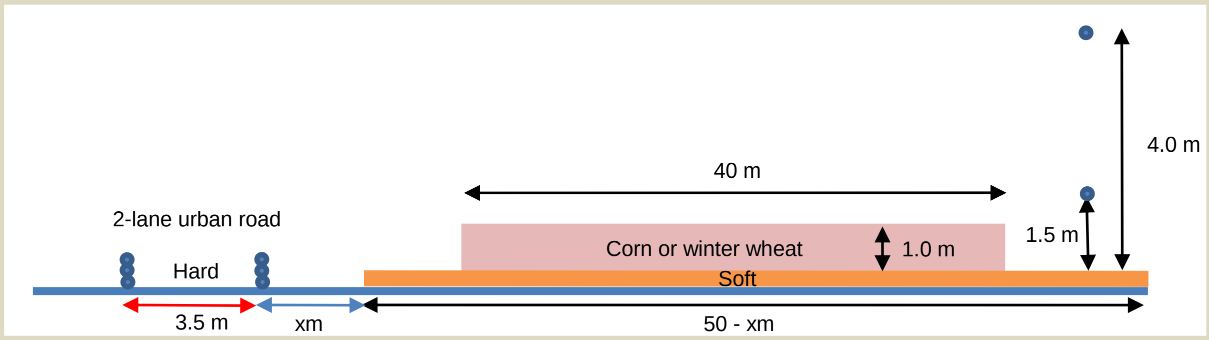
The main motivation for developing PERS is its unequalled noise reducing potential. The three properties influencing the noise reducing capacity of a dry and clean pavement are its texture, its porosity and its elasticity.

Absence of megatexture and the presence of fine, non-periodic macro-texture reduce tire vibrations and air pumping. Accessible voids suppress air pumping as well, but also reduce the horn effect. Pavements with optimized texture or porosity or a combination of the two (such as for two-layer porous asphalt) are widely used in a number of countries. The third parameter, elasticity, is generally not or very little exploited to reduce the tire/road noise. Conventional bituminous or cement concrete road surfaces are “hard” for the tire. The effect of noise reduction becomes significant when mechanical impedance approximates the elasticity of the tire.
As for costs, the price of PERS varies from country to country (from 9 €/person/dB/year in Poland up to 13 €/person/dB/year in Sweden). In Denmark a price of about 40 €/m² was estimated.

Implementation expected costs			
☐ Less expensive	☑ Comparable	☐ More expensive	○ Not available

Technical feasibility			
☐ 1	☐ 2	☑ 3	☐ 4

2.11 Soft ground along the road



2.11.1. Description

Noise can be decreased also by mitigating the ground effect by replacing hard ground with soft ground. Aim of this measure is to reduce sound reflections by improving the absorption feature of the terrain. This can be achieved with different types of surfaces, such as pasture, arable, sport field, lawn, long grass, urban zones. In rural areas, noise mitigation can also be achieved from cultivated field (for instance, corn, maize, reeds, etc.) as a function of width and height of vegetation.

2.11.2. Noise reduction

Noise reduction depends on the type of soft ground used to replace hard ground. Generally, the average reduction noise value goes from 2 dB(A) to 9 dB(A).
In table 1 the effect of some type of soft ground, like arable, lawn or long grass, are shown.

Table 11-1. Calculated reductions of noise from a two lane road related to the source and type of surfaces

Surface description	x m	Reduction (dB) compared to smooth hard ground					
		H = 1.5 m			H = 4 m		
		Lane 1	Lane 2	Average	Lane 1	Lane 2	Average
Lawn	0	9.4	9.1	9.3	5.5	3.9	4.6
	2.5	9.0	8.4	8.7	4.1	2.6	3.3
	5	8.3	7.6	7.9	2.8	1.6	2.1
Arable	0	9.0	8.8	8.9	5.2	3.8	4.4
	2.5	8.7	8.2	8.4	4.0	2.7	3.3
	5	9.1	7.5	7.8	2.8	1.7	2.2
Long grass	0	9.5	9.0	9.3	5.6	3.8	4.6
	2.5	8.9	8.3	8.6	4.0	2.5	3.2
	5	8.2	7.4	7.8	2.6	1.5	2.0

2.11.3. Environmental context and constraints

Context	☐ Agglomeration		☑ Suburban Area	
Road type	☑ Motorway	☑ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☑ Old Construction	

2.11.4. Implementation expected costs and benefits

The cost depends on the potential alternative use and value of the land alongside the road. The application of this measure is recommended in rural areas, where the cost of the land is less than in urban areas.

