

Technical support for Noise Action Plans

Measures and tools for Competent Authorities to reduce
environmental noise under the Environmental Noise Directive

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About this report

This report presents practical approaches and technical methods for reducing environmental noise in line with the requirements of the Environmental Noise Directive (END). It is intended to support competent authorities and stakeholders in developing effective Noise Action Plans by offering a structured overview of available measures, their expected benefits, and considerations for implementation.

The document brings together strategies, tools, and examples that can help decision-makers select cost-effective solutions tailored to local conditions. It also highlights factors such as feasibility, efficiency, constraints and co-benefits, ensuring that noise management efforts contribute to healthier and more sustainable living environments.

Table of Abbreviations

Abbreviation	Meaning
ADS-B	Automatic Dependent Surveillance - Broadcast
AEDT	Aviation Environmental Design Tool
AIP	Aeronautical Information Publication
ANSP	Air Navigation Service Provider
APU	Auxiliary Power Unit
ATC	Air Traffic Control
CA	Competent Authority
CAs	Competent Authorities
CDO	Continuous Descent Operations
CNOSSOS-EU	Common Noise Assessment Methods in Europe
COM	European Commission
CPX	Close-Proximity Method
DALY	Disability-Adjusted Life Year
dB	Decibel
dB(A)	A-weighted Decibel
EC	European Commission
ECAC	European Civil Aviation Conference
END	Environmental Noise Directive
EPA	Environmental Protection Agency
EPNdB	Effective Perceived Noise Level
EU	European Union
FMS	Flight Management System
GPU	Ground Power Unit
HSG	High-Speed Grinding
ICAO	International Civil Aviation Organization
INM	Integrated Noise Model
ISO	International Organization for Standardization
L_{den}	Day-Evening-Night sound level
L_{max}	Maximum sound level
L_{night}	Night-time sound level
LCA	Life Cycle Assessment
LD	Lower Drag
LP	Lower Power
MCDA	Multi-Criteria Decision Analysis
MS	Member States
NADP1, NADP2	Noise Abatement Departure Procedure 1 or 2
NAP	Noise Action Plan
NAPs	Noise Action Plans

Abbreviation	Meaning
NGCS	Next Generation Concrete Surface
NGO	Non-Governmental Organisation
PBN	Performance-Based Navigation
PCA	Pre-Conditioned Air
PERS	Poro-Elastic Road Surface
RNAV	Area Navigation
RNP	Required Navigation Performance
SEL	Sound Exposure Level
SID	Standard Instrument Departure
SMA	Stone Mastic Asphalt
STAR	Standard Terminal Arrival Route
TSI Noise	Technical Specifications for Interoperability – Noise
UIC	International Union of Railways
WHO	World Health Organization
WTP	Willingness-to-Pay

1. Introduction

1.1. Background and motivation

Under the Environmental Noise Directive (END) ⁽¹⁾, EU Member States (MS) are obliged to draw up Noise Action Plans (NAPs) before 18 July 2008 and review and, if necessary, revise these every five years. The NAPs are designed to manage noise issues and effects for:

- **major roads** with more than three million vehicle passages per year,
- **major railways** with more than 30 000 train passages per year,
- **major airports** with more than 50 000 movements per year, and
- **agglomerations** having a population in excess of 100 000 persons

with a view to preventing and reducing environmental noise where necessary and particularly where exposure levels can induce harmful effects on human health and to preserving environmental noise quality where it is good ⁽¹⁾. While the END sets minimum thresholds at 55 dB L_{den} and 50 dB L_{night} , the WHO Environmental Noise Guidelines of 2018 ⁽²⁾ suggests that harmful effects also occur at lower levels.

Following Article 11 of the END, the Commission has evaluated its implementation several times, latest in 2023 ⁽³⁾. The COM(2023) 139 report recommends that, among others, the Commission will prioritise actions on the EU level to:

- revise limits on tyres;
- speed up the introduction of quiet freight wagons by implementation of the ‘quieter routes’;
- promote enhanced procedures to reduce noise from aircraft landing and take-off;

¹ Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise, consolidated text, 2021-07-29, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02002L0049-20210729>

² World Health Organisations (WHO) Regional Office for Europe, *Environmental Noise Guidelines for the European Region*, 2018, <https://www.who.int/europe/publications/i/item/9789289053563>

³ Report from the Commission to the European Parliament in accordance with Article 11 of Directive 2002/49/EC, COM(2023) 139 final, 2023-03-20, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2023:139:FIN>

- introduce environmental charges to increase the use of quiet aircrafts.

For the MS, it is recommended that they accelerate their efforts to comply with NAP requirements, and to ensure that their NAPs systematically include:

- the introduction of quiet surfaces whenever a busy road is repaved;
- lowering of road speed limits, where other co-benefits such as safety are present;
- maintenance of railway tracks so that rails are kept smooth, and installation of low emission tracks in residential areas;
- setting appropriate noise abatement objectives on airport noise and implement effective measures to achieve them, in line with Regulation 598/2014, i.e. the Balanced Approach Regulation ⁽⁴⁾.

To aid Competent Authorities (CAs) in MS with effectively drafting their NAPs, the Commission has initiated the provision of the technical support document. This document focuses on maximising the effectiveness and efficiency of existing technical measures to reduce noise, considering factors such as feasibility, implementation time, costs, and benefits of measures. While competent authorities retain discretion over the final decisions, this technical support document is intended to be used in the decision-making process at the national level, for a pre-selection of the most cost-effective and efficient measures possible.

1.2. Scope

1.2.1. Noise sources and measures

This technical support document provides an overview of noise reduction measures aimed at addressing sources covered by the END: road traffic, rail traffic, aircraft and industry noise, both inside and outside the agglomerations.

Sources of noise that do not fall within the scope of the END, such as leisure, commercial and neighbour noise are not included in the technical support document. For industrial sources, specific technical noise reduction measures are not included, as these strongly depend on the type of activity and the acoustic characteristics (such as tonality, intermittency and frequency) that one-size-fits-all solutions cannot be proposed. Measures taken at the receiver, such

⁴ Regulation (EU) No 598/2014 of the European Parliament and of the Council of 16 April 2014 on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Union airports within a Balanced Approach, <https://eur-lex.europa.eu/eli/reg/2014/598/oj/eng>

as building insulation, and urban planning measures are included. These are considered 'horizontal' in the sense that they apply to any (ground-borne) noise source.

Where the END focuses on human health and wellbeing, the effect of underwater noise on biodiversity through its impact on marine animals is covered by the Marine Strategy Framework Directive ⁽⁵⁾. Where relevant, the technical support document will identify possible links between NAP measures to be considered by END CAs and underwater noise measures considered by these CAs or their counterpart authorities in the maritime transport and energy sectors.

Not included in the scope are measures on the EU or international level or measures, such as regulatory measures regarding vehicle and tyre noise limits or changes to the TSI Noise or Balanced Approach, as these are not within the control of the CAs. Also, the technical support document does not aim to address END noise immission limits or topics regarding EU funding for noise abatement.

More technical measures exist than are included in this technical support document. The selection of measures included is limited by the boundary conditions for this document and the writing process. A priority has been given to those measures that have been or can be commonly adopted by CAs in their NAPs, and for which enough information is available to provide a complete fact sheet. These measures are considered mature and widely available across the EU, and have a proven positive impact on the reduction of environmental noise.

1.3. Target audience

This technical support document is primarily targeted at:

- national or regional CAs responsible for drafting NAPs for major roads, railways and airports, and
- local CAs responsible for drafting NAPs for agglomerations.

In addition to the primary audience, the document will also be useful to any public authority, NGO, research institute or consultant looking for guidance into noise reduction measures.

⁵ Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive), consolidated text, 2017-06-07, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02008L0056-20170607>

1.4. Preparatory work

The preparation of this document has included the following steps:

- a literature review including
 - the END with Annexes, the latest Commission END evaluation report ⁽³⁾ and the Phenomena study report ⁽¹²⁾;
 - various EU-level State-of-the-Art reports, including EEA reports on the state of environmental noise in Europe, the UIC State-of-the-Art report on railway noise in Europe ⁽⁷³⁾ and several reports from the EPA Network Interest Group on Noise ⁽⁶⁾;
 - existing national NAP guidance documents from several EU countries including DE, FR, DK, BE, and from the UK;
 - several relevant ISO and EN standards, ICAO Docs and other standardisation and guidance documents;
 - many technical background documents, conference and journal papers and webpages;

All documents and webpages used can be found in the footnotes of this technical support document.

- an EU-level consultation survey using the EUSurvey online tool ⁽⁷⁾, which was distributed by DG Environment mainly to all CAs as well as the DG ENV Noise Expert Group, and which received 167 individual valid responses. The survey mainly focused on the contents of the NAPs, the various technical measures included for road, rail, aircraft noise and agglomerations, and the decision process for adoption of those measures;
- an EU-level hybrid workshop on July 1st 2025 hosted in Brussels, with 85 participants covering 20+ Member States. In the workshop, case studies and breakout sessions were held around road, rail, aircraft noise situations and agglomerations. Also, the survey results were presented and discussed, and the proposed document structure and factsheet contents were aligned with the participants.
- feedback on draft document versions was provided by experts from the Commission (DG ENV, DG MOVE), Eurocontrol / EASA, EEA and UIC, which was processed into this final document version.

⁶ <https://epanet.eea.europa.eu/reports-letters/reports>, in particular the 'IG Noise' reports

⁷ <https://ec.europa.eu/eusurvey/>

1.5. Document structure and reading guide

This report is structured as follows:

- Chapter 2 describes a set of criteria that influence decision-making on noise abatement measures. An Excel toolbox to facilitate the multi-criteria decision analysis, available as an Annex to this report, is described in Chapter 3.
- Each of the Chapters 4 to 6 contain fact sheets for noise abatement measures, namely for road traffic noise, rail traffic noise and aircraft noise respectively. Each chapter starts with an overview of all measures, including scores for the decision criteria, followed by a description of each individual noise measure in the form of a fact sheet (4 – 5 pages each).
- Chapter 7 includes fact sheets for ‘horizontal’ noise measures that apply to multiple noise sources and are taken in the propagation path or at the receiver.
- Chapter 8 targets agglomerations, which typically contain multiple noise sources in urban areas. This chapter does not contain any new noise measure fact sheets but instead provides some further specifications or implementation details on noise measures already mentioned in earlier chapter, as well as short descriptions of some additional noise measures.

The report is not intended to be read from beginning to end by any single reader. Instead, readers are advised to select which noise sources they are interested in and browse to the appropriate chapters. After reading the overview section, they can read any of the individual noise measure fact sheets. The fact sheets can be read and used independently of each other.

Alternatively, the Excel toolbox (see Chapter 3) could be used for a preselection of noise measures. It will then provide a list of sections in this document that contain the relevant information.

2. Selecting noise measures

2.1. High-level selection criteria

Many different noise abatement measures are available. Which measures are most likely to be included in the noise action plan depends on the local situation, the magnitude of the noise impact, the available budget and the ambition level, among other factors.

For the initial high-level selection of which noise measures to consider or not, a number of selection criteria is listed in [Table 1](#) below. For each criterion, a valuation in terms of positive, neutral or negative is defined. The order of these criteria, from high to low, is chosen based on the responses of the audience during the EU-level project workshop (see § 1.4).

Table 1 – Selection criteria for noise measures
Ordered by importance rating (high to low)

Criterion	Positive (+1)	Neutral (0)	Negative (-1)
Noise reduction	high (> 5 dB)	medium (2 – 5 dB)	low (0 – 2 dB)
Costs	free or cost-saving	low cost	high cost
Applicability	most situations	some situations	few situations
Scale of impact	large or everywhere	wider area (200 – 1,000 m)	local (< 200 m)
Availability	large choice everywhere	several products / suppliers	single product / supplier
Co-benefits	multiple	limited (1 – 2)	none
Constraints	none	limited (1 – 2)	multiple
Stakeholder complexity	simple / single	intermediate / multiple	complex / many
Maturity	common practice	limited practice	experimental
Information level	complete	partial	little

The criteria should be understood as follows:

- **Noise reduction:** the reduction of the noise level at the nearby receivers, in dB(A). In most measures this should be understood as a reduction of the long-term average noise level (L_{den} or L_{night}).
- **Costs:** the total life-cycle costs of the noise measure. The valuation is indicative as the exact costs depend strongly on the details of the measure and the local situation. Details on costs for individual measures are given in the fact sheets below.
- **Applicability:** Some noise measures may only apply to specific situations, such as certain parts of the infrastructure (e.g. bridges, rail curves) or

certain operations (e.g. taxiing aircraft). Other measures may be applicable everywhere, i.e. for any road, railway or airport.

- Scale of impact: the typical approximate area in which receivers subject to the noise are positively affected by the noise measure.
- Availability: Some noise measures are common, and various products will be available in any Member State. For others, only one or a few suppliers exist in Europe, so availability is lower.
- Co-benefits: additional positive impacts of the noise measure, besides the noise reduction, such as improvements of air quality, sustainability or safety, reduction of maintenance efforts, etc.
- Constraints: one or multiple constraints or negative side-effects of the noise measure, that limit the applicability or require balancing a trade-off. This could include maintenance, safety, environmental or sustainability aspects, among other impacts.
- Stakeholder complexity: the complexity of the decision process or the implementation of the noise measure, primarily determined by the number of stakeholders involved and the expected resistance level.
- Maturity: the stage of development a product, tool, or process has reached, indicating how much experience has been obtained with it, and to what extent it has been refined, tested, and adopted in practice.
- Information level: the amount of information that is available on a certain noise measure, including technical and acoustical details, costs and benefits, measurement and modelling methods or standards.

2.2. Cost-benefit methods

The decision process whether or not to implement a noise abatement measure will always include an analysis of costs and benefits. The END does not prescribe or provide a standardised methodology for balancing costs and benefits. Although such a methodology will also not be described in this report, some existing documentation and tooling is described below.

- The EU Handbook on the External Costs of Transport ⁽⁸⁾ provides methods and cost factors to quantify various categories of external costs, i.e. direct and indirect costs resulting from transport borne by society, including noise costs. The study provides Willingness-to-Pay (WTP) values in €/dB/person/year to calculate the total external noise costs

⁸ European Commission, CE Delft, van Essen H et al., *Handbook on the external costs of transport – Version 2019 – 1.1*, Publications Office, 2020, <https://data.europa.eu/doi/10.2832/51388>

(annoyance and health), allowing for a comparison of various noise abatement scenarios. The study also provides marginal noise costs in €/vehicle-km for road, rail and air transport, differentiated by vehicle type, time of day and rural or urban areas.

- The EPA Network Interest Group on Noise Abatement published a report on decision methods and cost/benefit methods for noise abatement measures in Europe ⁽⁹⁾. The report describes and compares different tools including Cost-Benefit Analysis, Cost-Effectiveness Analysis and Multi-Criteria Decision Analysis. To quantify the benefits, WTP values are given and DALY-based approaches ^(10,11) are presented.
- The Phenomena study report ⁽¹²⁾ has developed a specific methodology to quantify the health burden and its reduction at EU level over time. Here the health burden is quantified by two monetisation methods as well as in terms of annoyance, sleep disturbance and DALYs. Besides a description of the methodology, the report provides several noise measures for each transport source (road, rail, aircraft) as well as combinations of measures, and indicates the benefit-cost ratio for each.

These sources provide valuable information how to quantify and calculate the *benefits* from noise abatement measures, in terms of their reduction of external socio-economic impacts. Some information on the direct *costs* associated with the various noise measures is also given, particularly in the Phenomena report.

To calculate the direct financial costs for implementation of each noise measure, the fact sheets presented in this report each contain approximate cost values and a description of how to obtain more detailed cost estimations, if such information was found.

⁹ EPA Network Interest Group on Noise Abatement (IGNA), Peeters B, van Blokland GJ, *Decision and cost/benefit methods for noise abatement measures in Europe*, 2018-02, https://epanet.eea.europa.eu/reports-letters/reports-and-letters/ig-noise_cost-and-benefits-of-noise-abatement.pdf/view

¹⁰ Disability-Adjusted Life Year (DALY): a metric to quantify the burden of disease, developed by the WHO

¹¹ World Health Organisation (WHO) Regional Office for Europe, *Burden of disease from environmental noise – Quantification of healthy life years lost in Europe*, 2011, <https://www.who.int/europe/publications/i/item/9789289002295>

¹² European Commission: Directorate-General for Environment, ANOTEC, Tecnalía, TNO, Universitat Autònoma de Barcelona, VVA, Kantor, E., Klebba, M., Richer, C., Kubota, U., Zeisl, Y., Dittrich, M., Blanes Guardia, N., Fons Estevez, J., Salomons, E. Oosten, N. v., *Assessment of potential health benefits of noise abatement measures in the EU – Phenomena project*, Publications Office, 2021, <https://data.europa.eu/doi/10.2779/24566>

3. Toolbox

3.1. General description

This technical support document in the following chapters contains several different noise abatement measures for the different sources covered by the NAPs. The selection and prioritization of which noise abatement measures are most suitable for a CA depends on various criteria, as indicated in § 2.1. To aid this process, a toolbox has been developed, which is available as a Microsoft Excel file as an Annex ⁽¹³⁾ to this report.

The toolbox is an implementation of a multi-criteria decision analysis (MCDA) ⁽⁹⁾. Based on user-specified priorities of the various selection criteria, combined with a database of scores for individual noise measures, it calculates a weighted score for each measure and presents a top-N ranked list.

3.2. Toolbox manual

3.2.1. Toolbox tab

In the **User Input** block, see the figure below, users can check which NAP categories they are searching measures for: major roads, major railways, major airports and/or agglomerations. If a user selects *agglomerations*, further indicators appear to select which urban noise sources should be included: roads, railways, airports and/or industry.

The user can enter the maximum number of noise measures (i.e. the top-N) to display. Note that a particular selection may result in a lower number of measures than desired as the number of available measures in the database is limited.

For each of the ten selection criteria (see § 2.1) the user can then indicate its importance on a five-star scale (★ to ★★★★★) using the dropdown menu. The criteria are optional; the user can also leave an empty cell or select zero stars from the dropdown. There is also a customisable criterion labelled (*other*) with which the user can implement their own selection criterion, if data are supplied in the database, see § 3.2.2.

¹³ Please download the Annex (Toolbox) from <https://circabc.europa.eu/ui/group/7ee2560e-7a0d-4e16-8c61-f3a05ee2dd6f/library/4a5c9f95-d715-482c-8191-413d7858cb11>

Finally, the user should press the *Select noise measures* button to start the MCDA calculation. This results in a ranked list of noise measures in the **Results** block. For each measure this shows:

- the name of the noise measure,
- the NAP category it applies to,
- the measure score resulting from the calculation, on a 0% to 100% scale,
- the paragraph number and title in this document that contains the corresponding fact sheet ⁽¹⁴⁾.

User input

Noise Action Plan(s):

major roads	<input checked="" type="checkbox"/>
major railways	<input type="checkbox"/>
major airports	<input type="checkbox"/>
agglomerations	<input checked="" type="checkbox"/>

Agglomeration sources:

urban roads	<input checked="" type="checkbox"/>
urban railways	<input checked="" type="checkbox"/>
city airports	<input type="checkbox"/>
industry	<input type="checkbox"/>

Number of measures:

Importance

Noise reduction	★★★★★
Costs	★★★
Applicability	★
Scale of impact	★★★★
Availability	
Co-benefits	
Constraints	
Stakeholder complexity	
Maturity	
Information level (other)	

Select noise measures

Results

Noise measure	NAP type	Score	Document paragraph
Promotion of low noise tyres	major roads, urban roads	81%	4.2.1. Promotion of low noise tyres
Low noise pavements	major roads, urban roads	73%	4.2.4. Low noise pavements
Noise zoning	major roads, agglomerations	69%	7.4.1. Noise zoning
Loud vehicle control	urban roads	62%	4.2.6. Loud vehicle control
Wheel dampers	urban railways	58%	5.2.3. Wheel dampers

Source: M+P

Toolbox for noise measure selection: user interface and results

¹⁴ The document paragraph is a hyperlink that should open the PDF document on the right page. Depending on user's computer settings this may not work, and the user can manually browse to the corresponding paragraph number in the report.

3.2.2. Database tab

The *database* tab contains a list of every noise measure, the NAP category or categories it applies to, and its score on each of the ten criteria. The scores are limited to values of +1, 0 and -1, corresponding to the quality indicators given in [Table 1](#). The initial scores are given in the *Overview* sections of Chapters 4 to 7 below.

The database tab can be used to customise the toolbox mainly in two ways:

1. The existing scores (+1, 0 or 1) can be changed for individual noise measures, if the existing scores are considered inappropriate.
2. Additional measures can be added by inserting data as new rows in the database (up to row number 100). Each row should include the NAP category (¹⁵) and multiple comma-separated values may be supplied. The report bookmark column may be left empty.
3. The (*other*) column may be used to supply an initial criterion, by changing the column title and supplying a score to each noise measure.

¹⁵ Available options are: *major roads, major railways, major airports, agglomerations, urban roads, urban railways or city airports*

4. Road traffic noise measures

4.1. Overview

Road traffic noise is produced by the road vehicles themselves, where for most vehicles and driving conditions the tyres are the main source of noise. The tyre noise is influenced by the tyre design as well as the road surface. For a small number of vehicles, the noise produced by the driveline (e.g. the engine and exhaust) is also important. The vehicle driving speed also influences the noise emissions, both from tyres and driveline.

Table 2 below presents the most important measures to reduce the road traffic noise emissions. For each measure, a valuation of the different selection criteria is indicated, following the definitions given in § 2.1 above. The values are indicative and based on expert judgment by the authors. Each measure is described in more detail in the separate factsheets below.

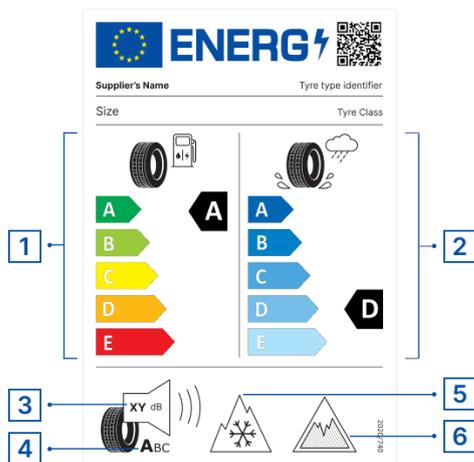
Table 2 – Overview of noise measures for road traffic

with an indication of ratings for each measure on the selection criteria (see § 2.1)

Noise measure	Noise reduction	Costs	Applicability	Scale of impact	Availability	Co-benefits	Constraints	Stakeholder complexity	Maturity	Information level
Promotion of low noise tyres	0	1	1	1	0	0	0	-1	0	0
Low noise pavements	1	0	1	0	1	1	0	0	1	1
Pavement maintenance	-1	0	1	0	1	1	0	0	0	0
Lower speed limits for major roads	0	0	1	0	1	1	-1	-1	1	1
Lower speed limits for urban roads	0	0	1	0	1	1	0	-1	1	1
Loud vehicle control	0	1	0	0	0	0	0	-1	0	0

4.2. Road traffic noise measure fact sheets

4.2.1. Promotion of low noise tyres



Source: European Commission
Tyre label example

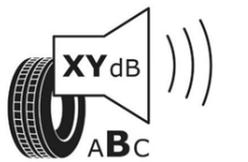
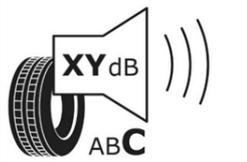


Source: Vredestein Tyres
Tyres with tyre label attached

Noise reduction mechanism

Some tyres make more rolling noise than others, depending on the tyre design (tread profile, rubber hardness, etc.), in combination with the road surface. For most roads with constant driving speeds exceeding 30 km/h, the tyres dominate the overall traffic noise, certainly for passenger cars. This dominance will increase with the further rise of electric vehicles. Tyres on the European market are required to have a *tyre label* as shown above, which includes a rolling noise rating in dB (3) as well as rolling noise class A, B or C (4). Tyres with a label A are ≥ 3 dB quieter than the maximum limit value (LV, see image below). Label C tyres are louder than the current limit value and hardly exist (< 0.5% of available tyres in the EPREL database⁽¹⁶⁾); such tyres should not be available in the EU market.