Implementation expected costs			
☑ Less expensive	☐ Comparable	☐ More expensive	◯ Not available

Technical feasibility			
☐ 1	☑ 2	☐ 3	☐ 4

2.12 Artificial surfaces

2.12.1. Description

Artificial surfaces are special surfaces proposed by LIER (laboratory of INRETS: Institut national de recherché sur les transports), in the DEUFRAKO project, designed to improve the acoustic characteristics of road pavements. Three types of surfaces were proposed in the project (Meunier, 2009):

1) A long slab covered with a single coat surface dressing in 4/6 aggregates.
2) A neighboring slab on which 5 mm diameter glass beads, with a 5 mm ± 0.3 mm diameter, were bonded onto a resin.
3) A slab in which a rhombic shaped pattern has been imprinted into the poured asphalt.

The first conventional surface dressing solution was composed by a maximum of D= 5 mm of aggregates, the aggregate dosage was 6 to 7 l/m^2, the emulsion used was a pure 160/220 emulsion of bitumen at a dosage of 65%.
The second surface was made of glass beads bonded onto two resin layers.
The third surface was achieved by embossing onto a bituminous support a pattern in a rhomb-shaped recess. To have a geometrical pattern a 2 x 0.5 m perforated metal plate, enabling the pattern to be imprinted onto the asphalt simply by pressure, was used. The formula of the asphalt was: 32% of 0/4 rolled gravel, 29 % of 4/6 crushed gravel, 28 % of filler, 1,5 % of Gilsonite, 9,5 % of Acidified 35/50 bitumen.

2.12.2. Noise reduction

In table 1 the main results of the CPB measurements made in the DEUFRAKO project are shown (Anfosso-Lédée, 2009, Auerbach, M., 2009).

Table 12-1- CPB measurements on the three new pavements

Pavement LAmax at 90 km/h	
Surface dressing	83.7 dB(A)
Glass beads	79.7 dB(A)
Moulding surface	81.2 dB(A)

Pavements with glass beads and moulding surfaces reduce noise respectively of about 4 dB(A) and 2,5 dB(A) compared to traditional surface dressing.

2.12.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☐ Motorway	☐ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☐ Renovated	☐ Old Construction	

Road age: Artificial surfaces modify the pavement structure and the different resistance of these elements glued into the porous asphalt influences the design of layer thickness. Therefore, they are suitable on new roads that could be designed evaluating the difference between this measure and traditional pavements.

2.12.4. Implementation expected costs and benefits

Costs details are not available.
National Road Administrations could contribute to improve technical and scientific knowledge by promoting transnational research projects to assess the effectiveness and efficiency of the measure, evaluate the effect of environmental conditions, experiment new materials to reduce costs.

Implementation expected costs			
○ Less expensive	○ Comparable	○ More expensive	◉ Not available

Technical feasibility			
☐ 1	☑ 2	☐ 3	☐ 4

At the time being, based on the technical feasibility of the measure (level 2), it seems unlikely to apply artificial surfaces on large scale, in particular for the small size of the metal plates imprinted into the asphalt (2 x 0.5 m).

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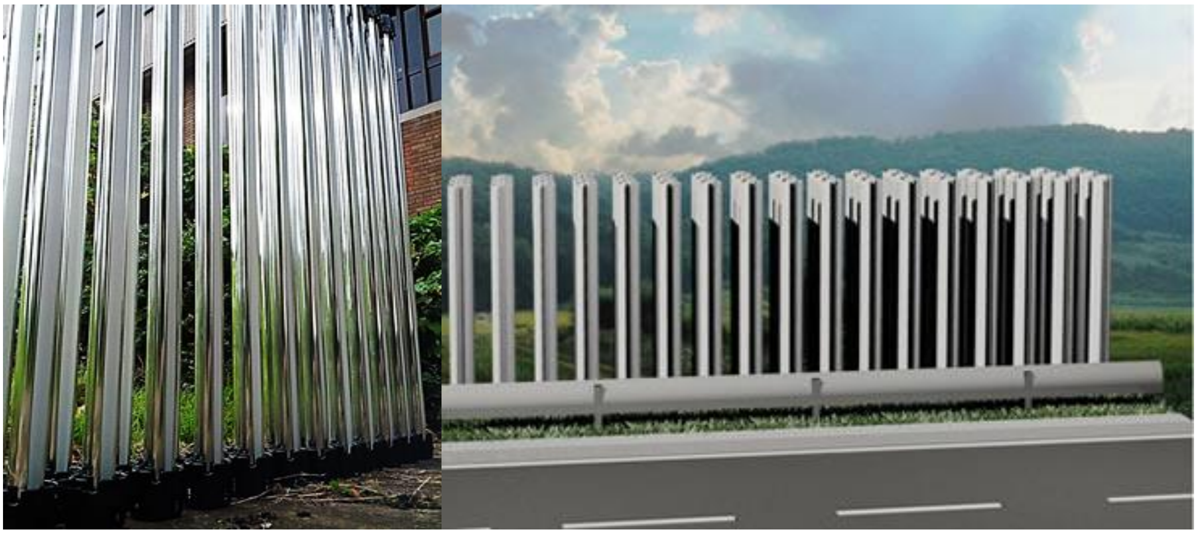
2.13 SONIC CRYSTALS



2.13.1. Description

Sonic crystals are noise barriers consisting of periodic arrays of circular cylinders that take their name from the analogous effect of photonic crystals on light. Sonic crystals are known to give high attenuation at selective frequencies as a consequence of multiple scattering and their potential use as noise barriers has involved several research road laboratories and National Road Administrations in the last years. One of the main advantages of sonic crystals is that by varying the distance between the cylinders it is possible to attain peaks of attenuation in a selected range of frequencies, allowing the barrier to be tuned on the most disturbing components (Miyashita, T., 2005).

2.13.2. Noise reduction

The global insertion loss of a sonic crystal barrier made of rigid resonant cavities can reach 9.5 dB(A) and 9 dB(A) for road traffic noise and tramway noise, respectively. When the interior of the cavities is covered by an absorbent material the global insertion loss values increase and reach 11.9 dB(A) and 13.9 dB(A). To facilitate the implementation of sonic crystal barriers, a random removal of some scatterers has shown a negligible effect on the degradation of their acoustical efficiency. This may lead on the contrary to an improvement of their effectiveness due to the creation of some resonant vacancies inside the noise barrier. Numerical results show that low height sonic crystal noise barriers can be used as effective noise barriers for both road traffic and tramway noise (Koussa, F., 2012). In addition, their implementation do not need any foundation and a wide choice of material are available for their construction.

Although the above cited insertion loss values are huge, care must be taken as the noise reduction is frequency dependent (Morandi, F., 2015). The insertion loss can show strong oscillations as a function of the frequency (Lee, H.P., 2015).

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2.13.3. Environmental context and constraints

Context	☑ Agglomeration		☑ Suburban Area	
Road type	☑ Motorway	☑ Main Road	☑ Highway	☑ Secondary Road
Road Age (years)	☑ New Construction	☑ Renovated	☑ Old Construction	

2.13.4. Implementation expected costs and benefits

Sonic crystals barriers have the property to be much more optically transparent and permeable to the wind than traditional acoustic road barriers. Furthermore, if sonic crystals are used as highway noise barriers on both sides of a road, multiple reflections are reduced thanks to their permeability. The appearance of a sonic crystal barrier might also have a rather positive aesthetic impact, such as a 'sculpture' consisting of vertical parallel cylinders that act as a sound barrier.
The implementation of sonic crystals, at least at a demonstrative level, could help to improve knowledge on their effectiveness, evaluate environmental conditions and efficiency, experiment new materials to reduce costs.

Implementation expected costs			
☐ Less expensive	☐ Comparable	☑ More expensive	○ Not available