¹⁶ <https://eprel.ec.europa.eu/screen/product/tyres>

$N \leq LV - 3$	$LV - 3 < N \leq LV$	$N > LV$
		

Source: EU regulation 2020/740 ⁽¹⁶⁾

Definition of tyre rolling noise classes A, B and C based on their limit value (LV)

The tyre label itself ⁽¹⁷⁾ and the appropriate limit values are defined in EU and international regulations ⁽¹⁸⁾ and are outside the scope of the Noise Action Plans. However, measures to promote the uptake of low-noise tyres and increase their penetration on the market are available at national and regional levels. Such measures may include the following:

- **communication**: public or targeted campaigns to inform tyre buyers about low-noise tyres and the tyre label, explaining how buying low-noise tyres helps to reduce environmental noise and improve public health;
- **facilitating**: ensuring that tyre sellers and tyre fitters have low-noise (label A) tyres available and actually offer these to their customers;
- **financial incentives**, such as subsidizing tyre sellers to sell more low-noise tyres or to offer discounts;
- **public procurement procedures** that require or favour low-noise tyres, such as for transport services or for purchase, lease or rent of vehicles.

Key Characteristics

Property	Value
Type of Measure	Source
Typical Scale / Dimensions	The scale and effect of promotional campaigns range from city to national scale.
Typical Materials / Tools	<ul style="list-style-type: none"> • public communication campaigns • financial incentives for tyre buyers or resellers, in business (lease) and consumer markets • public procurement schemes requiring or favouring low noise tyres
Lifespan / Maintenance	Promotional measures need to be continuous. Effects will disappear after the typical tyre lifespan of roughly 5-6 years.

¹⁷ Regulation (EU) 2020/740 of the European Parliament and of the Council of 25 May 2020 on the labelling of tyres with respect to fuel efficiency and other parameters, consolidated text, 2020-06-05, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02020R0740-20200605>

¹⁸ UN Regulation No 117 – Uniform provisions concerning the approval of tyres with regard to rolling sound emissions and/or to adhesion on wet surfaces and/or to rolling resistance [2025/1453], 2025-08-07, <https://eur-lex.europa.eu/eli/reg/2025/1453>

Property	Value
Regulatory Status	Tyre labels are mandatory for all tyres on the EU market since 2012 by EC Regulation 1222/2009 ⁽¹⁹⁾ , which was replaced with EU Regulation 2020/740 ⁽¹⁶⁾ .

Effectiveness

Noise reduction

0 to 3 dB.

For an individual vehicle, changing from noise label **B** to **A** could result in a 1 to ca. 4 dB quieter tyre ⁽¹²⁾. On a fleet scale, the effect of promoting quieter tyres is smaller and will depend on:

- the current percentage of low-noise tyres. In the Netherlands, for example, recent tyre sales show approximately 10% label A vs. 90% label B tyres;
- the effective increase in the percentage low-noise tyres. This would need to reach more than 50% of the running fleet in order to obtain a significant reduction of L_{den} / L_{night} exceeding 1 dB;
- the vehicle weight, as heavier vehicles have tyres that are wider and potentially reinforced (i.e. 'extra load' tyres) which are noisier and have higher limit values;
- the road surface: quieter tyres are more effective on smooth, well-maintained roads. On rough roads, the road pavement dominates the tyre noise, and thus the effect of quieter tyres is smaller ⁽²⁰⁾.

Studies in the past ^(21,22) have shown that the rolling noise rating on the tyre label does not fully correlate with rolling noise measurements on public roads.

¹⁹ Regulation (EC) No 1222/2009 of the European Parliament and of the Council of 25 November 2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02009R1222-20210501>

²⁰ van Blokland GJ, van Leeuwen M, *Efficiency of the combined application of silent tyres and silent road surfaces*, proceedings Inter-Noise 2010 Lisbon, 2010-06

²¹ Conference of European Directors of Roads (CEDR), Bühlmann E et al., *STEER – STrengthening the Effect of quieter tyres on European Roads*, Report 2022-07, 2022-06, <https://www.cedr.eu/docs/view/6373a6fec0dc7-en>

²² Bendtsen H et al, *NordTyre – the potential for noise reduction using less noisy tyres and road surfaces*, proceedings Euronoise 2018 Crete, 2018-05, https://www.euronoise2018.eu/docs/papers/455_Euronoise2018.pdf

The European Commission and the UNECE are working to improve the accuracy of the measurement methods as well as the representativeness of the tyre label for real-world noise emissions. This should ensure that Label **A** tyres are actually as quiet as they should be.

Impact area

The measure reduces the sound emission of the vehicles. It affects all receivers along the road where quieter tyres are used, also at larger distances.

In urban situations with low speeds and/or high acceleration, such as around crossings, the powertrain noise dominates and the reduction obtained from low-noise tyres will be less.

Advantages

Low-noise tyres may also reduce interior noise, enhancing driver and passenger comfort.

Limitations

- Trade-offs may exist with other tyre parameters. There are studies that show a negative correlation between tyre wet grip performance and rolling noise, or tyre handling and rolling noise. However, any type-approved tyre must fulfil minimum safety (wet grip) requirements. No studies were found that prove a negative trade-off of low noise tyres with tyre wear and lifespan.
- Tyres for commercial vehicles (trucks and buses) are often re-treaded one or several times during their lifetime: a new rubber tread layer is placed on an existing tyre carcass. Re-treaded tyres are not subject to the tyre label regulation, so a noise label A tyre option is not yet available for such tyres.

Costs

Approximate costs

- Low-noise tyre costs: several studies (^{23,24}), including the Phenomena study (¹²), have indicated no correlation between the tyre noise label and its price, concluding that low-noise tyres are not more expensive than other tyres.
- Public communication campaigns and financial incentives would require some budget. Public and targeted communication will be in the order of 100 k€, whereas a financial incentive programme to promote quieter tyres will cost several M€, depending on the ambition level and scale.

Noise modelling

- Modelling of the effect of quiet tyres requires adaptation of the source emission values.
- If the calculation software allows for this, the noise emission factors could be reduced by a constant dB value, e.g. -1 or -3 dB depending on the ambition level. If not, workarounds could be:
 - to reduce the number of vehicles accordingly, e.g. a reduction of -1,5 dB may be simulated by reducing the vehicle count by 30%, or
 - to add the tyre noise reduction to the road surface correction factor(s).
- If a frequency-dependent emission correction is available, the frequency range 500 – 4000 Hz where tyre noise is dominant could be emphasized.
- In END Annex II (CNOSSOS-EU) there is not currently a correction factor available for quieter tyres. This would require a manual correction of the road noise emission factor as described above. Alternatively, new set of road noise emission factors for a new low-noise tyre vehicle category could be developed. This would allow to calculate the effect of increasing % of such vehicles.

²³ Sliggers J, *Possible Future Tyre Noise Limits*, UNECE GRBP Informal document GRB-61-03, 2015-01-27, <https://unece.org/DAM/trans/doc/2015/wp29grb/GRB-61-03e.pdf>

²⁴ European Federation for Transport and Environment (T&E), Sandberg U, *Consumer Label for Tyres in Europe*, 2008-03-10, https://www.transportenvironment.org/uploads/files/2008_03_sandberg_labelling_tyres_eur_ope.pdf

Implementation

Considerations

- Earlier studies have shown that private consumers are generally not aware of or interested in the tyre label. Consumers tend to choose the tyres that are offered to them by their car garage or tyre fitter, or stick with the same tyre brand and make. It will be more effective and efficient to target low-noise tyre promotion efforts to businesses, such as lease companies, tyre resellers or garages, or vehicle manufacturers. Traffic noise reduction could be connected to their Corporate Social Responsibility targets or ambitions, and their company image.
- The EU Green Public Procurement Guidelines, specifically those in the Road Transport category ⁽²⁵⁾, provide voluntary criteria and ready-to-use texts to include low-noise (Label **A**) tyres in procurement procedures for transport services and the purchase, lease and rent of vehicles. Several languages are available.

Timeline

Low-noise tyres already exist, so promotional efforts may start today. The lifespan of most car tyres is less than 50.000 km ⁽²⁶⁾, which is 3-4 years at an average yearly mileage of 15.000 km, so it will take several years to change a significant portion of the existing tyre population.

Stakeholders

local and national governments, tyre branch organisations, tyre suppliers and resellers, lease companies, car dealers and repair shops, public consumers

²⁵ EU green public procurement criteria for road transport, Commission Staff Working Document SWD(2021) 296 final, 2021-10-18, <https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/b7a6cda6-f52a-4b86-9cea-3e6ddb69be8e/details>

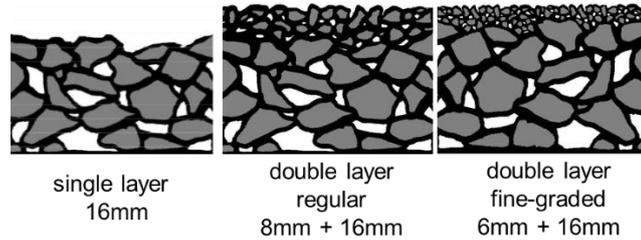
²⁶ ADAC, Silvestro D, *ADAC summer tyre test 2023 – Tyre abrasion vs. safety performance*, presentation in UNECE GRBP Task Force on Tyre Abrasion, TA-13-02, 2023-05-10, https://wiki.unece.org/download/attachments/198674102/TA-13-02%20Study_ADAC_tyre_abrasion_safety_RT%20english.pdf?api=v2

4.2.2. Low noise pavements



Source: M+P

Thin surface layers and low noise paving blocks, used in urban areas



Source: M+P

Drawing of three types of porous asphalt concrete, with varying surface texture

Noise reduction mechanism

For passenger cars with constant speeds ≥ 30 km/h and trucks ≥ 60 km/h, the tyres are the dominant source of long-time noise exposure (L_{den} / L_{night}). With electric vehicles, having quieter engines and larger tyres, this dominance increases further. The road surface has a large influence on the tyre/road interaction, and low noise pavements are an important noise reduction measure.

The two most important noise-related properties of road surfaces are:

- **surface texture**: a smoother surface, with smaller and/or flatter stone aggregates, leads to less tyre vibrations and less noise;
- **porosity**: porous pavements, containing up to 30% air voids in the upper layer, absorb noise leading to decreased tyre noise radiation efficiency. Porosity (above 5% air voids) also reduces tyre/road air pressure variations causing aerodynamic noise.

There have been developments of poro-elastic road surfaces (PERS), i.e. with rubber components, decreasing tyre vibrations leading to further noise reduction (^{27,28}). However, these are not (yet) proven to be durable and sustainable.

There are low noise versions available of different generic road surface types, including:

- **porous asphalt concrete (PAC)** surfaces: single- or double-layered and highly porous, mostly suitable for major roads;

²⁷ Goubert L, Sandberg U, *Construction and Performance of Poroelastic Road Surfaces Offering 10 dB of Noise Reduction* – PERSUADE Final Technical Report, Deliverable 8.7, 2016-01-07

²⁸ LIFE NEREIDE project (LIFE15 ENV/IT/000268), see <https://www.nereideproject.eu/en/>

- thin surface layers: asphalt surfaces, such as stone mastic asphalt (SMA) with smooth and optimised surface texture and a low to medium degree of porosity, more suitable for urban roads;
- optimised concrete pavements, including next-generation concrete surfaces (NGCS), where special concrete grinding techniques are applied to optimise the concrete surface texture;
- low-noise paving blocks, with optimised block and joint geometry and potentially porous, specifically designed for urban roads to retain the visual and practical advantages of paving blocks while lowering noise.

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	100 m or multiple km, up to full road network scale
Typical Materials / Tools	<ul style="list-style-type: none"> • multiple road surface products are commercially available from road contractors, for all types of roads; • low-noise surfaces exist in asphalt (bitumen-based) as well as concrete (cement-based) variations, as well as paving blocks; • for preventive or corrective cleaning of porous road surfaces, specialised porous asphalt cleaning vehicles exist;
Lifespan / Maintenance	<ul style="list-style-type: none"> • lifespan ranges from ca. 8 to 15 years before renewal, depending on surface type, traffic volume and traffic situation • low noise pavements are more sensitive to damage from accelerating / decelerating traffic as well as side motion (i.e. in narrow curves), which decreases the lifespan • maintenance includes regular asphalt repairs (ravelling, rutting, cracks and potholes); lifetime-prolonging techniques are available • porous pavements may need specialised cleaning on low traffic lanes (i.e. bypass or emergency lanes); normal lanes are usually self-cleaned by traffic and rainfall • the noise reduction of low noise pavements decreases over time, even if the surface is still in reasonable technical condition
Regulatory Status	-

Effectiveness

Noise reduction

The noise reduction typically varies from 2 to 4 dB for a thin layer surface up to 6 dB for a fine-graded double-layer porous asphalt, with respect to a regular

well-maintained dense (non-porous) asphalt surface (the reference surface) ⁽²⁹⁾. These values are averaged over the lifetime of the surface; initial reductions directly after laying are 1 to 3 dB higher.

Low noise concrete surfaces, e.g. NGCS, reduce noise by ca. 3 dB compared to regular washed or brushed concrete surfaces. Low noise paving blocks reduce noise by 2 to 3 dB compared to normal paving blocks.

For some roads or Member States the baseline, i.e. the typical pavement normally applied, is noisier than for others. For example, in Ireland where the relatively rough hot rolled asphalt has been the standard for long, and in the Nordic countries that have relatively rough pavements due to the use of studded tyres, the transition to a smooth SMA surface (e.g. 8 mm SMA) would lead to a few dB less noise with further reductions possible. Other countries have other, smoother, reference surfaces and need to apply specific low noise surfaces to reduce the noise. Overall, variation of noise emission due to road surface can cover a range of 13 dB, including the extremes of surface quality ⁽¹²⁾.

The noise reduction by low-noise asphalt pavements mainly occurs at medium to high frequencies with limited reduction at lower frequencies (< 500 Hz). For concrete surfaces or paving blocks, some reduction of low frequency noise may be expected.

Other acoustic effects

Low noise pavements also reduce interior noise, leading to increased passenger comfort.

The application of low noise pavements may require also simultaneous improvement of bridge and tunnel joints or other road elements, as such peak noises may be more prominent after replacement with a quieter road surface.

Impact area

Low noise road surfaces decrease the source emission of the road traffic, which has an effect all along the road up until several 100 m distance. At larger distances and inside buildings low frequency noise is more important, therefore the noticeable effect of the low noise road surface is smaller.

²⁹ European Climate, Infrastructure and Environment Executive Agency (CINEA), *Low Noise Road Surfaces – Factsheet*, 2024-10-14, https://cinea.ec.europa.eu/publications/digital-publications/low-noise-road-surfaces-factsheet_en

Advantages

- Smoother surface texture reduces vehicle energy consumption, leading to lower CO₂ and air pollutant emissions and increased electric vehicle range.
- Porous asphalt surfaces reduce water splash-and-spray, leading to increased traffic safety and road capacity.
- Porous asphalt surfaces capture tyre-road wear particles, reducing microplastic concentrations in water, soil and air ⁽³⁰⁾. Smoother texture will lead to lower tyre wear and reduce microplastic emissions.

Limitations

- Low noise pavements generally have lower durability, ranging from 8 to 12 years on urban roads and up to 15 years on major roads, compared to 15 to 20 years for regular asphalt pavements and 20+ years for concrete pavements. Reduced lifespan leads to more material waste, and more roadworks with associated air emissions and congestion.
- To minimise material use, horizontal recycling (i.e. old asphalt recycled into new asphalt) is important. Road materials should be chosen such that horizontal recycling is possible, which limits the use of certain bitumen additives used for low noise pavements. Asphalt recycling is under strong development in recent years, at least in some Member States, for example in NL.
- Low noise pavements, certainly porous pavements, are less suitable for crossings, entry/exit ramps and tight curves, due to increased longitudinal and sideway forces by the traffic.
- In countries with severe winter conditions, porous asphalt pavements may be less suitable as they damage more quickly in frost conditions.

Costs

Approximate costs

Investment costs for low noise road asphalt surfaces or paving blocks are usually 5 – 15% higher than for regular asphalt or paving blocks, which amounts

³⁰ Quik JTK et al., *Emission of Microplastics to Water, Soil, and Air: What can we do about it?*, RIVM report 2024-0106, 2024-10-01, <https://rivm.openrepository.com/entities/publication/97ec1fa9-5ebe-40b9-945a-984f0482fe4b>

to 5 – 10 €/m² additional costs, depending on the baseline. Yearly maintenance costs are mostly 5 – 20% higher.

Detailed cost calculations

A recently updated cost calculation tool for low noise pavements is available in the Netherlands ⁽³¹⁾, which provides life cycle costs in €/m² for various low noise pavement types compared to a chosen reference scenario.

According to recent Swiss life cycle analysis (LCA) studies, in urban areas the noise reduction and energy savings outweigh the increased investment and maintenance costs for low noise road surfaces ^(32,33). The reduction of external costs is equal to or up to 8% larger than the increased investment and maintenance costs ⁽³¹⁾.

Noise modelling

The END Annex II (CNOSSOS-EU) noise assessment method ⁽¹⁾ provides a road surface correction factor that can be used to incorporate low noise road surfaces directly in the calculation of the road noise emissions and in the noise mapping results. For each low noise pavement type, frequency-dependent correction values are needed. Table F-4 in Appendix F to the END Annex II provides default values for 13 pavement types, originating from the Dutch national noise assessment method. Some studies have established additional

³¹ <https://silentroads.nl/kostentool>, in Dutch, with manual, updated March 2025

³² Arbeitsgemeinschaft LCA-Strasse, Schindler J et al., *Lärmarme Strassenbeläge – Ökobilanz und Lebenszykluskosten Schlussbericht Forschungsprojekt*, assigned by Swiss Bundesanstalt für Umwelt (BAFU), 2024-03-08, https://www.bafu.admin.ch/dam/bafu/de/dokumente/laerm/externe-studien-berichte/laermarme-strassenbelaege-oekobilanz-und-lebenszykluskosten.pdf.download.pdf/LCA-LAB_Forschungsbericht.pdf

³³ Piao Z et al., *Modified life cycle assessment for Low-Noise urban roads including acoustics and monetarization*, Transportation Research Part D, 2022

correction values for other pavement types ^(34,35,36,37), each using their own methods. CEN WG TC227 is currently developing a technical specification (CEN TS 18194) that provides a method ⁽³⁸⁾ to establish new CNOSSOS-EU road surface correction values based on acoustic measurements with a CPX trailer ⁽³⁹⁾.

Most national calculation methods for road traffic noise, such as RLS-19 (DE), NMPB (FR), Nord200 (Nordic countries), CRTN (UK/IE) and Mrgw (NL) have methods and data available to calculate the effect of different road surfaces, including low-noise pavements.

For quick estimations, the Dutch road surface correction method ⁽⁴⁰⁾ provides single-value correction values for the overall dB(A) road noise emissions. However, these are based on previous legislation (before 2024) using older measurement data (2 – 13 years) and should therefore be considered indicative.

Any modelling of the road surface effect should take into account:

- the traffic mix (% of light and heavy vehicles) and the driving speeds;
- a clear definition of the reference (non-reducing) road surface type. For CNOSSOS-EU, the reference surface is a dense asphalt concrete or stone mastic asphalt of average age (2 – 7 years) in reasonable maintenance state ⁽¹⁾;
- the road surface age: preferably the correction values are based on the lifespan-average road surface performance, so as to avoid overestimation based on the temporary effect of a brand new road surface.

³⁴ Transport Infrastructure Ireland (TII), *Determination of Irish Road Surface Correction Factors for CNOSSOS*, TII Publication Number GE-ENV-01108, 2024-05, <https://cdn.tii.ie/publications/GE-ENV-01108-01.pdf>

³⁵ Shilton S et al., *Overview of Research Supporting Development of a National Noise Modelling System for England*, proceedings of Forum Acusticum / Euronoise 2025, 2025-06

³⁶ Ascari E et al., *Tuning user-defined pavements in CNOSSOS-EU towards reliable estimates of road noise exposure*, Transportation Research Part D, 2024

³⁷ Larsson K, *Swedish input data for road traffic noise in CNOSSOS-EU*, proceedings of Baltic-Nordic Acoustics Meeting BNAM 2021, 2021-05

³⁸ Anfosso-Ledee F, Goubert L, *The determination of road surface corrections for CNOSSOS-EU model for the emission of road traffic noise*, proceedings of ICA 2019 Aachen, 2019-09

³⁹ ISO 11819-2:2017, *Acoustics — Measurement of the influence of road surfaces on traffic noise, Part 2: The close-proximity method*, 2017-03

⁴⁰ <https://www.rivm.nl/geluid/rekenmodellen-en-tools/wegdekcorrectie-cwegdek>

Implementation

Considerations

- There is sufficient experience with procurement, construction and maintenance of low noise pavements in many European cities and on major roads in several countries, including DE, FR, NL, IT, AT and CH ⁽²⁸⁾. Also, there are several European road contractors from such countries who have experience and products available.
- For procurement of low noise pavements, it is advisable to include conformity-of-production measurements to check acoustic performance after installation ^(41,42) and potentially monitor the performance over time.
- The EU Green Public Procurement Guidelines, specifically those in the Road Design, Construction and Maintenance category ⁽⁴³⁾, provide voluntary criteria and ready-to-use texts in several languages, to specify low-noise pavements in procurement. Two ambition levels (core and comprehensive criteria) are given, specifying CPX-based ⁽³⁸⁾ noise levels to be checked shortly after construction as well as within 5 years after. A technical background report ⁽⁴⁴⁾ is also provided, which includes descriptions of low-noise pavement approaches in several EU countries.
- For cost-effectiveness and operational efficiency, replacement of low noise asphalt should be aligned or integrated with regular asphalt asset management and maintenance processes.

⁴¹ Conference of European Directors of Roads (CEDR), *State of the art in managing road traffic noise: noise-reducing pavements*, Technical Report 2017-01, 2016-12, <https://www.cedr.eu/download/Publications/2017/CEDR-TR2017-01-noise-reducing-pavements.pdf>

⁴² Garbarino E et al., *Revision of Green Public Procurement Criteria for Road Design, Construction and Maintenance. Procurement practice guidance document*, JRC EUR 28028 EN, 2016, https://publications.jrc.ec.europa.eu/repository/bitstream/JRC102168/jrc102168_gpp_roads_guidance_final.pdf

⁴³ EU Green Public Procurement Criteria for Road Design, Construction and Maintenance, Commission Staff Working Document SWD(2016) 203 final, 2016-06-10, <https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/57e2abc4-a42e-4666-8ce8-dfbc987b6f2d>

⁴⁴ Garbarino E et al., *Revision of Green Public Procurement Criteria for Road Design, Construction and Maintenance. Technical report and criteria proposal*, JRC EUR 28013 EN, 2016-06,

Timeline

- 6 months for planning, impact assessment and stakeholder engagement
- 6 – 9 months for design specification, procurement and contracting
- 2 – 3 months for construction, installation and conformity-of-production testing
- regular monitoring and maintenance during the surface lifetime

Stakeholders

national or local road authorities, municipalities and environmental agencies, road contractors, acoustic planners, measurement service providers

Further documentation

Several EU-funded research projects under the Horizon Europe and LIFE programmes have included or focused on low noise pavements, such as the NEMO project ⁽⁵⁵⁾ and the LIFE NEREIDE project ⁽²⁷⁾. The CEDR research project QUESTIM included data analysis and assessment of low-noise pavement durability.

The ongoing LIFE OPTIMUS project ⁽⁴⁵⁾ is developing a multi-criteria decision analysis tool that allows for a comprehensive evaluation of low-noise pavements, including relevant other parameters such as sustainability, durability and costs.

4.2.3. Pavement maintenance



Source: CROW, NL
Application of asphalt rejuvenator



Source: Wikipedia
Examples of road damage: cracking, potholes

⁴⁵ <https://www.vienrose.it/life-optimus/>

Noise reduction mechanism

Road surfaces degrade over time as a result of traffic load, weather, pollution and environmental influences. This leads to rougher surface texture, as a result of stone loss, ravelling and cracking, to deformation (rutting) and larger damages such as potholes. Rougher texture means more tyre vibrations and higher rolling noise levels. In porous pavements, porosity may decrease due to clogging or compaction. This leads to lower sound absorption as well as airflow noise reduction, thus higher rolling noise levels.

Pavement maintenance to prevent or correct such damages therefore leads to a reduction of traffic noise. Maintenance measures include corrective measures, i.e. surface repair, as well as preventive measures such as rejuvenation of asphalt binder, or monitoring systems for early detection of decreasing quality.

Proper road surface maintenance to reduce noise should also involve corrective or preventive maintenance of manhole covers, road markings, speed bumps, bridge / tunnel joints, tram rails and other discontinuities in the road, which may worsen over time due to road deformation or ground settling. Ensuring flatness and minimising discontinuities reduces rolling noise peaks.

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	any scale from very local (potholes) to road network level
Typical Materials / Tools	<ul style="list-style-type: none"> • asphalt or concrete repair works • reprofiling by grinding or milling, mainly for concrete • partial repaving of top layers • porous pavement cleaning • asphalt rejuvenator chemicals to restore bitumen performance • preventive maintenance monitoring, using e.g. surveillance vehicles with video, laser or acoustic/vibration sensors
Lifespan / Maintenance	Asphalt maintenance prolongs the lifespan of existing asphalt. It is a continuous process.
Regulatory Status	-

Effectiveness

Noise reduction

Road surface degradation leads to an increase of average traffic noise levels of 3 to 5 dB compared to newly laid surfaces. Maintenance cannot fully restore the

asphalt to its new conditions, so the average noise reduction is limited to ca. 1 to 3 dB.

Full replacement of the road surface with a new surface leads to higher noise reductions. In that sense, prolonging the lifetime of an existing, older and noisier road surface has a negative effect on the noise, if it leads to postponed re-pavement.

Other acoustic effects

Local pavement damages such as cracks and potholes can lead to noise peaks. Impulsive sounds are particularly disturbing and cause high annoyance and sleep disturbance. Road maintenance aimed at minimising discontinuities can therefore be particularly effective in noise reduction.

Impact area

Repairing a single pothole or a bad bridge joint may already have a positive impact on nearby residents up to 200 m away. Improvement of large-scale maintenance strategies by road authorities may improve traffic noise over many km, up to full network scale.

Advantages

- Improved road surface maintenance increases safety and road user comfort.
- Preventive road surface maintenance may lead to cost savings while improving noise reduction.

Limitations

- Although road surface maintenance leads to noise reduction compared to no maintenance, repaving the road with a new surface is preferable, from a noise perspective.

Costs

Approximate costs

Any road surface has maintenance costs. Increasing the maintenance level could range 10 - 50% in higher costs, although preventive maintenance

measures could significantly reduce this ⁽⁴⁶⁾. For low noise pavements, maintenance costs are 5 – 20% higher than for regular pavements.

Detailed cost calculations

For low noise pavements, a Dutch cost calculation tool is available ⁽³⁰⁾, which provides maintenance costs in €/m²/year for various low noise pavement types.

Noise modelling

Noise reductions as a result of increased road surface maintenance could be integrated in noise assessments or noise mapping using END Annex II (CNOSSOS-EU) or any other road noise assessment method.

No standardised noise reduction values for road maintenance are available, although a few studies exist ^(47,48). Measurements may be needed to quantify the reduction of the noise emission before being able to include it in noise calculations ⁽⁴⁶⁾.

Implementation

Considerations

Besides chemical rejuvenators, which may be relatively unknown, other road surface maintenance techniques are standard practice. Implementation of this measure, i.e. increasing the maintenance level to reduce noise, therefore comes down to deciding where and when maintenance works should be intensified, i.e. asset management. Some form of road surface monitoring will be required to steer the maintenance efforts.

⁴⁶ Pellecuer L, *Influence of pavement maintenance strategy on road traffic social and environmental impacts and associated costs*, Conference of the Transportation Association of Canada, 2016-09

⁴⁷ Freitas E et al., *The Influence of Pavement Degradation on Population Exposure to Road Traffic Noise*, Coatings, 2019-05-01

⁴⁸ Haider M et al., *Pavement Maintenance Influence on Road Traffic Noise Emission*, Roads and Airports Pavement Surface Characteristics, 2023-05

Timeline

Implementation will take some 6 months of coordination with road asset managers, and to implement road surface monitoring if not yet available. The actual maintenance works could start immediately after.

Stakeholders

national and local road authorities and asset managers, road contractors, measurement / monitoring service providers

4.2.4. Lower speed limits for major roads



Source: Stock Photo F1online
Night speed limit for noise protection in Germany



Source: Slim naar Antwerpen
Speed limit in Antwerp low emission zone

Noise reduction mechanism

A lower constant driving speed leads to less sound emitted by the rolling tyres and the vehicle driveline. This effect is stronger for the tyres, as the driveline noise depends on the engine rotational speed which is reduced by shifting to higher gears.

Most major roads will have a fairly constant driving speeds usually exceeding 70 km/h. Here, the tyre noise is dominant, and a reduction of driving speeds will lead to quieter traffic. Depending on the implementation, lower speed limits may be limited to certain times of day or night.

Key Characteristics

Property	Value
Type of Measure	traffic management

Property	Value
Typical Scale / Dimensions	road sections of several km, larger parts of the road network, or all major roads
Typical Materials / Tools	<ul style="list-style-type: none"> • a legislative order by the competent traffic authority • road signs indicating the maximum speed and, if applicable, the time window • lower speed limits may be combined with changes to the road itself, e.g. reducing the road width or the number of lanes • (increased) speed enforcement may be required
Lifespan / Maintenance	-
Regulatory Status	national or local legislation applies

Effectiveness

Noise reduction

Typically 0.5 to 3 dB, depending on:

- the change in speed limits: 100 km/h to 70 km/h leads to ca. 3 dB reduction, 130 km/h to 120 km/h leads to ca. 0.7 dB reduction;
- the actual driving speed: driving speeds will vary around the limit. The effect of the lower limit on the actual average speed may be smaller than the difference between the old and the new limit. This depends also on the level of enforcement and the traffic situation, i.e. the amount of congestion;
- the time window: if the limit only applies to certain times of day, the effect on the L_{den} will be lower.

Other acoustic effects

The momentary sound emission by the vehicle and its tyres will be lower at lower driving speeds, but it increases the pass-by duration. Therefore, the reduction of the time-average (equivalent) noise level (i.e. L_{den} or L_{eq}) is lower than the reduction of the momentary or maximum noise level (i.e. L_p or L_{max}). The dB reduction values given above include this negative effect.

The perceived noise reduction and the associated positive impact on annoyance and health may be greater than what may be expected purely from the reduction of the noise level in dB, although this was only proven for low speeds in urban areas, see § 4.2.5.

Lowering speed may positively or negatively affect the road capacity, depending on the situation. Speed reduction decreases traffic volume as drivers may

choose other routes or transport modes. The effect in dB of such traffic volume changes is secondary, compared to the speed reduction itself.

The lower traffic volume at the lower speed location may come at the expense of increased traffic noise and annoyance elsewhere. Lower speeds on major roads may move traffic towards alternative routes into residential areas. The net effect may be counterproductive for noise as well as safety and local air quality.

Impact area

The measure reduces the sound emission of the vehicles. It affects all receivers along the road where the speed is reduced, at any distance where the traffic noise can be heard (i.e. up to several km).

Advantages

- may reduce traffic volume in the targeted area, leading to further noise reduction
- increased safety in the targeted area
- lower energy / fuel consumption, leading to lower air pollutant and CO₂ emissions
- lower tyre and road wear, leading to reduction of microplastic emissions and maintenance costs

Limitations

- may lead to displacement of traffic to alternative (sub)urban routes if available ⁽⁴⁹⁾, potentially leading to increased noise exposure, air pollutions and safety impacts along these alternatives
- longer travel times

Costs

Approximate costs

Implementation costs are relatively low. In the Netherlands, the total costs of reducing the maximum speed on all motorways from 130 to 100 km/h in 2020

⁴⁹ Magkafas F et al., *Beyond Speed Reduction: A Systematic Literature Review of Traffic-Calming Effects on Public Health, Travel Behaviour, and Urban Liveability*, Infrastructures, 2025-06-16, <https://doi.org/10.3390/infrastructures10060147>

were ca. 19 M€, not including the external costs of increased travel times. Increased enforcement is assumed to be cost-neutral.

If lower speeds lead to increased travel times, then there are indirect economic effects due to loss of productive time for the road users. For busy roads, the road capacity may increase with lower speeds, leading to decreased travel times. The net effect on external time costs is therefore not obvious; it may be positive or negative.

Detailed cost calculations

Cost calculations for lower speed limits should include:

- additional or adapted road signalling
- planning and regulations

To calculate the effect of lower speed limits on external time costs for road users, traffic modelling would be needed to calculate the effect on road capacity and travel times. Standardised cost figures for travel times and congestion are given in the EU Handbook on External Costs of Transport ⁽⁵⁰⁾.

Noise modelling

The dB reduction from lower speed limits depends on the actual speed reduction, traffic composition (% of heavy traffic), changes in traffic volume, and the road surface. The reduction may be calculated with END Annex II (CNOSSOS-EU) or any other road noise calculation model.

The quality of the result will depend on the input speed and traffic flow data. Ideally, actual average traffic speeds per road segments should be obtained from measurements and/or traffic modelling. Using the posted maximum speed limit as input for the noise calculations may overestimate the effect of the lower speed limit when the actual effect on driving speeds is smaller.

Traffic flow data should be adapted to the lower vehicle speeds, using updated measurements and/or traffic modelling. It is important to include other routes in the area in the traffic modelling, as the lower speed limit may result in increased traffic on alternative roads nearby.

⁵⁰ European Commission: Directorate-General for Mobility and Transport, CE Delft, Essen, H. v., Fiorello, D., El Beyrouty, K. et al., *Handbook on the external costs of transport – Version 2019 – 1.1*, Publications Office, 2020, <https://data.europa.eu/doi/10.2832/51388>

Implementation

Considerations

- Adequate communication on the intended speed reduction is advised, targeting residents as well as road users. The reasoning and expected gains should be well explained to gain road user support.
- Increased speed enforcement may be needed, initially or permanently, to assure that drivers actually reduce their speed.
- Lower speed limits on major roads may lead to unwanted displacement of traffic to (sub)urban roads in the vicinity. It is advisable to implement lower speed limits on network- or city-level rather than by isolated interventions, ensuring that traffic is calmed in a coordinated and balanced manner certainly if the lower speed limit is applied on a local scale.

Timeline

< 1 year. Several months will be needed for planning and preparations. After implementation, some months may pass before drivers are used to the new situation.

Stakeholders

Road authority, road user associations

4.2.5. Lower speed limits for urban roads



Source: City of Köln, IMAGO/dieBildmanufaktur
30 km/h speed limit for noise protection



Source: City of Amsterdam
Road markings to visually narrow the road

Noise reduction mechanism

A lower constant driving speed leads to less sound emitted by the rolling tyres and the vehicle driveline. This effect is stronger for the tyres, as the driveline noise depends on the engine rotational speed which is reduced by shifting to higher gears.

For urban roads, although the relative contribution of the driveline is more than for high-speed roads, the tyre rolling noise is dominant for passenger cars driving at constant speeds of 30 km/h or more. For electric vehicles and newer combustion engine vehicles the tyres may be even more dominant. For older cars, sports cars or heavy vehicles the engine noise is more relevant. Engine noise is also relevant for situations with varying vehicle speeds, i.e. accelerating traffic near crossings.

Lowering the vehicle speed for urban areas, typically from 50 to 30 km/h, will reduce the tyre noise. Also, depending on the physical situation, it will reduce vehicle acceleration and thereby the engine noise.

Key Characteristics

Property	Value
Type of Measure	traffic management
Typical Scale / Dimensions	specific road sections, certain urban zones, or the whole city
Typical Materials / Tools	<ul style="list-style-type: none"> • a legislative order by the competent traffic authority • road signs indicating the maximum speed and, if applicable, the time window • lower speed limits should be combined with changes to the road itself, e.g. reduced road width, visual cues, bicycle lanes, etc. • (increased) speed enforcement may be required
Lifespan / Maintenance	-
Regulatory Status	national or local legislation applies

Effectiveness

Noise reduction

Typically 1,5 to 4 dB, depending on:

- the actual reduction in driving speed. A reduction in speed from 50 to 30 km/h leads to ca. 4 dB reduction, but realistically the change in driving speeds is lower.

- the fraction of heavy vehicles: the noise reduction is smaller for heavy vehicles. For roads with > 10% heavy vehicles the measure loses much of its effectivity ⁽⁵¹⁾.

Noise measurements and calculations in Switzerland ⁽⁵²⁾ and in Amsterdam show a reduction of 1,6 to 1,7 dB(A) on roads where the speed limit was reduced from 50 to 30 km/h. In Switzerland, it was shown that the noise reduction is not smaller for electric vehicles. In Amsterdam, where 30 km/h was introduced in most of the inner-city roads, except some important access roads, it was found that there was a reduction of vehicle speed and a noise reduction of 0,9 dB(A) also on the roads where the 50 km/h limit was retained, showing that there is a spill-over effect.

Other acoustic effects

The momentary sound emission by the vehicle and its tyres will be lower at lower driving speeds, but it increases the pass-by duration. Therefore, the reduction of the time-average (equivalent) noise level (i.e. L_{den} or L_{eq}) is lower than the reduction of the momentary or maximum noise level (i.e. L_p or L_{max}).

Lowering speed may positively or negatively affect the road capacity, depending on the situation. Speed reduction decreases traffic volume as drivers may choose other routes or transport modes. The effect in dB of such traffic volume changes is secondary compared to the speed reduction itself.

In Switzerland, it was shown ⁽⁵³⁾ that the public subjectively experienced a perceived annoyance reduction that was larger (equivalent to 2 to 4 dB(A)) than what would have been expected from the actual noise reduction that was measured (1,6 dB(A)). Another Swiss study on 50 to 30 km/h speed limit reduction shows that the positive health effect resulting from the noise reduction is actually larger than the positive health effect that results from increased traffic safety ⁽⁵⁴⁾.

⁵¹ Bühlmann E, Egger S, *Assessing the noise reduction potential of speed limit 30 km/h*, proceedings of Inter-Noise 2017 Hong Kong, 2017-08-27

⁵² Bundesamt für Strassen (ASTRA), Grolimund + Partner AG, Egger S et al., *Grundlagen zur Beurteilung der Lärmwirkung von Tempo 30*, 2017-02

⁵³ Brink M et al., *Lowering urban speed limits to 30 km/h reduces noise annoyance and shifts exposure–response relationships: Evidence from a field study in Zurich*, Environment International, 2022-12, <https://doi.org/10.1016/j.envint.2022.107651>

⁵⁴ Rossi IA et al., *Estimating the health benefits associated with a speed limit reduction to thirty kilometres per hour: A health impact assessment of noise and road traffic crashes for the Swiss city of Lausanne*, Environment International, 2020-12, <https://doi.org/10.1016/j.envint.2020.106126>

Impact area

The measure reduces the sound emission of the vehicles. It affects all receivers along the road where the speed is reduced.

Advantages

- safety is largely increased as a result of fewer and less severe traffic accidents with pedestrians and cyclists
- speed reduction may reduce traffic volume in the targeted area, leading to further noise reduction
- lower energy / fuel consumption, leading to lower air pollutant and CO₂ emissions
- lower tyre and road wear, leading to reduction of microplastic emissions and maintenance costs

Limitations

Besides maximum speed signs, changes to the road that support driving slower are recommended, such as:

- no physical separation of motorised traffic and cycling lanes;
- no visual separation of road lanes (no road markings in the middle);
- physical narrowing of the road, or visual narrowing with road markings.

Often, a road surface of paving blocks is applied to 30 km/h roads. However, if an asphalt road is repaved with paving blocks, this will increase the rolling noise level. If the speed reduction is combined with this repaving, it may lead to an increase of the noise. If the 50 km/h road was already paved with paving blocks, speed reduction will be effective.

Other limitations:

- The noise reduction by low-noise road surfaces is different, potentially lower, at 30 km/h. Road surface correction factors validated at 30 km/h are scarcely available.
- Speed reduction may lead to increased traffic on alternative routes if available, leading to increased noise exposure and other negative environmental and safety impacts.
- Speed reduction leads to longer travel times, for cars as well as public transport on the same roads, although the effect on average urban trips is small (in Amsterdam: < 5%).

Costs

Implementation of 30 km/h speed limits requires costs for:

- additional or adapted road signalling
- visual road adaptations (i.e. road markings)
- communication
- monitoring and enforcement

As an indication, for the City of Amsterdam the total costs to implement 30 km/h all over the city centre, on most of the roads, were estimated to be 32 M€ over the period 2021 – 2025 ⁽⁵⁵⁾.

Noise modelling

The dB reduction from lower speed limits depends on the actual speed reduction, traffic composition (% of heavy traffic), changes in traffic volume, and the road surface. The reduction may be calculated with END Annex II (CNOSSOS-EU) or any other road noise calculation model.

The quality of the result will depend on the input speed and traffic flow data. Ideally, actual average traffic speeds per road segments should be obtained from measurements and/or traffic modelling. Certainly for urban roads, using the posted maximum speed limit as an input for the noise calculations may overestimate the effect of the lower speed limit when the actual effect on driving speeds is smaller.

Implementation

Considerations

- Adequate communication on the intended speed reduction is advised, targeting residents as well as road users. The reasoning and expected gains should be well explained to gain road user support.
- Road adaptations including visual aspects are needed to support actual slower driving. Increased speed enforcement may also be needed, initially or permanently.

⁵⁵ City of Amsterdam, *Amsterdam veilig en leefbaar – 30 km/u in de stad*, 2021-12-30, https://assets.amsterdam.nl/publish/pages/1042158/beleidsnota_30km_in_de_stad.pdf (in Dutch)

- Lower speed limits on some roads may lead to unwanted traffic rerouting to other roads. It is advisable therefore to introduce lower speeds in a larger area so as to avoid unwanted rerouting.

Timeline

< 1 year. Several months will be needed for planning and preparations. After implementation, some months may pass before drivers are used to the new situation.

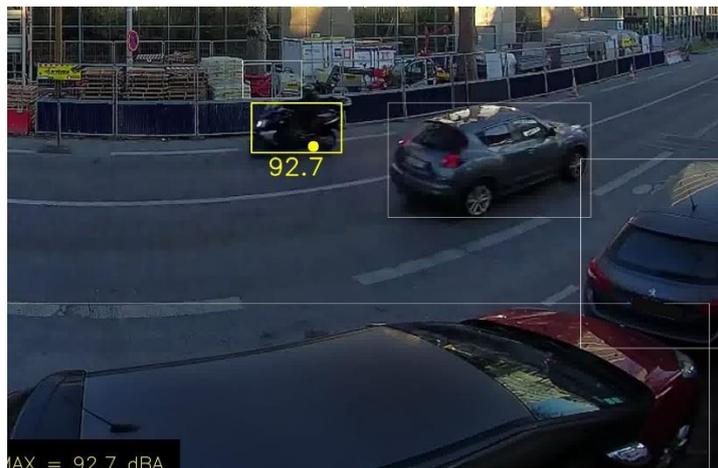
Stakeholders

Local road authority, traffic police, road user associations

4.2.6. Loud vehicle control



Source: dB FLASH
Noise camera by dB FLASH



Source: Bruitparif
Loud vehicle identified by Hydre noise camera

Noise reduction mechanism

In typical urban road traffic, a small fraction of the vehicles is considerably or excessively noisier than the rest. According to results of the EU research project NEMO (^{56,57}), 1% of the vehicles is 10 dB(A) louder than the majority. According

⁵⁶ www.nemo-cities.eu

⁵⁷ Peeters B, *Detection and analysis of high noise emitters in the H2020-project NEMO*, UNECE GRBP presentation TFVS-13-04, 2023-08-29, <https://wiki.unece.org/download/attachments/208536716/TFVS-13-04%20-%20High%20noise%20emitters%20in%20H2020%20-%20project%20NEMO.pptx>

to results ⁽⁵⁸⁾ of the LENS project ⁽⁵⁹⁾, the cause of the loudness is found in driving behaviour, vehicle modifications, or both. Motorcycles are strongly overrepresented: for motorcycles the percentage of loud vehicles is considerable higher than for passenger cars; in Amsterdam, 8% of motorcycles showed pass-by levels ≥ 80 dB(A), versus 0,2% of cars ⁽⁶⁰⁾. For passenger cars, high performance vehicles (i.e. sports cars) are more frequently loud than others, often due to modifications, although such modifications also occur for less high-end vehicles.

Although a small fraction of the total vehicle fleet, these loud vehicles lead to considerable annoyance and many complaints from inhabitants in cities as well as other locations, e.g. near touristic motorcycle routes ⁽⁶¹⁾.

Remote sensing technology, i.e. automated roadside noise measurements, have been developed by several suppliers in recent years, making unmanned detection and identification of loud vehicles technically possible. Automated enforcement or semi-automated enforcement (a remote officer evaluating audio/video recordings of loud vehicle events) requires a legal basis. Warning systems, using roadside displays to show loud pass-by events, may also positively influence driver behaviour.

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	neighbourhood to city level

⁵⁸ Dittrich M, Wessels P, *Loud vehicle monitoring in four Dutch cities and mitigation options*, UNECE GRBP presentation TFVS-17-04, 2025-02-17, <https://wiki.unece.org/download/attachments/277381240/TFVS-17-04%20-%20%28TNO%29%20Loud%20vehicle%20monitoring%20in%20four%20Dutch%20cities%20and%20mitigation%20options%20Final.pdf>

⁵⁹ <https://lens-horizoneurope.eu/>

⁶⁰ Peeters B, *Loud vehicle detection in Amsterdam – System description and measurement results*, UNECE GRBP presentation TFVS-17-08, 2025-02-17, <https://wiki.unece.org/download/attachments/277381240/TFVS-17-08%20-%20%28M%2BP%29%20Loud%20vehicle%20detection%20in%20Amsterdam.pptx?api=v2>

⁶¹ Schreckenber D et al., *Motorcycle Noise Study Baden-Württemberg, Part I: Long-term noise annoyance in residents living alongside busy motorcycle routes in the southwest of Germany*, proceedings 14th ICBEN Congress, 2023-06

Property	Value
Typical Materials / Tools	<ul style="list-style-type: none"> • remote sensing technology ('noise cameras') for detection of loud vehicles • a legal basis and definition of excessively loud vehicles, including sanctions • alternatively, roadside warning systems
Lifespan / Maintenance	Noise measurement systems require regular maintenance and calibration
Regulatory Status	<p>Type approval regulations for motor vehicles and vehicle components follow EU Regulation 2018/858 ⁽⁶²⁾, with noise limits and measurement methods defined in UNECE Regulations 41 ⁽⁶³⁾ for motorcycles and 51 ⁽⁶⁴⁾ for passenger cars.</p> <p>EU legislation does not currently provide a legal basis to allow sanctioning of loud vehicles other than by manual roadside inspections using subjective evaluation by an officer. A proposal to modify EU Directives on periodic technical inspections and roadside inspections was published in 2025 ⁽⁶⁵⁾, introducing remote sensing as an instrument as well as legal definitions of too loud vehicles.</p>

Effectiveness

Noise reduction

Loud vehicles cause individual noise peaks exceeding average traffic noise levels by 10 to 30 dB(A). The noise peaks tend to occur more frequently in evening periods, weekends or good weather days.

The reduction of yearly average noise exposure levels (L_{den} and L_{night}) is limited to 1 – 2 dB(A) depending on the baseline number of loud vehicles.

⁶² Regulation (EU) 2018/858 of the European Parliament and of the Council of 30 May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02018R0858-20240701>

⁶³ Regulation No 41 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of motor cycles with regard to noise, <https://eur-lex.europa.eu/eli/reg/2012/41/oj/eng>

⁶⁴ Regulation No 51 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of motor vehicles having at least four wheels with regard to their noise emissions, [https://eur-lex.europa.eu/eli/reg/2007/51\(2\)/oj/eng](https://eur-lex.europa.eu/eli/reg/2007/51(2)/oj/eng)

⁶⁵ Proposal for a Directive of the European Parliament and of the Council amending Directive 2014/45/EU on periodic roadworthiness tests for motor vehicles and their trailers and Directive 2014/47/EU on the technical roadside inspection of the roadworthiness of commercial vehicles circulating in the Union, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52025PC0180>

Other acoustic effects

Although scientific evidence is limited ⁽⁶⁶⁾, individual loud vehicle events are expected to lead to startling effects and increased annoyance and sleep disturbance compared to regular broadband and continuous traffic noise levels. Impulsive sounds ('pops and bangs') and strong tonal components ('roaring') contribute to the increased negative health impact ⁽⁶⁷⁾, which exceeds regular exposure-response functions assumed for traffic noise. For motorcycles on average, including non-modified vehicles, significantly higher exposure-response functions were found compared to passenger cars ^(68,68): motorcycles cause more than double the percentage of highly annoyed residents compared to passenger cars.

Impact area

Depending on the number of control points and the level of enforcement, loud vehicle events can be reduced on a street, neighbourhood or city level.