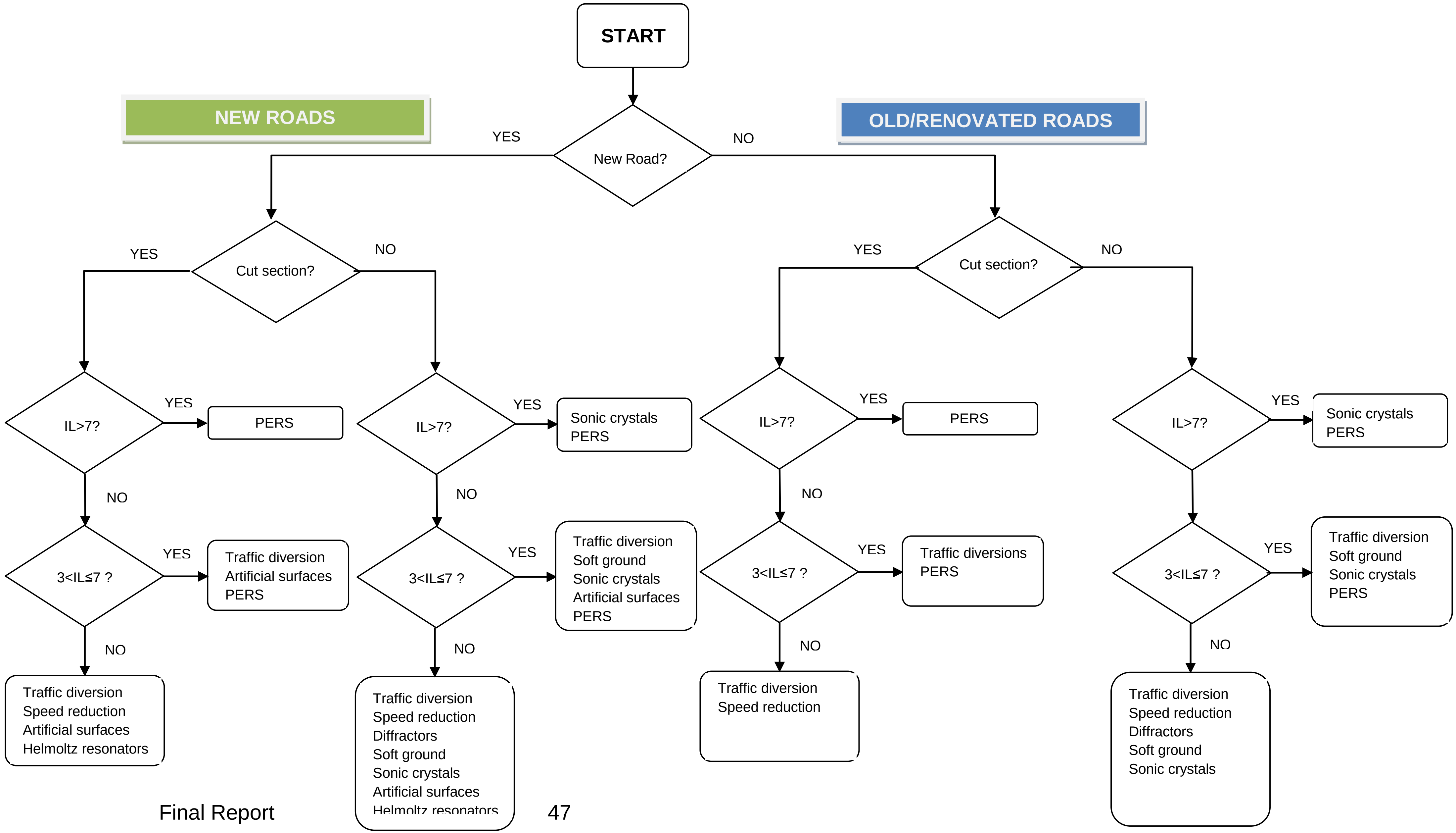
Technical feasibility			
☐ 1	☐ 2	☑ 3	☐ 4

3 Schematic procedure to implement alternative “smart” noise mitigation measures

In this paragraph a simple decision support tool is described to ease the identification of alternative “smart” noise mitigation measures suitable to different suburban scenarios.
The selection of the most suitable measure is based on the following parameters:

- **Road age:** a difference among old, new or renovated road is considered;
- **Road cross section:** different noise mitigation measures can be applied as a function of the road cross section. Plane diffractors can’t be implemented in cut sections, for instance; therefore, the choice of a measure should take into account of the road cross-section necessarily. Three main cross sections are considered in this procedure: fill, shallow and cut sections;
- **Noise reduction:** noise reduction usually depends on many factors and the same noise mitigation measure can perform differently in other environmental contexts. It should also be noted that a noise mitigation measure with high performance can also be used to achieve low insertion loss (IL), even if at higher cost, when any other solution is not applicable, due to strict boundary conditions. Taking into account that some of the investigated solutions show a wide range of noise reductions, it is convenient to split this range in three subsets: low noise reduction ($IL \leq 3$ dB(A)), medium noise reduction ($3 < IL \leq 7$ dB(A)) and high noise reduction ($IL > 7$ dB(A)).

The algorithm used to implement the decision support tool is described in the flow chart reported in figure 1.
The selection process starts from the road age specification and moves on with the selection of the road cross-section. Finally, the last step involves the choice of the required noise reduction. Each path can lead to one or more solutions, sorted in descending order over costs.