Advantages

- effective measure to reduce complaints and improve citizen support
- cost-effective compared to infrastructure changes; costs could be covered by financial sanctions of legal offences
- reduced vehicle tampering and aggressive driving leads to improved air quality and CO2 emissions; less aggressive driving increases safety

Limitations

- manual enforcement is time-consuming and inefficient
- legal basis for automated enforcement is lacking from EU and national regulations
- measurement standards to enable homologation of measurement systems do not yet exist

⁶⁶ Basner M, Smith MG, *The effects on sleep play a critical role in the long-term health consequences of noise exposure*, Sleep, 2024-02, <https://doi.org/10.1093/sleep/zsad314>

⁶⁷ Samani O, Altinsoy ME, *Effects of Frequency on Annoyance Caused by Motorcycle Noise*, proceedings DAGA 2021 Wien, 2021-08

⁶⁸ Benz S et al., *Motorcycle Noise Study Baden-Württemberg, Part II: Short-term noise annoyance in residents of busy motorcycle routes in the south of Germany*, proceedings 14th ICBEN congress, 2023-06

- license plate registration is subject to privacy regulations
- although significant reduction of annoyance and sleep disturbance is expected, the reduction of long-term equivalent noise levels (L_{den} and L_{night}) is limited; the effect of loud vehicle control will be hardly visible on noise maps as these are based on these long-term indicators

Costs

Approximate costs

- noise camera systems, including license plate recognition: €20.000 - €50.000 per location
- operational and maintenance costs: €2.000 - €5.000 per unit per year
- for semi-automated enforcement: staff time to review flagged noise events

If financial sanctions are instated, a limited number (2 – 10) of daily fines could cover the costs, depending on the height of the sanctions. The net costs of the noise measure would be zero.

Detailed cost calculations

Detailed cost calculations should include the number of measurement stations and estimations of staff costs to check every violation, or sample checking.

Noise modelling

No standardized noise modelling strategy currently exists to incorporate peak events from loud vehicles. Traffic noise calculation models such as END Annex II (CNOSSOS-EU) and national noise assessment methods are based on average annual traffic streams, not including peak noise events from loud vehicles. Motorcycle noise is typically not included in the noise mapping, as traffic data are hardly available.

Modelling the impact of loud vehicles could start with measurement data from remote sensing equipment, providing the number of events per hour/day/year and their levels. To calculate the impact on annoyance and sleep disturbance, regular exposure-response functions such as those in END Annex III do not suffice. Some studies have identified exposure-response functions, for

motorcycles for example, that differ significantly from other road traffic ⁽⁶⁹⁾. Correction factors for tonal and/or impulsive sounds could be relevant to account for this.

Implementation

Considerations

- For enforcement of loud vehicles, cooperation of police or traffic authorities as well as justice departments is required.
- Although reduction of loud vehicle events is effective to reduce complaints, the effect is currently difficult to quantify in terms of noise maps and action plans.
- Some cities and regional authorities have implemented a full or seasonal ban on motorcycles on certain roads, i.e. popular scenic routes, such as the Hautes-Pyrénées Natural Park (FR) and the Tyrol region (AT) ⁽⁷⁰⁾.

Timeline

- Legal processes towards automated enforcement based on local regulations: 6 – 12 months
- Installation of remote sensing equipment for data collection and road user warnings: 3 months

Stakeholders

Traffic police or authorities, justice department, remote sensing system suppliers, homologation / metrology institutions, municipalities and citizen organisations, vehicle user organisations

⁶⁹ Lechner C et al., *Effects of Motorcycle Noise on Annoyance – A Cross-Sectional Study in the Alps*, Int. J. Environ. Res. Public Health, 2020-02-29, <https://www.mdpi.com/1660-4601/17/5/1580>

⁷⁰ <https://www.tirol.gv.at/verkehr/verkehrs-und-seilbahnrecht/motorrad-fahrverbot/motorbike-driving-bans/general-information/>

5. Rail traffic noise measures

5.1. Overview

Railway noise mainly stems from the train wheels rolling over the steel rails, with surface imperfections (roughness) on both wheels and rails leading to vibrations and noise. Noise measures to reduce the noise emissions focus on avoiding and removing the surface imperfections, thereby preventing the rail and wheel vibrations, and on damping these vibrations to reduce the radiated noise.

Table 3 below presents the most important measures to reduce the railway noise emissions. For each measure, a valuation of the different selection criteria is indicated, following the definitions given in § 2.1 above. The values are indicative and based on expert judgment by the authors. Each measure is described in more detail in the separate factsheets below.

Table 3 – Overview of noise measures for railways

with an indication of ratings for each measure on the selection criteria (see § 2.1)

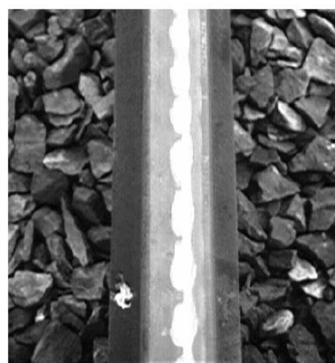
Noise measure	Noise reduction	Costs	Applicability	Scale of impact	Availability	Co-benefits	Constraints	Stakeholder complexity	Maturity	Information level
Acoustic rail roughness control	0	0	1	0	0	0	1	0	0	0
Composite brake blocks on freight wagons	0	0	1	0	1	1	-1	-1	1	1
Low-noise rail pads	1	0	1	1	1	-1	0	0	1	1
Rail dampers	0	0	1	0	1	-1	0	0	0	1
Wheel dampers	0	-1	1	1	0	-1	0	0	1	1

5.2. Rail traffic noise measure fact sheets

5.2.1. Acoustic rail roughness control



Source: M+P
Rail grinding train in action



Source: M+P
Typical corrugated rail pattern

Noise reduction mechanism

For major railways, the rolling noise produced by wheels and rails is the main source of noise emissions for driving speeds from ca. 40 to 200 km/h, although still present and relevant at higher speeds. Small-scale height variations of the railway surface (rail roughness) and wheel running band (wheel roughness) lead to rail and wheel excitation, resulting in noise. Rail roughness increases slowly over time as a result of traffic movements and environmental conditions. Smoothing the running surface of the rail (rail grinding) reduces the rolling noise.

Rail roughness control includes a regular process of rail grinding, which is the technique of smoothing / polishing the rail using moving (rotating) grinding stones. Rail grinding is part of normal rail maintenance to keep the rails in a good condition, which includes an acceptable roughness level. *Acoustic* rail grinding means a further lowering of the roughness to a less-than-average level, with the specific aim to reduce the rolling noise. Acoustic rail grinding focuses on specific longitudinal wavelengths that are relevant for rolling noise. Rather than grinding, the technique of rail milling is also applied, which removes less rail material ⁽¹²⁾. Some suppliers, e.g. ⁽⁷¹⁾ provide high speed grinding (HSG) techniques that can be done during normal rail traffic operations and that aim to eliminate rail defects at an early stage while reducing rolling noise.

Acoustic rail roughness control as a noise measure is only effective if the acoustic grinding is repeated over time (every 1 – 2 years, up to 7 – 8 years

⁷¹ <https://www.vossloh.com/en/products/smart-hsg-2>

depending on location and traffic load) to keep the roughness level low. The grinding interval may be based on rail roughness monitoring by means of measurements.

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	1 – 100 km track length
Typical Materials / Tools	<ul style="list-style-type: none"> specialised rail grinding trains and services are available from several companies in Europe some companies operate high-speed grinding (HSG) trains that may run in normal traffic, at 60 to 100 km/h rail roughness monitoring equipment and services are available: stationary on-track measurements are ISO-standardised; on-board vehicle systems are also available with standardisation in progress ⁽⁷²⁾
Lifespan / Maintenance	<ul style="list-style-type: none"> Acoustic rail roughness control needs to be integrated in a continuous rail maintenance process. The grinding interval to keep rail roughness on a particular section at a lower level ranges from 1 – 2 years up to 7 – 8 years, depending on the traffic intensity, rail construction and environmental factors.
Regulatory Status	No EU regulations specify the rail roughness for normal rail tracks. ISO 3095 ⁽⁷³⁾ does provide reference rail roughness levels for noise test tracks used for rolling stock noise certification.

Effectiveness

Noise reduction

Acoustic rail roughness control reduces railway noise by 1 to 3 dB, depending on the train type, with respect to regular well-maintained railway track. The effect may be larger if the track is in a bad condition before the grinding.

It is the total combined wheel-rail roughness that influences the rolling noise. Therefore, if the wheel roughness of the rolling stock is high, such as for railway wagons with cast iron brake blocks, the effect of acoustic rail grinding will be smaller or negligible. Also, rough wheels will lead to quicker increase of rail

⁷² Europe's Rail Joint Undertaking (ER-JU) project QuieterRail, funded by the European Union, <https://www.quieterail.eu/>

⁷³ ISO 3095:2025, Acoustics — Railway applications — Measurement of noise emitted by railbound vehicles

roughness. Acoustic rail grinding should be combined with measures to limit the wheel roughness.

Impact area

Acoustic rail roughness control leads to a reduction of the noise emission at the source, which has a positive effect on all dwellings near the low roughness track section, even for dwellings further away from the track.

Advantages

- Acoustic rail roughness control can be integrated as part of regular rail maintenance, leading to limited extra costs.
- Acoustic rail grinding, particularly high-speed grinding, is reported as an effective preventive maintenance measure that reduces early damages, leading to longer lifetime of the rails ^(12,74).

Limitations

- Acoustic rail roughness control is only effective for trains with well-maintained wheels, i.e. normal or low wheel roughness. Also, it is not effective if the rail roughness is already at a low level (i.e. below ISO3095 ⁽⁷²⁾ levels).
- The rail grinding itself also generates noise and is typically done at night which increases sleep disturbance. Although grinding is a regular maintenance activity, which will be done anyway, applying it as a noise measure will increase the frequency of grinding episodes, leading to additional annoyance or sleep disturbance.

Costs

Approximate costs

Reported costs for acoustic rail grinding ⁽⁷³⁾ are:

- UIC ⁽⁷³⁾: ca. €6000 per km track per year if acoustic grinding is integrated in a regular maintenance grinding process, and ca. €21000 per km per year if it is done outside such a maintenance process. These values,

⁷⁴ International Union of Railways (UIC), Schwanen W, Peeters B, Lutzenberger S, *Railway Noise in Europe – State of the art report*, https://www.uic.org/IMG/pdf/railway_noise_in_europe_state_of_the_art_report.pdf

from a Dutch 2006 study corrected for price level increase to 2025, assume that grinding is applied to 30 km of track for a period of 10 years in which grinding is repeated every 1 – 3 years;

- UBA ⁽⁹¹⁾: ca. €12500 per track km per grinding episode, corrected to 2025 price level, assuming grinding needs to be repeated every 4 years and not including costs for outservicing regular traffic, if grinding cannot be done in regular out-of-service periods. If a high-speed grinding (HSG) technique is applied, costs are ca. €6400 per track km per year assuming that the HSG is repeated three times per year. HSG is less severe grinding and can be done at 80 km/h, which could be done in regular traffic periods.
- Additional costs are needed for monitoring the rail roughness using on-board or stationary roughness measurements, in order to determine the required grinding interval.

Detailed cost calculations

For cost calculations, it is essential to consider how acoustic roughness control is integrated in existing rail maintenance processes and regimes. Research and tools to quantify costs and benefits for railway track measures, including roughness control, are under development in the European QuieterRail project ⁽⁷¹⁾. Costs will depend on how often grinding needs to be repeated, which depends on the rail traffic volume, particularly freight traffic.

Noise modelling

Calculating the noise emission reduction from lower rail roughness requires values for the rail roughness spectrum (assumed or measured), to be combined with the wheel roughness and train speed. The TWINS model for railway noise calculations is a common tool to perform these calculations. It was developed by the Institute of Sound and Vibration Research (ISVR) who have later integrated TWINS into their Train Noise Expert software ⁽⁷⁵⁾, and is also available at other expert organisations ⁽⁷⁶⁾. The END Annex II (CNOSSOS-EU) rail emission model is very similar to TWINS. Several national noise assessment methods, including those used in NL and DE as well as the Swiss SonRail model ⁽⁷⁷⁾, also have correction factors that can be used to incorporate lowered rail roughness.

⁷⁵ <https://www.trainnoiseexpert.com/details/>

⁷⁶ <https://www.tno.nl/media/2479/twins.pdf>

⁷⁷ https://www.empa.ch/web/s509/sonrail_model_description

Implementation

Considerations

On-board measurement systems to monitor the rail roughness using train-bound systems in normal traffic exist. Standardisation of the measurement methods and open-source tooling to analyse the measurement results are being developed in the QuieterRail project ⁽⁷¹⁾ as well as the UIC project ACORD ⁽⁷⁸⁾. Stationary on-track measurements are standardised ^(72,79), but can only measure short track sections.

Timeline

Initial acoustic rail grinding is an available technique and can be done on short term (3 – 6 months) and will have a noise reduction effect on short notice; directly after grinding there will be a slight increase of rail roughness (i.e. grinding marks) that will disappear after some weeks of rail traffic.

Integration of regular acoustic rail grinding into a rail roughness control and monitoring process will require rail infrastructure managers to develop such a process, align with regular maintenance planning and include roughness monitoring, which will take a longer period (ca. 1 year).

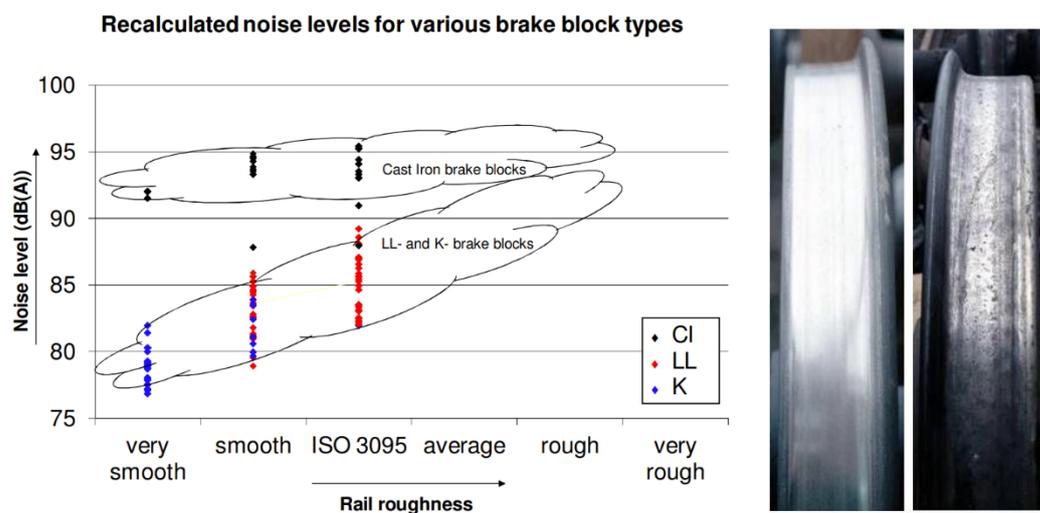
Stakeholders

railway infrastructure managers, rail grinding service companies, rail roughness monitoring suppliers

⁷⁸ <https://uic.org/projects-99/article/acord>

⁷⁹ EN 15610:2019+A1:2025, *Railway applications - Acoustics - Rail and wheel roughness measurement related to noise generation*

5.2.2. Composite brake blocks on freight wagons



Source: UIC ⁽⁸⁰⁾

Noise level for freight wagons with different brake blocks

Source: Deutsche Bahn

Smooth and rough train wheels

Noise reduction mechanism

The roughness of the train wheel running surface (wheel roughness) is an important factor for the rolling noise emission. Older freight wagons are equipped with cast iron (CI) brake blocks pressing on the running surface. High friction temperatures lead to increased wheel roughness, which increases noise. Replacing CI blocks with composite materials (LL- or K-blocks) limits the wheel roughening, leading to lower noise. As the lifetime of rail freight wagons can be several decades, existing brake systems should be replaced (retrofitting).

EU regulation 2019/774 of May 2019 ⁽⁸¹⁾ introduced the 'quieter routes' approach into the Technical Specifications for Interoperability (TSI Noise). This defines sections of the EU rail network, particularly those with more than 12 freight trains per night and exceeding 20 km length, where noisy freight wagons (in practice: those with CI brake blocks) are prohibited. Besides the direct noise reduction on these quieter routes, there is a 'spill-over' reduction on other routes where the same trains run. The regulation came into force in December 2024.

⁸⁰ UIC, de Vos P., *Real noise reduction of freight wagon retrofitting Supporting communication on noise reduction – Synthesis report*, 2013-01-18, https://uic.org/IMG/pdf/md-af20120302_noise_reduction_by_freight_wagon_retrofitting_synthesis_report_update_18012013.pdf

⁸¹ Commission Implementing Regulation (EU) 2019/774 of 16 May 2019 amending Regulation (EU) No 1304/2014 as regards application of the technical specification for interoperability relating to the subsystem 'rolling stock — noise' to the existing freight wagons, 2019-05-16, <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:32019R0774>

In parallel, some Member States have taken other measures to discourage or ban noisy freight wagons. These include unilateral regulatory bans for all such trains, also on non-quieter routes or on routes with considerable day-time freight traffic; in Germany, however, this national regulation was superseded by the EU regulations, so that the quieter routes approach is now in force ⁽⁸²⁾. These also include financial incentives such as noise-differentiated track access charges or bonus/malus systems, or facilitating measures. The German Deutsche Bahn, for example, made a mobile service team available to rail freight operators to replace the cast iron brake system at any location ⁽⁸³⁾.

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	<ul style="list-style-type: none"> • Reduced wheel roughness by CI brake block retrofitting reduces the rolling noise on the whole freight train network, everywhere the freight wagon runs. • Measures will only affect freight wagons running on non-quieter routes, which have limited numbers of night-time freight trains, or quieter routes with significant remaining day-time freight traffic.
Typical Materials / Tools	<ul style="list-style-type: none"> • Composite (K- or LL-type) brake blocks certified for EU railways are available from several manufacturers worldwide. LL-blocks are typically compatible with existing CI-block brake systems, whereas K-blocks require changes to the braking system. • EU funding for retrofitting has been made available through the Connecting Europe Facility (CEF). • Regulations, financial incentives and/or facilitating measures in addition to the TSI Noise quieter routes can be taken to further decrease the number of noisy freight trains, stimulating or requiring freight train retrofitting.
Lifespan / Maintenance	<ul style="list-style-type: none"> • Retrofitting of existing wagons can be done during regular or dedicated freight train brake maintenance work. • The lifespan of the composite brake blocks is longer than for cast iron brake blocks. • Composite brake blocks increase wheel wear, leading to an increase in wheel reprofiling frequency and lower wheel lifespan.

⁸² German Federal Ministry for Digital Affairs and Transport, *Gesetz zum Schienenlärmschutz (SchlärmschG)*, Bundesgesetzblatt Teil I, Nr. 301, 2024-10-10

⁸³ <https://www.db-fzi.com/fahrzeuginstandhaltung-en/Meta/News/aktuelles/For-low-noise-freight-trains-Mobile-service-teams-replace-brake-blocks-at-any-location-7314796>

Property	Value
Regulatory Status	The TSI Noise modified by EU Regulation 2019/774 prohibits noisy freight wagons on the Quieter Routes as of December 2024. More extensive regulatory prohibitions, i.e. a full ban, exist in some EU Member States. The UIC provides certification details as well as a registry of certified composite brake blocks ⁽⁸⁴⁾ .

Effectiveness

Noise reduction

For a single freight wagon with CI brake blocks, retrofitting with composite brake blocks leads to a reduction of the noise emission by ca. 10 dB(A), depending on the rail roughness. The effect on the Lden and Lnight along a rail freight line will be less, depending on the number freight trains and the baseline number of retrofitted wagons. To unlock the full potential, a relatively high percentage of wagons needs to be retrofitted as the noisiest wagons dominate the average level. If 50% of wagons are retrofitted, the long-term noise reduction is limited to ca. 2,5 dB(A) ⁽⁷³⁾.

Other acoustic effects

Smoother train wheels on freight wagons also improve the rail roughness, which may reduce the rolling noise for other freight and passenger trains running on the same tracks.

Impact area

The measure leads to a reduction of rolling noise emissions everywhere the train runs. The noise is reduced at all dwellings within several 100 m track distance.

Advantages

- For individual freight trains the measure is effective everywhere they run, including track sections outside of their geographical scope ('spill-over'). On the fleet level, wide adoption is needed for the measure to be effective.

⁸⁴ UIC CODE 541-4, *Brakes – Brakes with composite brake blocks – General conditions for the certification of composite brake blocks*, Appendix M – Composite brake blocks certified for international traffic, 2025-03-31, https://uic.org/IMG/pdf/20250130-541-4_annex_m-error6.pdf

- Compatible with most existing freight wagons.
- May also reduce rail roughness with positive impact on other traffic.

Limitations

- Composite brake blocks may exhibit lower braking performance under harsh winter conditions. The TSI Noise includes exceptions for rail routes running through such areas until the end of 2032.
- Rare wheelsets, such as tyred wheels, may require replacement of the axles and braking system rather than retrofitting the brake blocks. The TSI Noise includes exceptions for certain Member States, allowing such wheelsets to operate nationally.
- With the further decrease of noisy freight wagons as a result of the revised TSI Noise, the benefit of additional measures may be low and decrease further in the future.

Costs

Approximate costs ⁽⁸⁵⁾

Costs for retrofitting a four-axle freight wagon are collected from several sources and reports ⁽⁷³⁾ ranging from €350 to €9300 for LL-blocks and from €4200 to €15600 for K-blocks , which is a very wide range. Reported values for LL-blocks seem to concentrate around €1750 to €2700. Much higher values may arise for trains where the whole brake system needs replacement, other than just the brake blocks.

The additional costs for maintenance, mainly determined by increase wheel reprofiling needs, are estimated between €0.003 and €0.036 per km for K-blocks and between €0.004 and €0.04 for LL-blocks, with values concentrating around €0.005 to €0.01. These are the additional costs with respect to cast iron brake block systems.

These are the costs for retrofitting by the rolling stock owners. Part of these costs may be transferred to the national railway authorities by means of financial incentives, i.e. to subsidise the retrofitting or by means of a bonus system.

⁸⁵ Costs are corrected for Eurostat price level increase from source publication year to 2025

Detailed cost calculations

More detailed cost estimates could be provided by the rolling stock owners or maintenance service providers. Such cost calculations should include also the reduced lifespan and increased reprofiling of the wheels.

Noise modelling

Noise modelling of the effect of retrofitting can be done with END Annex II (CNOSSOS-EU) which provides default roughness spectra for wheels with cast iron and composite brake blocks, as well as disc brake system. Other modelling tools such as TWINS can also calculate the reduction using the same roughness spectra. The Dutch national method includes separate noise emission categories for CI and for composite brake block freight trains. The German Schall03 model also has a correction factor for the brake type.

Important input parameters for the modelling are the number of wagons to be retrofitted as well as the number of wagons already retrofitted in the baseline scenario.

Implementation

Considerations

- Unilateral or local restrictions on noisy freight wagons in addition to the TSI Noise may lead to legal disputes from train operators or international freight transport authorities.
- Competent Authorities for Noise Action Plans are typically not in direct control of freight train operations and maintenance. Retrofitting will therefore require legal authority over the rolling stock, or financial incentives for rolling stock owners or operators.

Timeline

Implementation of composite brake blocks involves tendering and installation during out-of-service train periods. The timeline to implementation regulatory measures or financial measures could be short, in the order of several months, but it will take a longer period for all freight wagons to be retrofitted.

Stakeholders

railway infrastructure managers, wagon owners, train manufacturers, wagon maintenance service providers, brake block suppliers

5.2.3. Low-noise rail pads



Source: Agico Group
Rail pad example



Source: UIC, LOWNOISEPAD project ⁽⁸⁶⁾
Rail pad under the rail (black)

Noise reduction mechanism

Rail pads are a component of the rail fastening system installed between the rail and the sleeper or the baseplate (for slab track). Rail pads are made of elastic material (e.g. rubber or polymers) and serve to protect the sleeper / baseplate against structural damage by the passing trains. The stiffness of the rail pad is an important factor for the noise radiated by the vibrating rail. A stiffer rail pad allows the vibration energy of the rail to be absorbed by the substructure, leading to a reduction of the rolling noise. This damping of the rail vibrations is expressed and measurable as an increase of the track decay rate (TDR).

Stiff rail pads, such as those made from ethylene-vinyl acetate (EVA) reduce the noise with respect to soft rail pads, but using pads that are too stiff may increase the sleeper / baseplate damage. An optimised rail pad would have a dynamic (frequency-dependent) stiffness behaviour: soft at low frequencies to prevent damage and stiff at higher frequencies to reduce noise. Optimised dampers lead to a further reduction of the rolling noise emission compared to normal soft or stiff rail pads, as demonstrated in the recent UIC project LOWNOISEPAD ⁽⁸⁵⁾.

Key Characteristics

Property	Value
Type of Measure	source

⁸⁶ UIC International Union of Railways, Optimised Rail Pad Performance for Noise Reduction: Outcomes and Recommendations – LOWNOISEPAD Final Report, 2023-10, https://uic.org/IMG/pdf/lownoisepad_optimised_rail_pad_performance_for_noise_reduction_final_report.pdf

Property	Value
Typical Scale / Dimensions	<ul style="list-style-type: none"> • Rail pads could be applied as an effective local noise measure over several 100 m length. • In practice, infrastructure managers will apply a certain rail pad type over larger parts of the network (5 – 100 km), or everywhere.
Typical Materials / Tools	<ul style="list-style-type: none"> • Stiff rail pads are generally available across Europe from several rail pad suppliers. • Optimised rail pads for further noise reduction exist and were a topic of investigation in LOWNOISEPAD. As results were anonymised, the market availability of such pads is unclear. • Rail pads require manual or machine-assisted installation by track workers.
Lifespan / Maintenance	Rail pad lifetime could be 10 – 15 years depending on traffic volume, location (i.e. in track curves) and weather conditions (i.e. sunlight), but evidence is limited.
Regulatory Status	Track Decay Rate (TDR) measurement methods are defined in EN 15641 ⁽⁸⁷⁾ . Pad stiffness definitions are found in EN 17495 ⁽⁸⁷⁾ .

Effectiveness

Noise reduction

According to UIC ^(72,85):

- optimised rail pads: 2 – 5 dB compared to regular soft pads, and 1.5 - 2.5 dB compared to regular stiff pads;
- regular stiff pads: ca. 2 – 3 dB compared to regular soft pads.

Rail pads decrease the noise mainly in the mid-to-high frequency range (500 Hz – 2 kHz). For high-speed railways, a smaller or no effect is reported ⁽⁸⁵⁾.

Other acoustic effects

Stiffer rail pads transfer part of the vibration energy from the rail to the sleepers. This may lead to a slight increase of noise radiated by the sleepers and substructure, in the low-frequency range (< 500 Hz). However, heavy concrete sleepers or slabs radiate much less sound than steel rails, therefore this increase is considerably smaller than the reduction obtained from lower rail emissions.

⁸⁷ EN 17495:2022, *Railway Applications: Acoustics – Determination of the dynamic stiffness of elastic track components related to noise and vibration: Rail pads and rail fastening assemblies*

Impact area

Low-noise rail pads lead to a reduction of the noise emission at the source, which has a positive effect on all dwellings near the low roughness track section, even for dwellings further away from the track.

Advantages

- No visual intrusion

Limitations

- Requires manual or machine-assisted installation by track workers during track maintenance period.
- (Too) stiff rail pads can increase sleeper or slab damage and maintenance.
- Stiffer rail pads may not be compatible with rail tracks embedded in concrete substructures, such as common for high-speed rail lines (e.g. Rheda-type tracks).

Costs

Approximate costs

No detailed costs for rail pads could be found in literature. According to UIC, stiff and soft rail pads show no significant difference in life cycle costs, and increased life cycle costs for optimised pads should not be an issue ⁽⁸⁵⁾. There is, however, little long-term data on optimised rail pad lifetimes.

Detailed cost calculations

Detailed cost calculations should include actual prices and lifecycle information from suppliers and/or infrastructure managers. As only the material properties are different, installation costs are expected to be the same for stiff, optimised and soft rail pads, assuming the replacement is done during regular maintenance.

Noise modelling

The noise reduction from low-noise rail pads can be calculated from the increase of the track decay rate (TDR, expressed in dB/m), with higher TDR

leading to higher reductions ⁽⁸⁵⁾. As a first approximation the noise reduction $\Delta L = -10 \log_{10}(TDR2/TDR1)$, where TDR2 is for the low-noise pads and TDR1 for the reference pads. This calculation should be done as a function of the sound frequency. However, a more accurate equation taking into account the wheel contribution is preferred ⁽⁸⁵⁾. TDR values could come from measurements ⁽⁸⁷⁾, literature or manufacturer values. Reference values are given in ISO3095 ⁽⁷²⁾.

END Annex II (CNOSSOS-EU) allows calculation of rail noise emissions for different track types and includes default frequency-dependent values for soft, medium stiff and hard rail pads. For non-standard, i.e. optimised rail pad stiffness, custom transfer functions should be developed based on TDR measurements or modelling. Railway infrastructure managers could initiate such measurement research, but coordinated research by the European Commission or the UIC is recommended as this would be more efficient.

Implementation

Considerations

- Selection of the optimal rail pad for a given track type and substructure will require preparatory research which may include modelling or measurements. Expertise should be sought from other EU rail infrastructure managers or from the UIC.
- For rail tracks already equipped with stiff rail pads, the reduction by application of optimised pads may be limited. Also, on rail tracks that already have low TDR, such as tracks equipped with rail dampers, the reduction of optimised pads will be lower.

Timeline

- 3-6 months for preparatory research.
- > 3 months for planning and installation. The installation will need to be planned within regular track maintenance work, which has a longer time interval than 3 months, or it would come at considerable additional costs.

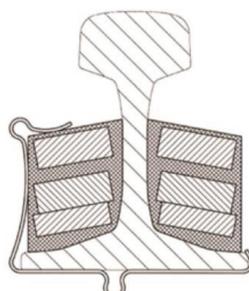
Stakeholders

railway infrastructure managers, rail pad suppliers, maintenance workers, and rail noise experts for track decay rate measurements and acoustic modelling

5.2.4. Rail dampers



Source: Tata Steel
SilentTrack® tuned rail dampers



Source: UIC
Measurements with S&V rail dampers

Noise reduction mechanism

Wheel/rail interaction forces lead to vibration of the wheels and rails, which causes rolling noise emissions. The vibrations of the rail can be reduced by rail dampers. These are tuned mass-spring-damper elements attached to the side of the rail, that are able to absorb vibration energy from the rail, reducing the radiated noise. Using other terminology, these rail dampers increase the track decay rate (TDR), which means that rail vibrations die out more quickly, reducing the overall noise levels.

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	<ul style="list-style-type: none"> • Rail dampers can be applied on a local scale, near noise-sensitive areas (100 m – several km) • The source emissions are reduced, affecting all nearby areas within several 100 m lateral distance from the track
Typical Materials / Tools	<ul style="list-style-type: none"> • Multiple suppliers of rail dampers exist in Europe • Rail dampers are manually installed directly on the rail track, with installation speeds up to several 100 m per hour
Lifespan / Maintenance	<ul style="list-style-type: none"> • Manufacturers claim up to 25 years of lifespan, but not much evidence is currently available • Rail dampers are usually clamped or bolted onto the rails, making them individually removable and often reusable in case of rail replacements • The dampers do not require maintenance, other than inspection followed by replacement in case of breakdown • Rail dampers are designed not to hamper regular rail maintenance (i.e. rail grinding or ballast tamping). Ballast tamping and ploughing can damage the rail dampers, requiring partial replacements.

Property	Value
Regulatory Status	Track Decay Rate (TDR) measurement methods are defined in EN 15641 ⁽⁸⁸⁾ .

Effectiveness

Noise reduction

Rail dampers may reduce the rolling noise by up to 3 dB with exceptional higher values reported. If the track decay rate is already high, such as for rails with high rail pad stiffness, the added effect of rail dampers is low or negligible.

Rail dampers are not very effective at low frequencies (< 400 Hz). Consequently, in situations where low frequencies are relatively important, such as at large distance (several 100 m or more) from the track or for receivers behind a noise barrier, the noise reduction will be lower.

Impact area

Rail dampers lead to a reduction of the noise emission at the source, which has a positive effect on all dwellings near the low roughness track section, even for dwellings further away from the track.

Advantages

- Can be installed on a local scale, near noise hot-spot locations
- No visual intrusion
- Lower rail vibrations could decrease rail wear

Limitations

- Noise reduction is limited in combination with stiff rail pads or high wheel roughness
- Requires manual installation labour and full track access
- Depending on the rail inspection system, rail dampers prevent automated scanning and identification of the rail wear

⁸⁸ EN 15461, Railway applications – Noise emission – Characterisation of the dynamical properties of track sections for pass by noise measurements

- For application in curved track, safety problems are reported due to corrosion and cracks below the railhead

Costs

Approximate costs

The costs for rail dampers are estimated between €260 and €400 per meter of track, price level 2021 ⁽⁷³⁾.

Detailed cost calculations

A main factor influencing the costs is the availability of train-free periods available for track installation of the rail dampers.

The presence of rail dampers may also increase maintenance costs in case of rail replacement, as it takes time to remove and remount the dampers. Additionally, as rail dampers hamper automated rail inspection techniques (scanning), manual or alternative inspections need to be performed leading to higher costs. When applied in tighter curves, additional inspections, e.g. using ultrasonic measurements, should be done to detect railhead cracking.

Noise modelling

Modelling the effect of rail dampers requires in-depth expertise and modelling tools such as TWINS, RIM or the STARDAMP software tool ^(89,90). As input, it requires values for the track decay rate, which can be obtained from manufacturers or track measurements ⁽⁸⁷⁾. As a result, adapted noise emission factors for noise assessment modelling, or adapted track transfer functions for TWINS and CNOSSOS-EU approaches, should be developed. No default values for rail damped tracks are given for CNOSSOS-EU. Several national noise assessment methods do provide default values for rail damped tracks.

⁸⁹ Betgen B et al., *The STARDAMP Software: An Assessment Tool for Wheel and Rail Damper Efficiency*, proceedings DAGA 2013 conference, 2013-03

⁹⁰ Toward M et al., *Estimating the performance of rail dampers using laboratory methods and software predictions*, Proceedings of the 11th International Workshop on Railway Noise, 2013-09

Implementation

Considerations

Design specifications or standards for rail dampers are not available. Limitations mentioned above should be considered. Rail damper performance could be specified and tested by prescribing the desired maximum track decay rate. Track decay rate measurements are specified in EN 15461 ⁽⁸⁷⁾.

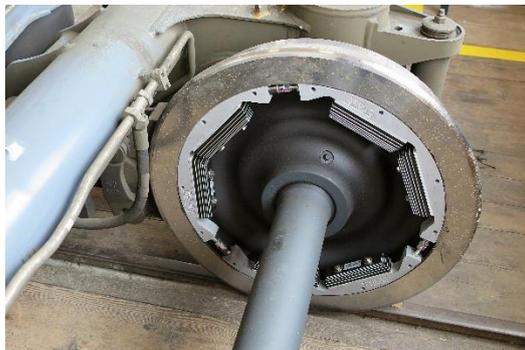
Timeline

Implementation of rail dampers involves acoustic planning, tendering, installation planning in train-free periods, and installation steps. In total, 6 – 12 months would be needed.

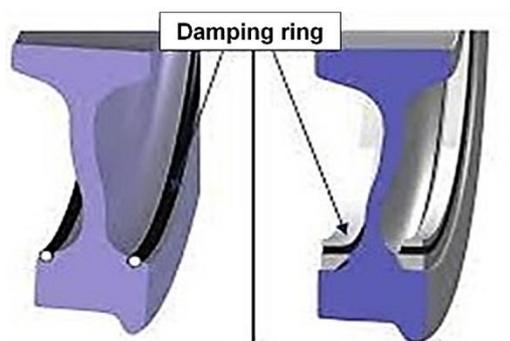
Stakeholders

railway infrastructure managers, rail damper suppliers and installation service providers, rail noise experts for track decay rate measurements and acoustic modelling

5.2.5. Wheel dampers



Source: Wikipedia
Example of wheel damper



Source: Koizumi S. ⁽⁹¹⁾
Wheel with noise-damping ring

Noise reduction mechanism

Wheel/rail interaction forces lead to vibration of the wheels and rails, which causes rolling noise emissions. The vibrations of the wheel can be reduced by

⁹¹ Koizumi S., *Advance in Railway Vehicle Technology and Future Prospects Mainly in Relation to Bogie*, Nippon Steel & Sumitomo Metal Technical Report No. 105, 2023

wheel dampers. These are tuned mass-spring-damper elements that are able to absorb vibration energy from the wheel, reducing the radiated noise. The concept of wheel dampers is similar to rail dampers but optimised for wheel mounting and tuned to the specific resonances of the wheel. Different types of wheel dampers exist, such as damper blocks, rings or discs.

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	Wheel dampers are installed on all wheels of a wagon, and then reduce the rolling noise everywhere the wagon runs. The measure is effective for dwellings within several 100 m lateral distance to the track.
Typical Materials / Tools	<ul style="list-style-type: none"> • Several suppliers of wheel dampers exist in Europe • Wheel dampers are typically retrofitted on existing freight or passenger wagons, including urban / light rail vehicles
Lifespan / Maintenance	15 – 20 years
Regulatory Status	-

Effectiveness

Noise reduction

Wheel dampers may reduce the overall rolling noise levels by up to 5 dB. They are particularly effective to reduce curve squeal noise, reducing the noise peak by up to 10 – 15 dB in some cases.

The effect on Lden and Lnight levels depends on the baseline, the number of trains installed with wheel dampers, and the track condition. For optimal effect, all wagons on a train and all wheels on each wagon should be equipped with wheel dampers.

Other acoustic effects

Rolling noise reduction, and squeal noise reduction in particular, is also beneficial for indoor train noise and passenger comfort.

Impact area

Wheel dampers reduce the rolling noise everywhere the damped wagons run, although the height of the reduction depends on local conditions.

Advantages

- Effective everywhere, particularly effective to combat curve squeal
- Also works for urban and light rail trains
- Reduced wheel vibrations may reduce wheel wear, increasing its lifetime

Limitations

- Wheel dampers can only be installed by rail vehicle owners. Local authorities only have control over locally operated vehicles. For national rail authorities, financial incentives or regulations may be needed to persuade or oblige international passenger and freight operators to use wheel damped train wagons.
- Wheel dampers are mostly used on wheels with disc-braked axles, such as on light rail and (high-speed) passenger trains. They are not applicable when the brake discs are mounted on the wheel, which is common for powered axles on locomotives.
- For freight trains with tread block braking systems, wheel dampers are uncommon. Also, as freight trains may contain wagons from different cargo operators, it is even more complex to ensure that large numbers of wagons are equipped with wheel dampers. Within a freight train, a small number of noisy (non-wheel damped) wagons may dominate the train noise.
- Wheel dampers hinder technical wheel inspections, e.g. to identify cracks or coating discolouring.

Costs

Approximate costs

Purchase and installation costs for wheel dampers are estimated at €10000 to €32000 for a wagon with four axles (price level 2016, corrected to 2025) ^(73,92). Maintenance costs are estimated at €250 to €500 per wagon per year ⁽⁹¹⁾.

⁹² Umweltbundesamt, Strategien zur effektiven Minderung des Schienengüterverkehrslärms, report no. 19/2017, March 2017, <https://www.umweltbundesamt.de/publikationen/strategien-zur-effektiven-minderung-des>

Detailed cost calculations

The lower price range given above assumes application of wheel dampers on a large scale, using dampers that can be installed on existing wheels. The higher price range is for smaller scale application or for wheel dampers that require replacement of the wheel set.

Noise modelling

Modelling the effect of rail dampers requires in-depth expertise and modelling tools such as TWINS, RIM or STARDAMP ⁽⁸⁸⁾. For modelling with END Annex II (CNOSSOS-EU), transfer function values for damped wheels are not provided and need to be developed using such tools and input data from measurements (e.g. ISO3095 ⁽⁷²⁾) or manufacturer specifications. Some national noise assessment methods do provide calculation options for passenger and/or freight wagons with damped wheels, but these are not compatible with CNOSSOS-EU.

Implementation

Considerations

- Design specifications or standards for wheel dampers, e.g. for tendering purposes, are not available. Technical data rely on manufacturer specifications.
- Competent Authorities for Noise Action Plans usually do not own or control the rolling stock, preventing them from mandating modifications such as wheel dampers. Implementation therefore requires legal authority over rolling stock and/or financial incentives for rolling stock owners.

Timeline

Implementation of rail dampers involves tendering and installation during out-of-service train periods. The timeline to implementation is short, in the order of several months, assuming that the wheel dampers are available in high enough quantities.

Stakeholders

wagon owners, train manufacturers, wagon maintenance service providers, authorities for wheel damper certification, and rail noise experts for track decay rate measurements and acoustic modelling

6. Aircraft noise measures

6.1. Overview

6.1.1. Balanced Approach

Aircraft noise from major airports falls within the scope of the END and consequently requires five-yearly updates of the NAP, including noise measures to prevent negative impacts. Aircraft noise at the same time is also subject to EU Regulation 598/2014⁽⁹³⁾ which is the European regulatory implementation of the ICAO Balanced Approach to Aircraft Noise Management⁽⁹⁴⁾. Aircraft noise measures are categorised in the Balanced Approach using four pillars:

1. Reduction of noise at source, by the introduction of noise standards for aircraft certification, and by encouraging the use of quieter aircraft such as by introducing financial incentives. These noise standards are described in successive Chapters in the ICAO Annex 16 Volume 1⁽⁹⁵⁾;
2. Land-use planning and management, ensuring that residential areas and other noise-sensitive buildings are not within areas severely affected by aircraft noise, such as by introducing noise zones around airports, and by acoustic insulation measures to exposed dwellings;
3. Noise abatement operational procedures, to minimise the noise emitted by aircraft during landing and take-off operations;
4. Operating restrictions to limit operations for all aircraft or for noisier aircraft types, including night curfews. Operating restrictions are last-resort measures, only to be taken after all other measures have been implemented or considered.

⁹³ Regulation (EU) No 598/2014 of the European Parliament and of the Council of 16 April 2014 on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Union airports within a Balanced Approach, 2014-06-12, <https://eur-lex.europa.eu/eli/reg/2014/598/oj/eng>

⁹⁴ ICAO Resolution A41-20: Consolidated statement of continuing ICAO policies and practices related to environmental protection — General provisions, noise and local air quality, 2001, https://www.icao.int/sites/default/files/sp-files/environmental-protection/Documents/Resolution_A41-20_General_provisions_noise_and_LAQ.pdf

⁹⁵ ICAO Annex 16 to the Convention on International Civil Aviation – Environmental Protection, Volume I – Aircraft Noise, Eighth Edition, 2017-07

The aircraft noise measures in this chapter mainly focus on Pillars 3 and 4 of the Balanced Approach.

Source reduction by new noise standards (Pillar 1) is outside of the scope of NAPs and generally not within control of the NAP Competent Authorities. Several airports do however have restrictions or higher financial charges for older, noisier aircraft based on noise standards published by ICAO.

Land-use planning and management (Pillar 2), including noise zoning and building insulation measures, are covered in Chapter 7 of this report as such measures also apply to other noise sources (road, rail and industry).

6.1.2. Selected aircraft noise measures

In this technical support document, priority is given to those noise reduction measures that are or can be commonly used by CAs in their NAPs, and for which enough information is available to provide complete fact sheets. For aircraft noise, this selection has been based on an analysis of which noise measures have been commonly adopted by several major airports in the EU, and that have a significant positive effect on the noise impact if implemented correctly. The analysis is built upon earlier results from the ANIMA and Phenomena projects, with additional input from the literature review.

Other noise measures exist that are currently not included, because insufficient information was available or for which the expected noise reduction is limited. Such measures could be included in a future document revision or expansion, when more information becomes available. Not excluding other measures, these include for instance climb operations other than NADP1/2, single-engine taxiing procedures, and ground run-up restrictions.

Restrictions (forced phase-out) of older aircraft, that do not comply with more recent ICAO noise standards ⁽⁹⁴⁾, is not included as a noise measure fact sheet. Such phase-out measures are considered as operating restrictions under Pillar 4 of the ICAO Balanced Approach and require notification to the European Commission possibly followed by scrutiny of the procedures. There are several airports that have financial incentive schemes in place based on the ICAO standards, such that higher take-off and landing charges are applied to older, noisier aircraft. Such financial incentives are not presented as a fact sheet within the current scope of this technical support document.

Table 4 below presents the selected measures to reduce aircraft noise emissions. For each measure, a valuation of the different selection criteria is indicated, following the definitions given in § 2.1 above. The values are indicative and based on expert judgment by the authors. Each measure is described in more detail in the separate factsheets below.

6.1.3. Ground-borne and drone noise

In addition to noise measures under the Balanced Approach, sections § 6.2.7 to § 6.2.9 below include measures to reduce ground-borne airport noise, i.e. aircraft activities on the ground, such as taxiing.

Lastly, section § 6.3 of this Chapter provides technical support for noise from unmanned aircraft (drones). It does not contain specific noise measures described in fact sheets, but provides a more general description of regulations, measurement and modelling methods and recommendations for NAPs.

Table 4 – Overview of measures for aircraft noise

with an indication of ratings for each measure on the selection criteria (see § 2.1)

Noise measure	Noise reduction	Costs	Applicability	Scale of impact	Availability	Co-benefits	Constraints	Stakeholder complexity	Maturity	Information level
Noise Abatement Departure Procedures	0	0	1	0	1	-1	0	1	1	1
Continuous Descent Operations	0	1	1	0	1	0	1	0	1	1
Lower Power or Lower Drag approach profiles	0	0	1	0	1	0	0	0	1	0
Flight track dispersion or concentration	1	0	0	1	1	0	-1	-1	1	0
Preferential runway use	0	0	0	0	1	-1	0	0	1	1
Airport curfews	1	0	0	1	1	0	-1	-1	1	1
Reverse thrust use restrictions	0	0	0	0	1	-1	0	0	1	1
Restrictions for auxiliary power units	1	0	0	-1	1	0	0	0	1	0
Aircraft towing instead of engine taxiing	1	-1	0	-1	1	0	0	-1	1	0

6.1.4. General considerations

Each of the fact sheets below on individual measures describes their advantages and limitations. But in general, it is advised to take the following points into consideration:

- Any noise reduction measure that affects operational procedures, such as changes to horizontal flight paths or to take-off and landing profiles,

may have other environmental impacts, in particular on **fuel burn, local air quality around airports**, and the **CO₂ footprint**. Close to airports, flight procedures are already often designed to minimise noise impacts on surrounding communities, for example through non-straight SIDs and STARs ⁽¹⁰⁷⁾, even if this is not optimal from a fuel efficiency perspective.

- Many noise abatement measures can **go hand in hand with reduced fuel consumption**, particularly those based on lower engine power and smoother profiles, such as continuous descent operations. However, **other noise measures may increase fuel use**, depending on local conditions and operational constraints. These can include certain noise abatement departure procedures, as well as airport curfews, which may require aircraft operators to increase flight speeds in order to land within the permitted time window. As a result, noise reduction measures often need to be **balanced against other environmental impacts**.
- Noise measures may also affect airport capacity, either **directly**, by limiting the number of flights, or **indirectly**, by reducing the efficiency of air traffic management. Some operational measures, such as reduced reverse thrust braking, can increase separation requirements between aircraft, which may reduce runway throughput under specific conditions. Where capacity constraints arise, airlines may shift part of their operations to other nearby airports, potentially leading to a **redistribution of noise impacts** rather than an overall reduction.

Due to these potential consequences, noise reduction measures need to be carefully balanced against other airport requirements. Some airports have organised a dedicated stakeholder group around environmental topics, which enables a wider decision-making process. This is a general recommendation that other airports should consider.

6.1.5. Costs for noise measures

Determining the exact costs associated with the implementation of operational noise mitigation procedures and other noise measures presents a significant methodological challenge. Publicly available sources generally do not provide a detailed cost breakdown for individual noise measures for the following reasons:

- Airports and air navigation service providers implement optimised operational measures; however, the associated cost information is mostly internal, commercially sensitive, and typically not disclosed separately for each procedure.
- Operational procedures are generally assessed within the framework of broader NAPs or Balanced Approach assessments, in which costs can only be estimated indirectly.

- Even where cost-effectiveness analyses have been conducted (for example, at Schiphol Airport), specific cost figures for individual operational procedures are not published.

Accordingly, for the purposes of this document, reliance is placed primarily on indirect cost estimates, evidence from comparable projects (Phnomena, ANIMA, etc.), and findings from available studies and documented implementation examples.

In addition, publicly available data on airport noise management expenditures may be used to support or contextualise the cost ranges presented in the fact sheets. While detailed cost data for individual noise mitigation measures are uncommon in NAPs, airports do publish summary budgets or annual cost estimates for noise mitigation activities. Although such figures are not attributable to specific measures, they represent actual costs reported in NAPs and relate to comparable noise management activities, including procedure assessment, monitoring, staffing, and stakeholder or community engagement. These data may therefore be used as real-world airport examples to demonstrate that the cost ranges proposed in this document are reasonable and practicable in an operational context.