START
NEW ROADS
OLD/RENOVATED ROADS
New Road?
YES
NO
Cut section?
YES
NO
Cut section?
YES
NO
IL>7?
YES
PERS
NO
3<IL≤7 ?
YES
Traffic diversion
Artificial surfaces
PERS
NO
Traffic diversion
Speed reduction
Artificial surfaces
Helmoltz resonators
IL>7?
YES
Sonic crystals
PERS
NO
3<IL≤7 ?
YES
Traffic diversion
Soft ground
Sonic crystals
Artificial surfaces
PERS
NO
Traffic diversion
Speed reduction
Diffractors
Soft ground
Sonic crystals
Artificial surfaces
Helmoltz resonators
IL>7?
YES
PERS
NO
3<IL≤7 ?
YES
Traffic diversions
PERS
NO
Traffic diversion
Speed reduction
IL>7?
YES
Sonic crystals
PERS
NO
3<IL≤7 ?
YES
Traffic diversion
Soft ground
Sonic crystals
PERS
NO
Traffic diversion
Speed reduction
Diffractors
Soft ground
Sonic crystals

4 Conclusions and summary recommendations

Alternative smart noise mitigation measures are defined as a series of technological solutions, strategies and actions that can be used to mitigating noise in an unconventional and innovative way.
Four well-defined categories are identified and described in this report:

a) Measures applied to traffic control and management
b) Road design measures
c) Socio-economic actions
d) Innovative technological solutions

Among the analysed measures, only those measures that can be considered as promising solutions for NRAs are described in detail.

Based on the analysis carried out in this report, some important conclusions can be drawn:

- In order to achieve higher levels of noise mitigation (IL>7 dB(A)), two specific innovative technological solutions are promising, Poroelastic Road Surfaces (PERS) and sonic crystals; while PERS can be used everywhere, sonic crystal barriers, like any other type of noise barrier, cannot be installed in deep cuttings. Among these technical solutions, PERS are recognized for its unequalled noise reducing potential. For all of them a technical feasibility level equal to 3 is identified (Initial demonstration of measure on public roads), this confirming that the implementation of these measures, at least at a demonstrative level, could help to improve knowledge on their effectiveness, evaluate environmental conditions and efficiency, experiment new materials to reduce costs that, actually, are the principal factor limiting their use on a large scale.
- In order to achieve medium levels of noise mitigation (3<IL≤7 dB(A)), some measures other than PERS and sonic crystals are available, like diffractors; they can achieve noise reductions up to 4 dB(A) but, for safety reasons, they can be installed along highways only. In addition, they are incompatible with road safety barriers, therefore the use of this technique is not suitable in cut and fill sections, but on shallow sections only.

  Some other investigated measures, even if effective in reducing noise, actually need to be further developed in order to improve their technical feasibility level:

  a) Replacing hard ground with soft ground is a measure that can lead to noise reductions ranging from 2 dB(A) to 9 dB(A), but with a low level of technical feasibility (2). Furthermore, the applicability of this measure is limited to rural areas, where the cost of the land is lower than in urban areas.

  b) Artificial surfaces can allow to obtain noise reductions ranging from 2.5 to 4 dB(A), but they show a low level of technical feasibility (2) and its application on a large scale seems unlikely.

For these measures, NRAs could contribute to improve technical and scientific knowledge by promoting transnational research projects to upgrade the technical feasibility at least at level 3.

In junctions, the introduction of roundabouts can allow to obtain up to 4 dB(A) of noise reductions with very limited incremental costs.

Helmoltz resonators pavements are more costly than twin layer porous asphalt, but they are efficient in noise reduction as a twin layer of open porous asphalt.

- When lower levels of noise mitigation (IL≤3 dB(A)) are needed, some traffic management measures can be applied, also as part of future ITS applications. Despite they are mainly used for safety, capacity and environmental reasons, to smooth traffic, reduce congestion and speed, improve air quality and provide assistance in case of accidents, they can also be effectively implemented to abate noise. In order to be effective in reducing noise, they have to reduce both congestion and free flow speeds.
- Socio-economic actions, like new EU tyre and vehicle noise limits, can be effective in obtaining noise reductions ranging between 2 and 4 dB(A), and particularly in reducing noise mitigation costs for NRAs. Further improvements are still achievable, but their feasibility mostly depends on the availability of vehicles and tires producers to investing in the design and development of new more silent cars.

Based on these considerations and taking into account the effectiveness and costs of each investigated measure, the schematic procedure and the decision-making support tool developed in this WP could finally help decision makers in selecting, among the available alternative smart mitigation measures, those specific measures that better suit their needs.

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