Annex A in this report contains tables listing reported costs or cost indications for several EU and UK airports in various categories, such as building insulation programmes, noise monitoring & track keeping systems, airspace change and noise management actions. This annex shows the information that is typically available in NAPs and other public sources. The number of UK airports included is relatively high, because the literature review revealed that their NAPs generally contain more specific information about costs separatable in categories.

6.1.6. Further documentation

In addition to the information on aircraft noise reduction in this technical support document, the following sources are recommended:

- The EU-funded project ANIMA ⁽⁹⁶⁾ running from 2017 to 2021 has developed a Noise Platform that includes a noise management toolkit as well as documentation of good practices of implemented noise measures at various airports. The successive EU-funded PULSAR ⁽⁹⁷⁾ project aims to create a European platform for environmental aviation. The PULSAR website provides valuable information on noise interventions, available through <https://www.pulsar-project.eu/noise-platform>.

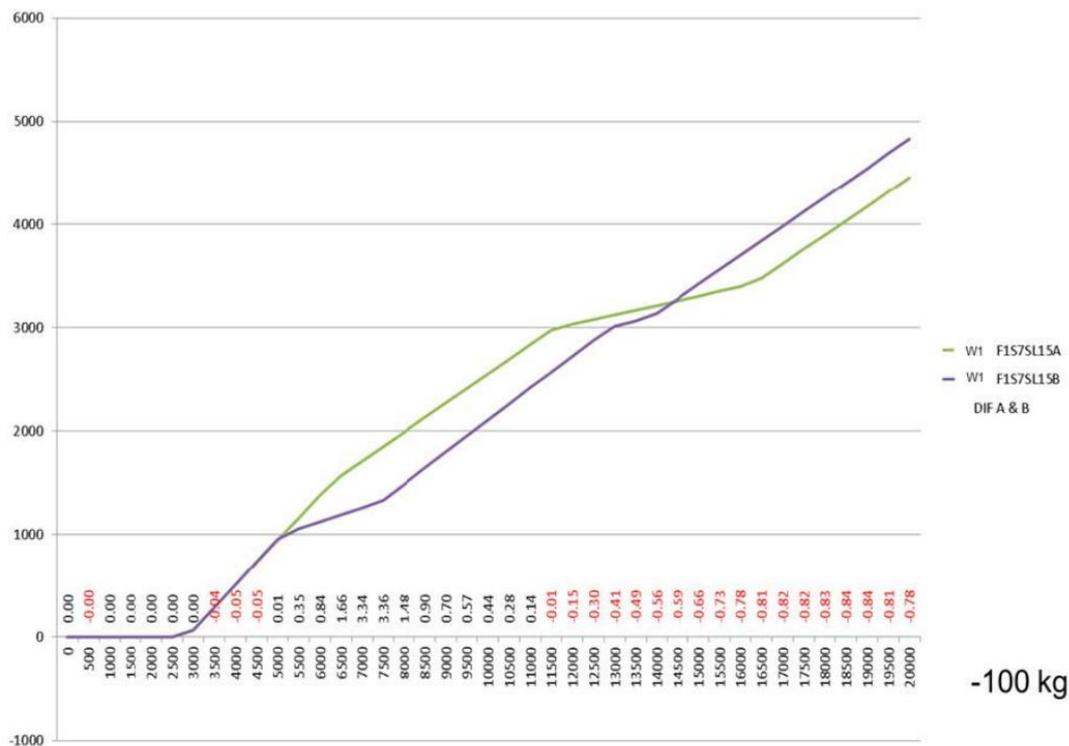
⁹⁶ ANIMA: Aviation Noise Impact Management through Novel Approaches

⁹⁷ PULSAR: Propelling eUropean Leadership through Synergizing Aviation Research

- The noise management toolset (NMT) developed in ANIMA can be used for simple comparisons of noise intervention scenarios in terms of noise indicators (e.g. L_{den} and L_{night}) and number of people exposed, which can help the decision-making on airport noise measures. NMT is available as an online tool, with a public toolset available for demonstration and educational purposes, as well as a commercial version available for airport authorities. It is available through <https://nmt.anotec.es/>.
- The Phenomena study report ⁽¹²⁾, which has been a source of information for this technical support document in general, provides a list of noise measures also for aircraft noise, with indications of the benefit-cost ratio resulting from simulations or various scenarios.

6.2. Aircraft noise measure fact sheets

6.2.1. Noise Abatement Departure Procedures (NADP1 and NADP2)



Source: EUROCONTROL ⁽¹⁰²⁾

NADP2 vs. NADP1 profiles for wide body aircraft, with thrust reduction after clean

Noise reduction mechanism

NADP1 and NADP2 modify thrust reduction, acceleration, and flap retraction points during aircraft take-off. Both rely on modifications to thrust and flap

schedules, reducing overall Sound Exposure Levels (SEL) for affected communities. Both NADP1 and NADP2 reduce noise compared to non-NADP operations. The two procedures are optimised for different target areas:

- **NADP1** reduces noise near the airport by delaying flap retraction and reducing thrust at a higher altitude.
- **NADP2** allows earlier acceleration and flap retraction, reducing noise further along the departure path.

Property	NADP1	NADP2
<i>thrust reduction height</i>	higher	lower
<i>acceleration point</i>	later	earlier
<i>flap retraction</i>	delayed	sooner
<i>focus area</i>	close-in noise-sensitive zones	distant noise-sensitive areas
<i>community affected</i>	those near runway ends	those under climb-out paths

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	Effective at horizontal distances from the runway of 0 – 6 km for NADP1 and > 6 km for NADP2
Typical Materials / Tools	<ul style="list-style-type: none"> • Aeronautical Information Publications (AIP) with recommendations or requirements for NADP1 or NADP2 use • Potential compliance monitoring and penalties • Communication and awareness campaigns towards aircraft operators / airlines
Lifespan / Maintenance	-
Regulatory Status	EU Regulation 598/2014 ⁽⁹²⁾ implements the ICAO Balanced Approach to Aircraft Noise Management ⁽⁹³⁾ in which noise abatement operational procedures are generally included. The NADP1 and NADP2 procedures are separately described in ICAO Doc 8168 ⁽⁹⁸⁾ .

Effectiveness

Noise reduction

NADP1 for a single flight provides 5 to 8 dB(A) reduction (L_{\max} or *SEL*) near the runway (within 6 km), affecting areas near the airport boundaries. NADP2 provides 3 to 6 dB(A) reduction beyond 6 km distance from the runway, to areas

⁹⁸ ICAO Doc 8168, *Procedures for air navigation services – Aircraft Operations: Volume II – Flight Procedures*, Seventh Edition, 2020, and *Volume III – Aircraft Operating Procedures*, First Edition, 2018

under the departure paths. The total reduction for a single flight depends on the aircraft type. The overall reduction on community noise exposure (L_{den} / L_{night}) depends on the level of compliance by all airport operators.

NADP1 and 2 are quite commonly adopted by airports: among case studies from the ANIMA project ⁽⁹⁵⁾, Helsinki and Amsterdam Schiphol airport are mentioned as examples where it is implemented, stating for instance that 80% of all Schiphol departures follow NADP2.

Advantages

- **Cost-effective:** No need for new infrastructure. Quick implementation with measurable results.
- **Flexible:** Aircraft operators do not always have full discretion in selecting Noise Abatement Departure Procedures (NADPs), as a specific procedure (e.g., NADP1) may be mandated or recommended in national AIPs or by airport authorities. Operators often prefer NADP2 for fuel efficiency, but actual use is determined by published procedures and regulatory approval. Where NADPs are dynamically designed to address local noise concerns, procedures can be adapted for specific communities, but all procedures must comply with ICAO PANS-OPS and regulatory requirements.
- **ICAO-compliant:** Fits into Balanced Approach to noise management.
- **Community Support:** Can be used to address complaints from specific neighbourhoods.

Limitations

- **Operational Impact:** Slight increase in fuel burn and time to climb, depending on the procedure. NADP1 burns more fuel than NADP2, with an average difference of 150 kg per flight ⁽¹⁰²⁾. Requires consistent compliance from all operators.
- **Operational Responsibility:** With the introduction of NADP1/2 in ICAO Doc 8168, the aircraft operator rather than the airport is deemed responsible for deciding the exact altitude and speeds. The actual noise reduction and effective distance from the airport therefore depends on the operator, based on aircraft type / weight and meteorological conditions.
- **Monitoring** of actual operator behaviour and command & control measures may be needed to ensure compliance with the procedures.
- **Airspace Integration:** Needs careful coordination with air traffic control and other departure procedures.

- **Weather Constraints:** Noise Abatement Departure Procedures (NADP1 and NADP2) may be limited in effectiveness under adverse meteorological conditions, but this does not make the procedures themselves impossible to fly. According to ICAO PANS-OPS (Doc 8168), noise abatement is not required when runway contamination, low visibility, or strong winds affect safety or aircraft performance. In such conditions, the departure procedure remains authorised, but the full noise benefit may be reduced.

Costs

Costs for introduction of improved flight profiles such as NADP include:

- **Development:** €10,000–€50,000 (procedure design, modelling, stakeholder coordination), given typical aviation procedure consultancy rates and the expected scope of work based on experience;
- **Training:** €2,500–€10,000 per airline/operator, based on a typical course fee around €1,250 ⁽⁹⁹⁾ and several participants;
- **Monitoring systems:** €50,000+, if noise monitoring and compliance tracking are added, based on experience with existing solutions.

In the Phenomena study report ⁽¹²⁾ table 5.8, implementation costs for improved flight profiles, including NADP among other noise-optimised procedures, are estimated to be 100 M€ as a total for the EU27, plus 25 M€ per year for training. The report also mentions significant cost reductions (150 M€/year) from fuel savings.

See section § 6.1.5 for general remarks and limitations to these cost figures.

Detailed cost calculations

Detailed cost calculations need to take into account the airport size, airspace complexity and the number of operators.

Noise modelling

To support noise impact assessment, ECAC Doc29 ⁽¹⁰⁰⁾ provides the common calculation method for aircraft noise, which is implemented in the IMPACT

⁹⁹ <https://aaltronav.eu/training/courses/NABT>

¹⁰⁰ European Civil Aviation Conference / Conference Européenne de l'Aviation Civile (ECAC.CEAC) Doc 29, *Report on Standard Method of Computing Noise Contours around Civil Airports*, Volume 1 & 2, 4th Edition, 2016-12-07

calculation tool provided by EUROCONTROL. Internationally, ICAO Doc 9911 ⁽¹⁰¹⁾ and the Aviation Environmental Design Tool (AEDT) ⁽¹⁰²⁾ are used, Fwhich are equivalent. Noise modelling requires:

- **Model scenarios:** compare NADP1, NADP2 with standard procedures
- **Input data** required include aircraft performance, meteorology, population distribution
- **Validation** could be done with ground noise measurements and community feedback

Noise and Track Keeping (NTK) systems can be used for monitoring, verification and public engagement.

Implementation

Considerations

Most airports still impose NADP1, even though NADP2 is on average more fuel-efficient. The optimal configuration depends on aircraft type, weight and meteorological conditions. Therefore, a dynamic allocation between NADP1 and NADP2 should be encouraged. Eurocontrol and ICAO advise that the aircraft operator should be enabled to make a choice between the two ⁽¹⁰³⁾.

Implementation details will depend on:

- the runway and airspace configuration
- the fleet mix, e.g. narrow-body vs. wide-body aircraft, legacy vs. newer aircraft
- operational constraints vs. noise reduction objectives
- support from the public as well as the airlines, and training for aircraft operators; in principle, no changes to air traffic control (ATC) procedures are needed.

¹⁰¹ ICAO Doc 9911, *Recommended Method for Computing Noise Contours Around Airports*, 2nd Edition, 2018

¹⁰² <https://aedt.faa.gov/>

¹⁰³ Hoyas F, EUROCONTROL, *Revisiting Noise Abatement Departure Procedures (NADP) Application*, in: ICAO, *2025 Environmental Report – Skyward Action: Realizing Aviation’s Sustainable Future*, Chapter Ten: Aircraft Noise, 2025, https://www.icao.int/sites/default/files/sp-files/environmental-protection/Documents/EnvironmentReport-2010/2025/Envreport2025_94.pdf

EUROCONTROL has published a contribution to the ICAO 2025 Environmental Report, describing details of NADP1 and NADP2 on the noise reduction and the trade-off with fuel burn ⁽¹⁰²⁾.

Constraints

- Fixed procedures do not fit all aircraft: performance varies by aircraft type, weight, and daily atmospheric conditions, so a single imposed NADP is often inefficient.
- Some airports currently impose outdated or prescriptive NADPs without considering the traffic mix or actual noise-sensitive areas.
- Operators often lack proper tools and detailed manufacturer data, limiting their ability to select the optimal procedure for each departure.
- Some Member States have constraints at the national governance level, e.g. Aeronautical Information Publications (AIPs) imposed by the national aviation authority, or other national government policies. Removing or adapting these to allow NADP1 or NADP2 based on the current situation is recommended.

Timeline

- 0–3 months: Noise assessment and community analysis
- 3–6 months: Procedure design and modelling
- 6–9 months: Stakeholder consultations and training
- 9–12 months: Pilot implementation and monitoring
- 12 months: Full rollout and periodic review

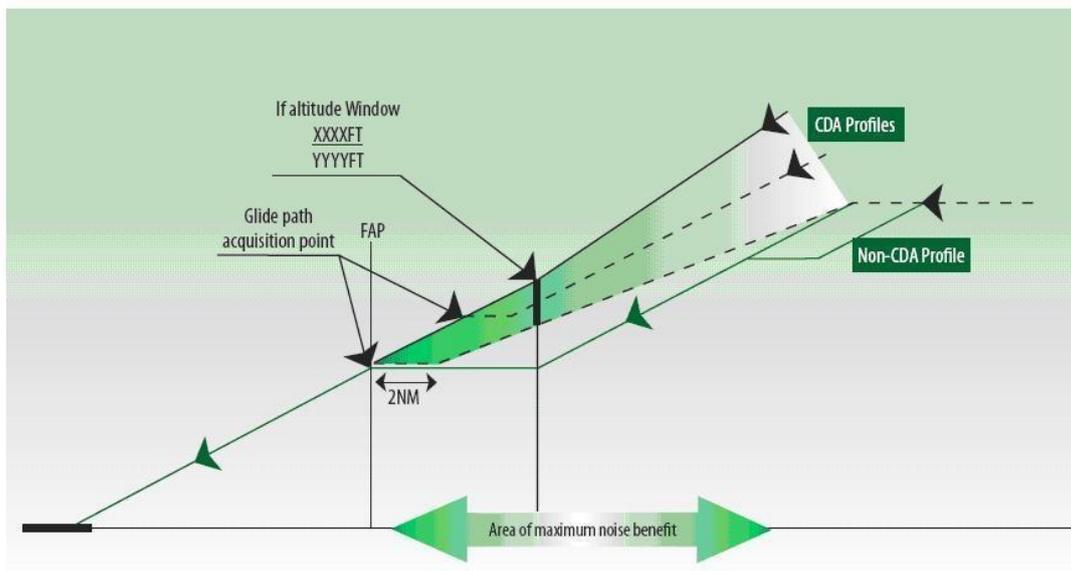
Stakeholders

For local implementation: airport operator, air traffic control / navigation service provider, aircraft operators, civil aviation authority, environmental authorities, local authorities and communities.

ICAO and EUROCONTROL provide general definitions and guidance on NADP procedures.

6.2.2. Continuous Descent Operations (CDO)

also known as *Continuous Descent Approach (CDA)* or *Optimized Profile Descent (OPD)*



Source: Eurocontrol

Conceptual diagram of Continuous Descent Approach

Noise reduction mechanism

CDO is a flying technique that minimizes level-flight segments during approach by enabling a continuous descent with idle or near-idle thrust. This reduces engine power usage, minimizes the need for speed brakes and configuration changes, and avoids the higher thrust required during level-off in conventional step-down approaches. As a result, noise exposure and peak noise levels are reduced for communities located beneath the descent path. The aircraft descends along a smooth, uninterrupted profile, to the extent allowed by airspace and ATC constraints.

Key Characteristics

Property	Value
Type of Measure	<ul style="list-style-type: none"> • source: reduction of aircraft noise emission • propagation: increasing source-receiver distance
Typical Scale / Dimensions	<ul style="list-style-type: none"> • Vertical range: from top of descent to final approach fix height, with actual heights depending on flight and procedure • Horizontal path: CDO procedure starts typically 30–120 NM from runway threshold and leads to significant noise reductions between 8 and 25 NM (15 – 45 km) distance.

Property	Value
Typical Materials / Tools	<ul style="list-style-type: none"> • Onboard flight management system (FMS) • Updated STARs (Standard Terminal Arrival Routes) and transitions • Air traffic control (ATC) procedures and automation tools • Flight crew and ATC training materials • Aeronautical Information Publication (AIP) by airports or national aviation authorities
Lifespan / Maintenance	<ul style="list-style-type: none"> • Long-term implementation; periodic updates based on airspace changes • Requires ongoing coordination and procedural reviews
Regulatory Status	EU Regulation 598/2014 ⁽⁹²⁾ implements the ICAO Balanced Approach to Aircraft Noise Management ⁽⁹³⁾ in which noise abatement operational procedures are generally included. ICAO Doc 9931 ⁽¹⁰⁴⁾ provides a CDO Manual, and ICAO Doc 8168 ⁽⁹⁷⁾ provides instructions for CDA.

Effectiveness

Noise reduction

According to EUROCONTROL ⁽¹⁰⁵⁾, CDOs have been demonstrated to provide noise level reductions for a single arrival of between 1 to 5 dB(A), typically at 8 to 25 nautical miles (15 to 45 km) from the runway threshold, when compared to a non-CDO (i.e. step-down) flight. The overall reduction of noise exposure in L_{den} / L_{night} is smaller than or equal to this value, depending on the level of compliance by aircraft operators.

Other acoustic effects

CDO provides a generally smoother approach profile, with more consistent and lower peak level, due to fewer engine changes and later gear deployment.

Impact area

CDO affects communities located under typical intermediate approach paths, before the final approach fix. It is particularly effective in reducing exposure for

¹⁰⁴ ICAO Doc 9931, Continuous Descent Operations (CDO) Manual, First Edition, 2010

¹⁰⁵ EUROCONTROL, *European CCO / CDO Action Plan*, 2020-08, <https://www.eurocontrol.int/publication/european-cco-cdo-action-plan>

residents 8 – 25 NM from the runway. It does not affect the final approach segment below the final approach fix height.

Advantages

- **Environmental Benefits:** Lower engine power usage also leads to reduced fuel burn and CO₂ emissions, up to 35 kg fuel (110 kg CO₂) per arrival as a network-wide average (¹⁰⁶). Many airlines already implement CDO approaches for this reason.
- **Cost-Effective:** No infrastructure needed, minimal investments
- **Scalable:** Can be introduced on smaller scale and expanded to more flights. Can be integrated with Performance-Based Navigation (PBN)
- **ICAO-compliant:** Fits into Balanced Approach to noise management.

Limitations

- **Airspace Constraints:** Requires sufficient airspace and flexibility in arrival management.
- **Traffic Volume:** High-density terminal areas may require stepped descents in certain peak periods
- **Coordination Dependency:** Needs full cooperation between ATC and operators. ATC using intermittent descent clearances is often a blocking factor for CDO techniques.
- **Terrain and Weather:** Local geography or meteorological factors may restrict CDO application
- **Mixed Fleet Complexity:** Different aircraft types may perform CDO differently

Costs

Approximate costs

Costs are expected to be similar in order to those for noise abatement departure procedures, see § 6.2.1. If a reconfiguration of the airspace is needed to accommodate CDO, this will lead to considerably higher costs.

See section § 6.1.5 for general remarks and limitations to these cost figures.

¹⁰⁶ <https://www.eurocontrol.int/concept/continuous-climb-and-descent-operations>

Detailed cost calculations

Detailed cost calculations need to take into account the airport size, airspace complexity and the number of operators. The lower fuel burn associated with CDO may lead to cost savings, counteracting CDO implementation costs.

Noise modelling

To support implementation, ECAC Doc29 ⁽⁹⁹⁾ provides the common calculation method for aircraft noise, which is implemented in the IMPACT calculation tool provided by EUROCONTROL. Internationally, ICAO Doc 9911 ⁽¹⁰⁰⁾ and the Aviation Environmental Design Tool (AEDT) ⁽¹⁰¹⁾ are used, which are equivalent. Noise modelling steps include:

- **Model scenarios:** compare CDO with conventional procedures
- **Input data** required include CDO and conventional approach profiles as defined in the Aircraft Noise and Performance Database (ANP), traffic data including different aircraft types, and population distribution
- **Validation** could be done with ground noise measurements, radar track data, stakeholder and community feedback.

Implementation

Considerations

Implementation details will depend on:

- the airspace structure and interoperability with other procedures
- aircraft equipage and compatibility of the flight management system
- operational constraints and traffic volume vs. environmental benefits and priorities
- support from communities, air traffic control and airlines

CDO is actually a flying technique, rather than a separate predefined procedure. CDO must be facilitated by air traffic control (ATC), who may require conventional stepped descent procedures in dense traffic or difficult weather conditions.

Timeline

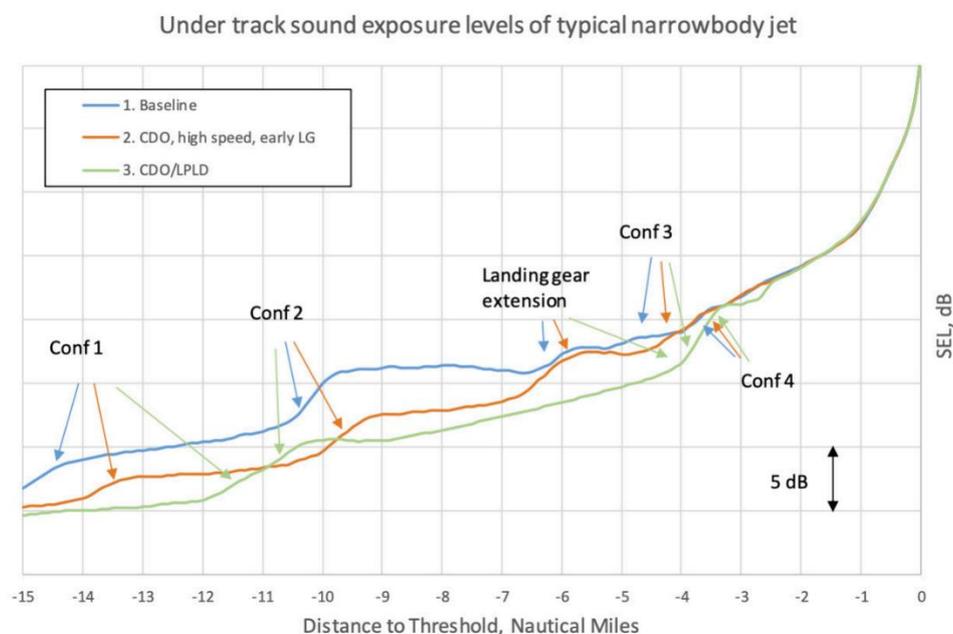
- 0–3 months: Feasibility study and airspace assessment

- 3–6 months: Procedure design and simulation. This will take significantly longer if route or airspace redesign is required, which depends on the local airport situation.
- 6–9 months: Stakeholder consultation and pilot phase
- 9–12 months: Full rollout, monitoring, and feedback loop
- 12+ months: Optimization and potential expansion

Stakeholders

Airport Operator, Air Navigation Service Provider (ATC), Aircraft Operators, Civil Aviation Authorities, Environmental Authorities, Local Communities and Municipalities, International Bodies (e.g., ICAO, EUROCONTROL)

6.2.3. Lower Power (LP) or Lower Drag (LD) approach profiles



Source: Eurocontrol CDO/CCO Action Plan ⁽¹⁰⁴⁾

Comparison of sound exposure levels for three approach profiles: baseline, continuous descent (CDO) and CDO combined with LP/LD

Noise reduction mechanism

A lower power / lower drag (LP/LD) approach is a flight technique, rather than a separate procedure. It is applied within the descent/approach phase over populated areas, by delaying flap and gear deployment and maintaining low engine thrust, resulting in a cleaner aerodynamic profile for as long as operationally feasible. LP/LD reduces both aerodynamic and engine noise

during approach, particularly when used in combination with a continuous descent profile (CDO).

Key Characteristics

Property	Value
Type of Measure	source: operational flight technique
Typical Scale / Dimensions	<ul style="list-style-type: none"> applied during the later portion of the descent, typically the last few thousand feet prior to the final approach fix; exact altitudes and distances depend on aircraft type, procedure design, and STAR/transition structure most effective for communities within 5 – 20 km from runway threshold
Typical Materials / Tools	<ul style="list-style-type: none"> on-board flight management system (FMS) software supporting LP/LD configuration STARs and transitions supporting continuous, predictable descent sensor-based navigation ⁽¹⁰⁷⁾ surveillance sensors (radar, Mode S, ADS-B, multilateration) pilot and ATC training and guidance materials
Lifespan / Maintenance	long-term technique; periodic reviews should be aligned with changes in airspace, procedures, or fleet mix
Regulatory Status	EU Regulation 598/2014 ⁽⁹²⁾ implements the ICAO Balanced Approach to Aircraft Noise Management ⁽⁹³⁾ in which noise abatement operational procedures are generally included. ICAO Doc 9931 ⁽¹⁰³⁾ provides a CDO Manual, and ICAO Doc 8168 ⁽⁹⁷⁾ provides instructions for CDA.

Effectiveness

Noise reduction

According to the European CCO/CDO Action Plan ⁽¹⁰⁴⁾, LP/LD techniques can reduce noise levels by approximately 2 – 5 dB, typically within 3 – 10 NM (5 – 20 km) before the runway threshold. Under certain operational conditions, the area of benefit may extend closer to the runway threshold.

Other acoustic effects

LP/LD modifies the timing and location of flap and gear deployment, which may shift tonal elements of the approach noise. Benefits depend on where configuration changes occur relative to populated areas.

¹⁰⁷ ICAO Doc 9613, Performance-based Navigation (PBN) Manual, Fifth Edition, 2023

The measure may lead to reduced on-board noise, enhancing passenger and staff comfort.

Impact area

The measure is most effective within the intermediate approach segment, 5 – 20 km from the runway threshold.

Advantages

- No infrastructure changes required.
- Can be implemented rapidly where airspace and ATC predictability allow.
- Potential fuel savings due to reduced drag and lower thrust. Many airlines already apply LP/LD techniques for this reason.
- Integrates naturally with CDO and PBN-based arrival concepts.
- Improved passenger comfort (fewer speed brake uses, smoother flight).

Limitations

- Strongly dependent on ATC predictability and available sequencing tools
- May be constrained in high-density traffic situations
- Aircraft performance and pilot technique vary between fleet types
- Operational feasibility depends on STAR/transition design and terrain constraints

Costs

It is not possible to provide approximate cost figures with reasonable accuracy. Costs relate mainly to procedure review, training, operational coordination and monitoring and compliance systems. Exact amounts depend heavily on local context, including the airspace complexity, number of operators and number of procedures. Fuel savings may offset implementation costs.

Noise modelling

To support implementation, ECAC Doc29 ⁽⁹⁹⁾ provides the common calculation method for aircraft noise, which is implemented in the IMPACT calculation tool provided by EUROCONTROL. Internationally, ICAO Doc 9911 ⁽¹⁰⁰⁾ and the Aviation Environmental Design Tool (AEDT) ⁽¹⁰¹⁾ are used, which are equivalent. Noise modelling requires:

- **Model scenarios:** compare LP/LD with conventional procedures and/or CDO procedures without LP/LD profiles.
- **Input data** required include aircraft performance databases from manufacturers (e.g. Boeing, Airbus), LP/LD profile definitions with power settings, aircraft types and approach speeds, meteorology, topography and population distribution
- **Validation** could be done with ground noise measurements, radar track data, and stakeholder and community feedback.

Implementation

Considerations

- Must be strategically supported through Standard Arrival Routes (STARs) and transition design
- Requires predictable ATC operations and sequencing
- Needs coordination between air navigations service providers, ATC, aircraft operators, and airport authority
- Requires availability of capable Flight Management System (FMS) in aircraft fleet, and operational policies
- Communication with communities to explain expected impacts

Example implementation cases are found at several European airports using CDO-focused arrival structures, including Frankfurt, Zurich and Gatwick airport.

Timeline

Timelines depend on the extent of airspace and procedure design adjustments. A typical sequence involves:

- Feasibility study and stakeholder alignment
- Procedure design and modelling
- Training and rollout coordination
- Monitoring and refinement

Stakeholders

Airport Operator, Air Navigation Service Provider (ANSP), Airlines / Flight Operations Managers, Civil Aviation Authority (CAA), Local noise/environmental authorities

6.2.4. Flight track dispersion or concentration around an airport



Source: Schiphol Airport
Horizontal departure and approach paths from/to the Kaagbaan runway

Noise reduction mechanism

Departure and approach flights around an airport follow predefined paths. In practice, aircraft trajectories may deviate to some extent from these paths by taking shorter or wider turns, following slightly different bearings, etc. Slight variations due to aircraft type, weight and meteorological conditions are normal and not considered deviations from the predefined procedures. Intentional procedure deviations are instructed by air traffic control (ATC). The airport could strategically take measures to either limit this dispersion or increase it.

By altering the distribution of aircraft over available flight paths, the airport can either:

- concentrate flights along narrow corridors (e.g., via RNAV) to limit the total area affected by noise or to avoid overflying noise-sensitive areas, or
- disperse flights to spread out noise over a wider area, reducing repetitive noise exposure for any single community.

Both strategies aim to minimize the impact of aircraft noise on populations, depending on local demographics, geography, and political context.

Key Characteristics

Property	Value
Type of Measure	traffic management
Typical Scale / Dimensions	<ul style="list-style-type: none"> affects communities below departure and arrival routes from a few km up to roughly 150 km radius from the airport often applied to the approach and climb-out paths between the airport and the higher en-route flight space (SID/STAR paths ⁽¹⁰⁸⁾)
Typical Materials / Tools	<ul style="list-style-type: none"> airspace design strategy and flight procedure design tools performance-based navigation (PBN) procedures using sensor-based navigation (RNAV or RNP) ⁽¹⁰⁶⁾ air traffic control (ATC) software and surveillance sensors
Lifespan / Maintenance	<ul style="list-style-type: none"> minimal physical maintenance of equipment; mainly involves procedural and software updates requires regular review of procedures every 3-5 years or upon significant operational changes
Regulatory Status	-

Effectiveness

Noise reduction

The potential noise reduction is relatively high; up to 10 dB(A) in L_{den} / L_{night} levels for impacted communities, although this depends on many factors.

- *Concentration* of flight tracks reduces the impacted areas but increases the occurrence and average noise levels in these areas. Recommended if flight tracks are predominantly over non-sensitive areas, to avoid overflying nearby communities.
- *Dispersion* of flight tracks reduces the noise levels and occurrence in certain areas but exposes larger areas to lower noise levels. It distributes the burden over a larger population. Recommended if overflying sensitive areas is unavoidable.

The lateral placement of flight tracks is one of the most influential parameters for aircraft noise exposure. Even relatively small changes in lateral routing can lead to significant noise benefits or disbenefits for communities located tens of kilometres from the airport, particularly along departure routes where aircraft remain at lower altitudes for extended distances.

¹⁰⁸ SID: standard instrument departure, STAR: standard terminal arrival route

Other acoustic effects

A flight track concentration strategy, assisted by using e.g. PBN, may lead to (very) high noise exposure for residents under or close to the centreline. Oppositely, flight track dispersion reduces noise for communities directly under the concentrated flight paths, but at the expense of increasing noise for people living further away from these paths. Overall, the number of people exposed to high noise levels is reduced, but the number of people exposed to medium noise levels may increase, depending on the population distribution.

Both effects need to be balanced together with local communities. There are examples, such as for Heathrow airport, where residents preferred a fair distribution of medium levels over all of them, instead of exposure to high levels to some of them ⁽¹⁰⁹⁾.

Impact area

Affects communities under major flight departure or approach tracks, starting close to the airport perimeter up to roughly 80 NM (150 km) of the airport, depending on the existing flight routes and geographic situation.

Advantages

- **Flexibility:** Can be adjusted based on feedback or changing demographics
- **Political balancing:** Option to share noise burden or protect sensitive areas
- No physical **infrastructure** required
- Compatible with **existing** ATC and PBN technologies

Limitations

- **Public perception:** *Concentration* may lead to community resistance in high-exposure zones, while *dispersion* may draw complaints from previously unaffected areas.
- **Airspace complexity:** May increase controller workload, and can conflict with other airspace users.

¹⁰⁹ Ohlenforst B et al., *Exemplification case studies as a focus for the implementation of best practices related to aircraft noise management at airports*, proceedings Inter-Noise 2021 Washington, 2025-08

- **Weather and terrain:** May limit usable track options or require altitude constraints.

Costs

Public cost figures for flight track optimisation could not be found. Such costs should include:

- Procedure design of new flight tracks and validation
- Public consultation and outreach
- ATC training and software updates

In table 5.8 of the Phenomena study report ⁽¹²⁾, total investment costs for avionics (i.e. PBN and other electronic equipment, plus training) are estimated at 50 M€ for the whole EU.

Noise modelling

Noise modelling can be done with ECAC Doc29 ⁽⁹⁹⁾, implemented in the IMPACT calculation tool, or the equivalent international method of ICAO Doc 9911 ⁽¹⁰⁰⁾ implemented in the Aviation Environmental Design Tool (AEDT) ⁽¹⁰¹⁾.

Total L_{den} and L_{night} levels should be calculated from (weighted) distributions of flight tracks, or individual flight track data from radar or ADS-B systems. Further inputs required are population data, aircraft fleet mixes and operational frequencies

Implementation

Considerations

- Stakeholder analysis and participation are important, and should involve citizens from both benefitting areas and areas where noise levels will increase.
- Runway configurations, prevailing winds and terrain are important to consider.
- Potential conflicts with safety, capacity and efficiency should be evaluated.

Timeline

- 0–3 months: Feasibility and options study

- 3–6 months: Noise modelling and stakeholder engagement
- 6–9 months: Procedure design and regulatory approval
- 9–12 months: ATC training, communication, and implementation
- 12+ months: Monitoring and post-implementation review

Stakeholders

Civil Aviation Authority (CAA), Air Navigation Service Provider (ANSP), Airport operator, Local governments and residents' associations, Environmental and noise control bodies

Further documentation

- UK Civil Aviation Authority, CAP1378: *Airspace Design Guidance: Noise Mitigation Considerations when Designing PBN Departure and Arrival Procedures*, 2016-04-18, <https://www.caa.co.uk/our-work/publications/documents/content/cap1378/>
- Community engagement case studies (Heathrow, Schiphol) from the ANIMA project (¹⁰⁸)

6.2.5. Preferential runway use



Source: AMS Schiphol Airport
Multiple runway configuration around Schiphol

Noise reduction mechanism

Preferential runway use is a noise abatement procedure where specific runways (or runway directions) are prioritized for take-offs and landings in order to reduce noise exposure over the most affected or noise-sensitive communities. This measure redistributes flight operations to routes with lower population density, preferable geographical conditions, or favourable noise propagation characteristics.

It may be applied permanently, during specific time windows (e.g., nighttime), or in certain meteorological conditions.

Preference can be based on:

- Runway orientation and distance to residential areas
- Land-use patterns (industrial zones, water bodies, agricultural land)
- Terrain characteristics affecting noise propagation
- Time of day (e.g., nighttime preferential runway system)
- Aircraft type or operational mode (arrivals vs departures)

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	Reduces noise exposure for communities located near non-preferential runways or runway directions; may increase exposure in less sensitive zones.
Typical Materials / Tools	<ul style="list-style-type: none"> • Aeronautical Information Publication (AIP) to define the runway use regulation • ATC operational guidelines • Flight track monitoring systems (radar, ADS-B) • Noise monitoring terminals (fixed/mobile) • Community consultation materials
Lifespan / Maintenance	Tow vehicles: 10 – 15 years lifespan with regular maintenance.
Regulatory Status	Considered an operational noise abatement procedure under ICAO Balanced Approach ⁽⁹³⁾ . Must comply with EU Regulation 598/2014 ⁽⁹²⁾ if introduced as a restriction with significant operational impact. Prior consultation and assessment of alternatives may be required.

Effectiveness

Noise reduction

Preferential runway use does not reduce total airport noise, but redistributes it. Noise exposure reduction of 3 to 7 dB(A) L_{den} or L_{night} have been observed for communities near non-preferential runway directions, depending on:

- Traffic volumes
- Runway geometry and orientation
- Time of day (largest benefit at night)
- Degree of compliance and weather-driven variability

It may significantly reduce single-event maxima (L_{max}) for specific neighbourhoods when arrivals/departures are shifted away.

Other acoustic effects

- May increase noise exposure in areas located under the preferred runway's paths (if previously less affected).
- Potential for track concentration if RNAV procedures are used.
- May combine with continuous descent approaches to amplify noise benefits.

Impact area

Affects all flight paths associated with:

- Non-preferred runway(s) where operations are reduced
- Preferred runway(s) by increasing noise immissions under their approach and take-off paths.

The impact is strongest near runway ends and under the departure/arrival corridors.

Advantages

- Low-cost measure with immediate effect once implemented
- Low impact on airport capacity if implemented flexibly

- Improves noise climate for the most affected communities
- High public acceptance when transparently communicated
- Flexible — can be tailored to different times of day, weather, or aircraft types
- Effective when combined with other operational measures (CDA, NADP1/2)

Limitations

- Possible increase in noise for communities under preferred runways
- Strong dependence on weather (wind direction, crosswind limits)
- May require ATC workload increases or sequencing constraints
- Risk of bottlenecks if preferential use limits runway availability
- Requires robust communication to avoid perceived unfairness
- If implemented rigidly, may reduce operational resilience during peak periods or adverse weather; temporary suspensions may be required

Costs

Public cost figures for preferential runway systems were not found. A full calculation of costs should include:

- Stakeholder engagement and community communication
- ATC procedure design, updates to tools and charts, and training
- Updates to AIP, NOTAMs, and airport manuals
- Enhancements to flight track monitoring systems
- Public communication programme (maps, explanatory materials)

Preferential runway use typically has low direct cost, but indirect operational costs may arise due to:

- Reduced flexibility under certain wind conditions
- Additional fuel burn if routes become longer

Noise modelling

Standard noise modelling tools such as IMPACT, IMMI, CadnaA and SoundPLAN, can simulate runway-use scenarios.

Required inputs:

- Baseline and modified runway usage percentages
- Flight schedules and aircraft mix
- Arrival/departure tracks (including RNAV/STARS/SIDS)
- Meteorological variation (wind availability)

Comparison of scenarios:

- Change in L_{den} , L_{night} , and SEL distributions
- Redistribution contours
- Evaluation of beneficiary vs adversely affected populations

Validation:

- Fixed noise monitoring terminals
- Radar/ADS-B compliance checks
- Community complaint data correlation

Implementation

Considerations

- Preferential runway systems may not be seen as purely a noise abatement procedure, but rather as an airport operations distribution system that enables noise reduction.
- Preferential runway systems are typically established or approved by the competent aviation or environmental authority, following political or regulatory decisions, with implementation by the airport operator and air navigation service provider.
- Define preferential/non-preferential runways and their time windows
- Assess wind and weather feasibility (typically 70–90% applicability)
- Ensure ATC involvement from the start
- Conduct Balanced Approach assessment if impacts are significant
- Communicate logic and expected benefits to communities
- Develop a compliance monitoring framework
- Set clear exceptions (e.g., safety, emergencies, tailwind limits)

Timeline

- 0–2 months: Feasibility study, wind analysis, community mapping
- 2–4 months: Procedure design, ATC simulations
- 4–6 months: Regulatory consultation, AIP drafting
- 6–8 months: Publication, training, communication
- 8–12 months: Go-live and continuous monitoring

Stakeholders

Airport Management, Air Traffic Control (ATC), Airlines, Civil Aviation Authority, Local Authorities and Residents, Environmental Agencies, Noise Mapping/Modelling Experts, National/EU Regulators.

Further documentation

- ICAO Doc 8168 ⁽⁹⁷⁾ – Procedures for Air Navigation Services – Aircraft Operations (PANS-OPS)
- ICAO Doc 9829 ⁽¹¹⁰⁾ – Balanced Approach to Aircraft Noise
- ACI World Guidance on Balanced Approach ⁽¹¹²⁾
- Example implementations: Amsterdam Schiphol, Sydney, Zurich, Vienna

6.2.6. Airport curfews

Noise reduction mechanism

Airport curfews restrict or prohibit aircraft operations during **sensitive night-time hours**. These restrictions reduce **peak night noise levels**, mitigate sleep disturbance, and lower long-term noise exposure (L_{night} and L_{den}).

The time window for the curfew may vary from typically 22:00 – 00:00 until 05:00 – 07:00, depending on the local situation, typical flight time patterns and community requirements. Furthermore the curfew may be:

- Full: no operations during designated hours
- Partial: limited types of aircraft, reduced number of slots and/or restrictions on certain operating modes (i.e. prohibiting either take-offs or landings after or before certain hours)
- Conditional: based on noise certification or weather conditions

Key Characteristics

Property	Value
Type of Measure	operating restrictions
Typical Scale / Dimensions	Reduces noise exposure, sleep disturbance and annoyance for all areas impacted by the night-time airport noise.
Typical Materials / Tools	<ul style="list-style-type: none"> regulatory documentation (NOTAMs ⁽¹¹⁰⁾, airport rules) slot scheduling tools monitoring systems for compliance (e.g. flight radar, ADS-B, or optionally noise monitors)
Lifespan / Maintenance	May need regular evaluation depending on traffic evolution or legal challenges.
Regulatory Status	Operating restrictions, including curfews, are subject to the ICAO Balanced Approach implemented in EU Regulation 598/2014 ⁽⁹²⁾ . Here, and in the ICAO Doc 9829 Guidance ⁽¹¹¹⁾ , operating restrictions are clearly defined as a last resort measure, only to be implemented after all other measures and their costs and benefits have been thoroughly considered. Failure to consider other measures may lead to legal disputes around curfew implementation.

Effectiveness

Noise reduction

A full ban on night flights would eliminate all night-time noise exposure, reducing L_{night} to background noise levels. A partial or conditional curfew degree will reduce several dB depending on typical flight time patterns and aircraft types, with higher reductions if targeted towards the noisiest aircraft types. Curfews may (nearly) completely eliminate night-time peak events (L_{max}) and aviation-related sleep disturbance.

Other acoustic effects

Night-time curfews may lead to an increase of traffic during the day and specifically in shoulder hours, i.e. shortly before curfew start and after curfew end, creating higher noise levels in late evening and early morning.

¹¹⁰ NOTAM: Notice to Airmen, or Notice to Air Missions, are formal notifications issues to pilots. These are legally binding but generally of a temporary nature, i.e. in hazardous situations.

¹¹¹ ICAO Doc 9829, *Guidance on the Balanced Approach to Aircraft Noise Management*, Second Edition, 2008

Impact area

Impacts any area subject to night-time airport noise. This may be limited to certain runways or runway directions that are allowed or preferred during the night.

Advantages

- Highly effective in reducing the most disturbing night-time noise
- Directly improves public health, due to reduced sleep disturbance and cardiovascular impacts
- Facilitates strong community relations and social acceptance
- Simple to monitor and enforce, using existing flight tracking systems

Limitations

- Operational and economic impacts: reduces airport capacity and connectivity
- May affect cargo flights and long-haul operations, which are typical night-time flights
- Can create (higher) noise peaks in shoulder hours around curfew start/end
- Risk of airline resistance or legal challenges under EU Regulation 598/2014
- Requires state-level authorization in some jurisdictions
- Notification of the European Commission is required and can be followed by scrutiny of correctly following the Balanced Approach procedures

Costs

A complete cost calculation should include:

- Stakeholder consultation and legal framework
- Slot reallocation and IT system updates
- Compliance monitoring tools
- Public communication, signage, and response management

Indirect potential economic loss due to the flight restriction (e.g. revenue from cargo and long-haul flights) should be calculated separately and is specific to

the airport. The more night flights an airport has, the higher the economic loss, but also the higher the noise reduction and public health benefits will be.

In the Phenomena study report ⁽¹²⁾, the profit loss for a single lost operation is €6000. For the whole EU, this is extrapolated to 2.6 billion €, assuming that 50% of all night flights are lost.

Noise modelling

Regular noise modelling tools based on Doc29 ⁽⁹⁹⁾ can be used, which are available in IMPACT, CadnaA, SoundPLAN, IMMI or other noise calculation software. The effect of such measures will also be visible on updates of the strategic noise maps.

To model the effect of the measure, flight traffic input data (flight schedules, aircraft types and runway usage patterns) are needed for the scenarios with and without curfew. Comparison of the results for both scenarios is straightforward. Validation could take place with long-term night noise (Lnight) monitoring measurements, by comparing the actual night flight data with modelled inputs, and by analysing complaints of nearby communities.

Implementation

Considerations

- Curfew hours and scope (total, partial or conditional bans) need to be defined.
- Early engagement with airlines, ATC and cargo operators is needed.
- The whole Balanced Approach procedure acc. EU 598/2014, including all alternative measures, needs to be followed before implementing this measure. This includes notification to EU and possible scrutiny of the procedure.
- Contingency plans and slots need to be made available, for emergency cases.
- Exemption and enforcement procedures need to be developed and transparently communicated to both aviation and community stakeholders.

Timeline

- 0–6 months: Feasibility study, noise impact assessment
- 6–18 months: Consultation and revision

- 6–18 months: Regulatory and legislative procedures
- 18–24 months: Communication campaign and introduction period
- 24–30 months: Go-live, compliance monitoring begins

Total timeline is approximately 2 – 3 years.

For example, for Heathrow, Gatwick and Stansted airport in UK, public consultation started in 2020 and night flight restricted regime started in October 2022 ⁽¹¹²⁾.

Stakeholders

Airport Management, Airlines and Cargo Operators, Civil Aviation Authority, Air Traffic Control (ATC), Local Authorities and Residents, Environmental and Health Agencies, National/EU Regulators

Further documentation

- ACI World Guidance on Balanced Approach ⁽¹¹³⁾
- Example implementations of curfews: Frankfurt, Zurich (full), Heathrow (partial)

6.2.7. Reverse thrust use restrictions



¹¹² <https://www.gov.uk/government/consultations/night-flight-restrictions-heathrow-gatwick-and-stansted-airports-from-october-2025>

¹¹³ Airports Council International (ACI) World, Guidance on the Application of the ICAO Balanced Approach to Aircraft Noise Management, 2024, <https://store.aci.aero/product/guidance-on-the-application-of-the-icao-balanced-approach-to-aircraft-noise-management/>

Source: Aerocorner.com
Thrust reverser on KLM Fokker 70

Noise reduction mechanism

Reverse thrust is used by aircraft engines to decelerate after touchdown. Different types of internal and external engine thrust reversers exist. When unrestricted, especially in high-thrust settings, it generates high noise levels at and beyond the runway ends, often affecting nearby residential areas. By **limiting the use of reverse thrust to idle settings** or prohibiting it unless safety requires it (e.g., on short or wet runways), noise can be significantly reduced.

Aircraft deceleration is then mainly achieved through **wheel brakes and spoilers**, which produce significantly less noise.

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	along the entire runway length and up to 5 km away from runway thresholds
Typical Materials / Tools	<ul style="list-style-type: none"> operational policies and NOTAMs ⁽¹⁰⁹⁾ runway braking action monitoring systems training and communications to air traffic controllers and pilots optional signage or markings at touchdown zones (not required)
Lifespan / Maintenance	-
Regulatory Status	Reverse thrust use restrictions are not explicitly mentioned in the EU 598/2014 ⁽⁹²⁾ and the ICAO Balanced Approach ⁽¹¹⁰⁾ , but are considered as part of the third pillar: noise abatement operational procedures.

Effectiveness

Noise reduction

The peak noise from reverse thrust use is reduced by 4 – 12 dB(A) near the runway ends, as measured for several jet engine aircraft ⁽¹¹⁴⁾. The measure is

¹¹⁴ UK Civil Aviation Authority, Environmental Research and Consultancy Department, White S et al., *Noise Measurements of Reverse Thrust at Heathrow and Stansted Airports*, ERCD Report 1007, 2010-12, <https://www.caa.co.uk/publication/download/14020>

particularly effective during night hours in which the peak noise is relatively disturbing.

Other acoustic effects

Eliminating reverse thrust use will also decrease cabin noise during landing.

Impact area

The measure is mostly effective for residential areas directly below the landing paths, along the runway and up to 5 km distance from runway exit points.

Advantages

- no physical infrastructure changes required
- low-cost and quick implementation
- effective for peak noise reduction
- can be selectively applied (e.g. only in night periods or on specific runways)

Limitations

- **Safety:** Reverse thrust use must be allowed in poor weather conditions, short or slippery runways and in critical or emergency cases.
- **Operational impact:**
 - may increase runway occupancy time (affecting capacity); full mechanical braking may not always be feasible due to short turnaround times
 - could slightly increase brake wear on landing gear ⁽¹¹³⁾
- **Aircraft variability:** effectiveness and necessity depend on aircraft type, landing weight and runway length
- **Compliance monitoring** by real-time detection of reverse thrust use requires advanced monitoring systems.

Costs

Public cost figures for reverse thrust use restrictions were not found. A complete cost calculation should include:

- Procedure design and stakeholder consultation

- Internal/external communication
- Pilot and ATC training and materials development
- Optional monitoring setup (noise monitors near runway ends)

See § 6.1.5 for general remarks and limitations to cost figures for aircraft noise measures.

Noise modelling

Noise modelling could be done with integrated noise models based on Doc29, such as the IMPACT tool by EUROCONTROL, provided with manufacturer data for thrust reverser noise levels.

Input data required include:

- aircraft types and reverse thrust use profiles
- runway geometry with threshold locations
- weather conditions and time-of-day patterns
- population data

Validation could be done by on-site noise measurements near runway ends, with advanced equipment capable of detecting reverse thrust use, which could include smart audio equipment and/or acoustic cameras. Radar and engine telemetry data could be used to monitor aircraft operational data.

Implementation

Considerations

For implementation of the measure within safety and operational boundaries, coordination with air traffic control and airlines is essential. Limiting the measure to night time only, or to specific runways, may improve operational acceptability.

Timeline

- 0–2 months: Feasibility study and impact modelling
- 2–4 months: Stakeholder consultation and procedure drafting
- 4–6 months: Policy issuance, ATC/pilot training, public communication
- 6–12 months: Monitoring, compliance feedback, fine-tuning

Stakeholders

Airport Operator, Airport Safety Oversight Bodies, Air Traffic Control, Aircraft Operators / Airlines, Civil Aviation Authority, Local Communities / Municipalities

6.2.8. Restrictions for auxiliary power units (APUs)



Source: Honeywell Aerospace Technologies
Auxiliary power unit (APU)

Noise reduction mechanism

The APU, a small jet engine usually located at the tail of the aircraft, powers onboard systems, such as climate conditioning and electrical systems, while parked. Restricting its use – especially during night hours or beyond a fixed timeframe – reduces continuous noise emissions near gates, taxiways, and apron areas. By encouraging or requiring airlines to use ground power units (GPUs) or pre-conditioned air (PCA) systems instead of APUs, the ground-borne aircraft noise is reduced.

Key Characteristics

Property	Value
Type of Measure	source
Typical Scale / Dimensions	APU noise impacts typically extend 50 – 300 meters from the aircraft. This measure is relevant for apron areas adjacent to terminals, or residential zones close to the airport.

Property	Value
Typical Materials / Tools	<ul style="list-style-type: none"> • alternatives for APUs to be provided by the airport: <ul style="list-style-type: none"> ○ fixed or mobile ground power units (GPUs) as alternative power supply ○ pre-conditioned air (PCA) supply systems, eliminating the need for on-board air conditioning • signage, operational policies, guidance and/or enforcement technology (e.g. apron monitoring)
Lifespan / Maintenance	GPUs and PCA systems' lifespan is typically 10 – 20 years with routine maintenance
Regulatory Status	-

Effectiveness

Noise reduction

- Noise reduction values of 10 to 20 dB(A) at the aircraft stand are reported (^{115,116}) when replacing APU use with GPU/PCA.
- Reduction of tonal and high-frequency background noise, which is relatively disturbing
- Particularly effective at night or in proximity to noise-sensitive buildings

Other acoustic effects

Reduction of noise at the airport, e.g. in apron zones and for passengers.

Impact area

- Immediate airport perimeter and nearby residential or hotel areas
- Indoor airport workers, maintenance personnel, and passengers

Advantages

- Substantial noise reduction at low cost

¹¹⁵ Souaid E, *Do You Need a GPU?*, 2024-01, https://www.researchgate.net/publication/382252762_Do_You_Need_a_GPU

¹¹⁶ Cologne Bonn Airport, *Dirst electric ground support equipment has arrived in Cologne/Bonn.*, 2024-10-01, <https://www.cologne-bonn-airport.com/en/company/newsroom/press-releases/detail/dirst-electric-ground-support-equipment-has-arrived-in-cologne-bonn.html>

- Immediate local benefit for both community and workers
- Improved air quality, by eliminating APU fuel burn
- Compatibility with existing aircraft — no retrofit required
- Supports green airport certifications (e.g., ACA, LEED, ISO 14001)

Limitations

- Requires GPU / PCA infrastructure at all airport stands
- Requires monitoring and penalties for non-compliance
- Exceptions should be possible, in case of emergencies, aircraft or ground unit malfunctions, or extreme weather conditions
- Older aircrafts may not be compatible with all GPU / PCA systems

Costs

Approximate costs

- GPU/PCA installation: €100,000–€200,000 per gate or €170,000 for a mobile unit ⁽¹¹⁷⁾
- Signage and communication: €2,000–€5,000
- Monitoring/enforcement systems: €20,000+ (per apron or per camera system)

Detailed cost calculations

Example calculation for 10 gates:

- Fixed GPU installation (10 gates): €100,000 × 10 = €1,000,000
- PCA system installation (optional): €150,000 × 10 = €1,500,000
- Operational signage and control: €20,000
- Training and enforcement (annual): €50,000
- Total Initial Cost Estimate: **€3.0 million** for 10 years

¹¹⁷ NLR, SEO, Adler M at al., *Aviation Investments Towards Destination 2050*, research report, 2023-03, <https://www.destination2050.eu/wp-content/uploads/2023/03/The-Price-of-Net-Zero-Report.pdf>

Note: Use of mobile GPUs/PCAs reduces investment costs but increases operating labour costs.

Noise modelling

Noise modelling could be done with simplified noise contour models (e.g. CadnaA). Additional data on APU noise emission profiles are needed as these are not available in the ICAO Aircraft Noise & Performance (ANP) database. Such data could be obtained from APU or aircraft manufacturers, airport noise measurements or dedicated studies. A specific measurement method for APU noise is defined in SAE ARP1307⁽¹¹⁸⁾.

Input data required include:

- Aircraft types, APU models and operating durations
- Apron layout, stand occupancy, weather/wind data
- Substitute GPU/PCA usage rates
- Population data for nearby residents and/or airport visitors and workers

Validation could be done by on-site noise measurements, worker exposure data or measurements, and by correlating with community noise complaints patterns.

Implementation

Considerations

Operating restrictions must be clearly communicated to aircraft operators and airlines.

Timeline

- 0–3 months: Feasibility study and equipment audit
- 3–6 months: Infrastructure procurement and policy drafting
- 6–9 months: Installation of GPU/PCA, staff training, communication
- 9–12 months: Enforcement launch and compliance monitoring
- 12+ months: Feedback collection, optimization, expansion to cargo/remote stands

¹¹⁸ SAE ARP1307C – Measurement of Exterior Noise Produced by Aircraft Auxiliary Power Units (APUs) and Associated Aircraft Systems During Ground Operation, 2024-05-24

Stakeholders

Airport Authority (operations, engineering, environment), Ground Handling Companies, Aircraft Operators / Airlines, Civil Aviation Authority, Labor Unions (maintenance and ramp staff), Nearby Residents and Local Authorities, Environmental NGOs and advocacy groups

6.2.9. Aircraft towing instead of engine taxiing



Source: Edyouvid
Aircraft pushed back by towing vehicle



Source: Skybrary
Towbarless tug vehicle

Noise reduction mechanism

Replaces engine taxiing with electric, hybrid, or autonomous towing solutions (tugs, etc.), reducing noise and local emissions during pushback and taxi operations.

Key Characteristics

Property	Value
Type of Measure	Operational measure for ground noise reduction
Typical Scale / Dimensions	Noise reduction at gates, apron, and taxiways between terminal and runway
Typical Materials / Tools	<ul style="list-style-type: none"> • electric or hybrid-electric tugs; • towbar or towbarless systems; • towing SOPs; • driver training and airside coordination protocols
Lifespan / Maintenance	Tow vehicles: 10 – 15 years lifespan with regular maintenance.
Regulatory Status	Standard operational measure; implementation subject to airport/airline coordination

Effectiveness

Noise reduction

- Up to 13 dB(A) reduction of ground noise $L_{A,eq}$ levels compared to idle engine taxiing (¹¹⁹), even when the aircraft's APU is running
- Substantial reduction of low-frequency rumbling noise in adjacent residential areas

Other acoustic effects

Reduces indoor aircraft noise for passengers while taxiing.

Co-benefits:

- Improves local air quality and reduces CO₂ emissions
- Reduces indoor aircraft noise for passengers during taxi

Impact area

- Airport apron and taxiways; indoor airport workers, maintenance personnel, and passengers
- Surrounding communities

Advantages

- Substantial noise reduction in ground noise, especially effective during night operations
- Improved air quality and CO₂ emissions, by reducing aircraft engine fuel burn; some fuel burn from engine warm-up remains necessary
- Improved safety for ground workers
- No infrastructure changes needed

¹¹⁹ Hein K, Baumann S, *Acoustical comparison of conventional taxiing and dispatch towing – TaxiBot's contribution to ground noise abatement*, proceedings 30th Congress of the International Council of the Aeronautical Sciences (ICAS), 2016-09, https://www.icas.org/icas_archive/ICAS2016/data/papers/2016_0454_paper.pdf

Limitations

- Adds complexity to ground operations, requires coordination between aircraft, air traffic control and tug services
- Scalability requires larger tug vehicle fleet and trained personnel
- Not applicable in all weather conditions or emergency situations
- Some older and newer aircraft may not be compatible with tug systems, e.g. due to nosewheel strength requirements; aircraft should be certified for sustainable taxiing
- May not be possible in case of tight taxi layouts

Costs

Prices for electric tow tractors or towbarless tug vehicles are expected to exceed €300,000, up to ca. 1M€. Public price values from suppliers could not be found.

A complete cost calculation should include:

- Procurement of electric towbarless tractors
- Staff training and certification
- Tow operation software and dispatch system
- Annual O&M (staff, maintenance, energy)

See § 6.1.5 for general remarks and limitations to cost figures for aircraft noise measures.

Noise modelling

Noise modelling may be done with AEDT ⁽¹⁰¹⁾, which has a taxiing noise calculation module. Generic tools such as CadnaA or SoundPLAN would require manual input of noise emissions for ground operations.

Input data required include:

- Source emission factors for engine taxiing (for reference) and hybrid/electric tug noise
- Taxi routes and timetables

Implementation

Considerations

Eurocontrol has published a guidance document on sustainable taxiing operations ⁽¹²⁰⁾, which provides results from expert panel discussions, as well as recommendations for implementation.

- Successful implementation requires involvement of all stakeholders (operational, regulatory and industry), decision-making based on local, airport-specific and up-to-date cost-benefit analysis, and proper evaluation to explain environmental benefits.
- Taxiing convoys (aircraft + ground vehicle) need to be considered similar to regular taxiing aircraft, be identifiable with similar lighting and use existing infrastructure as much as possible.
- Consistent and safe practices require standardised communication, protocols, checklists and training.

Timeline

- 0–3 months: Feasibility and route analysis
- 3–6 months: Procurement and personnel training
- 6–9 months: Testing and SOP finalization
- 9–12 months: Full implementation on selected taxiways
- Long-term: Expansion to all viable aircraft/times

Stakeholders

Airport Operations, Ground Handling Companies, Airlines (for participation and scheduling), Tow vehicle suppliers and maintenance contractors, Air traffic and ground control, Environmental and Safety Authorities

¹²⁰ Eurocontrol, Hop P, Leeman E, *Sustainable Taxi Operations – Concept of Operations & Industry Guidance*, 2024-03-29, <https://www.eurocontrol.int/publication/sustainable-taxi-operations>

Further documentation

- ICAO Annex 14 to the Convention on International Civil Aviation – Aerodromes, Volume I: Aerodrome Design and Operations, Ninth Edition, 2022-07
- ICAO Doc 10121 – Manual on Ground Handling, First Edition, 2019

6.3. Drones

6.3.1. General description

Unmanned aircraft (UA), commonly referred to as ‘drones’, are an emerging new form of mobility. Urban air mobility using drones is expected to increase rapidly in the upcoming years. Use cases, excluding military applications, include public services, such as medical or emergency transport, surveillance and inspection, but also commercial delivery of goods and food. Air taxis, i.e. larger UA to transport passengers, are also expected in some years. It is expected that all Europeans will start seeing and hearing drones regularly in their living area before 2030 ⁽¹²¹⁾.

The sound emitted by drones is distinctive, although highly dependent on factors such as drone type, size, propeller design and operational phase (i.e. take-off, landing, hovering or cruise). Noise characteristics vary significantly, with higher perceptibility typically during low altitude operations and lower impact during high-altitude cruise. Drone noise levels are not necessarily higher than common urban sound sources such as road traffic or conventional aviation, depending on context and exposure. Studies from various institutes show, however, that the spectral and temporal characteristics of drone sounds cause them to be more distinctive (i.e. more noticeable, attracting more attention) and disturbing than road traffic and conventional aviation, even at the

¹²¹ EPA Network Interest Group on Noise Abatement (IGNA), Peeters B and Schwanen W, *Noise from Drones*, report M+P.BAFU.22.01.2 (final), 2024-09-12, <https://epanet.eea.europa.eu/reports-letters/reports-and-letters/interest-group-noise-noise-from-drones-1.pdf/view>

same overall noise level (^{122,123,124}). Psychoacoustic sound indicators, such as sharpness, roughness and tonality, are suggested by these researchers to capture the specific acoustic characteristics of drone noise. Research from the MUSE project (¹²⁵) indicates, however, that there is currently no consensus on appropriate noise metrics for drones, and that subjective aspects such as visual presence, visual pollution and privacy concerns remain difficult to quantify. Research shows that noise and other environmental problems, such as the impact on wildlife, are among people's top concerns (¹²⁶).

6.3.2. Regulations and policy

The Commission has established regulations for UA systems and operations, with two important regulations being:

- EU regulation 2019/945 (¹²⁷) provides technical requirements for Unmanned Aviation Systems (UAS), i.e. the UA itself plus ground equipment, communication systems, etc. The regulation defines different UA classes C1 to C6 based on technical properties and weight (up to 25 kg). It also includes maximum sound power levels for classes C1 and C2, ranging from 81 to 97 dB(A) depending on the weight.

¹²² Schäffer B et al., *Drone Noise Emission Characteristics and Noise Effects on Humans—A Systematic Review*, Int. J. Environ. Res. Public Health 2021, 2021-06-01, <https://doi.org/10.3390/ijerph18115940>

¹²³ Torija AJ et al., *Psychoacoustic Characterisation of a Small Fixed-pitch Quadcopter*, Proceedings of Inter-Noise 2019 Madrid, 2019-06, https://www.sea-acustica.es/INTERNOISE_2019/Fchrs/Proceedings/1423.pdf

¹²⁴ Lotinga MJB et al., *Noise from Unconventional Aircraft: A Review of Current Measurement Techniques, Psychoacoustics, Metrics and Regulation*, Current Pollution Reports, 2023-12-07, <https://doi.org/10.1007/s40726-023-00285-4>

¹²⁵ <https://musesesarproject.eu/>

¹²⁶ European Aviation Safety Agency (EASA), McKinsey & Company, *Study on the societal acceptance of Urban Air Mobility in Europe*, 2021-05-19, <https://www.easa.europa.eu/en/full-report-study-societal-acceptance-urban-air-mobility-europe>

¹²⁷ Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems, Consolidated text, 2025-06-24, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02019R0945-20250624>

- EU regulation 2019/947 ⁽¹²⁸⁾ establishes rules for UAS operations and operators. It defines operations in the ‘open’, ‘specific’ and ‘certified’ category, with increasingly strict requirements for the UAS, pilots and registration. Both the ‘specific’ and ‘certified’ category allow for operations beyond the visual line of sight (BVLOS), where the ‘certified’ category allows high-risk UA operations such as in denser urban areas. This regulation allows Member States to prohibit or restrict UAS operations and/or require UAS operations to meet specific environmental standards (including noise).

In their EU Drone Strategy 2.0 ⁽¹²⁹⁾, the Commission foresees a future where drones play an important role in European mobility, but it wants to ensure that society supports this. The strategy calls for national, regional and local municipalities to ensure that drone services are aligned with citizens’ needs. It concludes that the drone sector must be mindful of its environmental impact in terms of noise, energy consumption and visual nuisances. The Strategy references the Zero Pollution Action Plan, which links with the environmental targets set for EU transport policies, including noise and air pollution.

6.3.3. Noise measurement and modelling methods

Noise measurement methods

- The maximum sound power levels for class C1/C2 drones in EU regulation 2019/945 are based on the generic ISO3744 measurement method ⁽¹³⁰⁾ that is also used for other noise sources such as industrial installations or outdoor equipment.
- The ISO5305 standard ⁽¹³¹⁾ defines noise measurement methods specifically for UAS up to 150 kg, including laboratory, wind tunnel and outdoor measurements.

¹²⁸ Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft, Consolidated text, 2025-05-01, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02019R0947-20250501>

¹²⁹ Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – *A Drone Strategy 2.0 for a Smart and Sustainable Unmanned Aircraft Eco-System in Europe*, COM(2022) 652 final, https://transport.ec.europa.eu/system/files/2022-11/COM_2022_652_drone_strategy_2.0.pdf

¹³⁰ ISO 3744:2010, *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane*, 2010-10

¹³¹ ISO 5305:2024, *Noise measurements for UAS (unmanned aircraft systems)*, 2024-01

- EASA has published noise measurement guidelines for UAS up to 600 kg operating in the specific category ⁽¹³²⁾. EASA intends to further develop and prescribe this method, rather than the ISO5305, as a basis for sound power limits for larger drones (classes C5/C6).

Noise modelling

Current aircraft noise modelling tools, based on Doc29 ⁽⁹⁹⁾ including AEDT ⁽¹⁰¹⁾ and the strategic noise mapping methods in END Annex II, do not allow for calculations of drone noise exposure. For this purpose, EASA is developing the NORAH2 model ⁽¹³³⁾ that allows sound immission calculations for rotorcraft, i.e. helicopters and propeller drones. The current version of NORAH2 is provided as an open-access software tool and includes pre-measured sound emission data for several helicopter types. EASA has announced ⁽¹³⁴⁾ that they will develop and publish such data also for drones, and that they will engage with the Commission to integrate the NORAH2 model into the Environmental Noise Directive.

Noise modelling of drones will also require the definition of drone flight paths as well as traffic data: the number of drone flights, the types of drones, flight speeds and other operational data. This is currently a topic of drone researchers, e.g. ^(135,136,137), but no standardised methodology is available yet.

6.3.4. Noise measures and recommendations for NAPs

In Europe, unmanned air mobility is currently still at a very low level, with very limited operations in residential areas, often related to pilot projects. As such the health impact as well as the number of complaints is yet low. With the potentially strong rise of drone flights also in urban skies, a future negative impact on noise and public health is a reasonable concern ⁽¹²⁰⁾.

¹³² European Aviation Safety Agency (EASA), *Guidelines on Noise Measurement of Unmanned Aircraft Systems Lighter than 600 kg Operating in the Specific Category (Low and Medium Risk)*, 2023-06-12, <https://www.easa.europa.eu/en/document-library/product-certification-consultations/guidelines-noise-measurement-unmanned-aircraft>

¹³³ <https://www.easa.europa.eu/en/research-projects/environmental-research-rotorcraft-noise>

¹³⁴ <https://www.easa.europa.eu/en/newsroom-and-events/events/webinar-upgrade-noise-rotorcraft-model-norah-final-dissemination-event>

¹³⁵ SESAR Joint Undertaking research project MUSE, <https://musesesarproject.eu/>

¹³⁶ EU Horizon Europe research project RefMap, <https://www.refmap.eu/>

¹³⁷ LeGriffon I, Ruaud E, *Drone fleet noise impact calculation – a methodology*, proceedings Inter-Noise 2024 Nantes, 2024-08, <https://hal.science/hal-04711864/document>

Specific noise measures to prevent or reduce drone noise impacts cannot be currently provided, but will be along similar lines as for general aircraft noise such as prescribed by the Balanced Approach, i.e.:

- reduction of noise at source by developing standards and noise emission limits for UA;
- land-use planning and management to separate regions with higher intensity UA operations from residential and nature areas, such as by careful planning of drone corridors and take-off and landing hubs ('vertiports');
- noise abatement operational procedures, such as low-noise take-off and landings. For drones in particular, which fly at much lower heights than other aircraft, minimum flight heights may be instated, as well as limitations to hovering (i.e. still-hanging) procedures such as during package drop-off;
- operating restrictions to limit UA operations in certain geographical zones (i.e. 'no-fly zones'), either as a full ban, limited to certain drone types or use cases (e.g. only emergency drones) and/or to certain times of day.

As such specific measures cannot currently be advised, only general recommendations can be given with regards to NAPs:

- It is advised, also by the Commission, that NAPs for agglomerations include a section on drone noise. Cities and citizens should familiarise themselves with the topic of drones, be aware of the potential future noise issues and start developing local policies.
- Cities and regional authorities have an important role in the future of drone mobility. They should
 - engage with their citizens to form a supported opinion on where, how and when drones should be allowed to operate;
 - engage with their national environmental and aviation authorities, to discuss what their options are in terms of allowing or restricting operations, and how governance over the local airspace can be arranged;
 - be prepared for requests for permissions to operate from drone service providers, and requests for prohibiting this from residents.

In parallel, development of noise assessment methods on the EU level should continue, to enable quantitative support for decisions on drone noise policy and measures. Member States will certainly need guidance to implement such methods on national and local scales.

7. Propagation, receiver and planning measures

7.1. Overview

Measures in the preceding chapters mainly aim to reduce noise at the source, limiting the sound emissions. This chapter describes noise measures that are taken after the sound has been generated and travels through the air to the receiver. Whereas source measures are generally source-specific, the measures in this chapter are more general, or 'horizontal', in the sense that they apply to multiple, or any sources of sound.

- Noise *propagation* measures exist to prevent emitted sound from reaching the receiver, by blocking, diverting or absorbing it.
- Further down the path, measures can be taken at the *receiver* side. The receiver in this case is defined as the individual dwelling or building that people live in.
- *Urban planning* measures focus on the geographic distribution of activities, typically separating residents from noisy activities, or other measures that improve the acoustic quality on an area scale.

Table 5 below presents the most important horizontal measures to reduce the noise emissions in the propagation path or at the receiver. For each measure, a valuation of the different selection criteria is indicated, following the definitions given in § 2.1 above. The values are indicative and based on expert judgment by the authors. Each measure is described in a separate factsheet in § 7.2 to § 7.4.

Table 5 – Overview of horizontal noise measures

Noise measure	Noise reduction	Costs	Applicability	Scale of impact	Availability	Co-benefits	Constraints	Stakeholder complexity	Maturity	Information level
Noise barriers	1	-1	0	-1	1	0	0	0	1	1
Acoustic building insulation	1	-1	1	-1	1	0	1	0	1	1
Noise zoning	1	0	0	0	1	0	1	-1	1	1

7.2. Propagation measures

7.2.1. Noise barriers



Source: Municipality Diemen
Motorway noise barrier with solar panels



Source: Eurekarail
Green (coconut fibre) noise barrier



Source: Wikipedia
Railway noise barrier



Source: Gramm Barrier Systems
Steel sound-absorbing noise barrier

Noise reduction mechanism

Noise barriers are a common measure to prevent sound emitted by a source to travel (propagate) to the receiver. Noise barriers are applied as a noise measure for various sources, including road or rail traffic, ground-borne airport noise and industrial sources. Temporary barriers also exist, e.g. for construction noise.

Noise barriers block the sound from passing through (*insulation*). The barrier prevents noise emitted by the source from reaching the receiver on the other side of the barrier. Instead, the sound is reflected back towards the source (*reflection*), unless the barrier itself is sound-absorbing (*absorption*). A smaller fraction of the sound will bend over the edge of the barrier (*diffraction*) and still reach the receiver. The effectiveness of the noise barrier increases with its height.

Key Characteristics

Property	Value
Type of Measure	propagation
Typical Scale / Dimensions	<ul style="list-style-type: none"> • 1 – 10 m high • 50 m to several km long • preferably close to the source, i.e. within 2 – 20 m
Typical Materials / Tools	<ul style="list-style-type: none"> • Noise barriers are mostly made of concrete, wood, glass or polycarbonate panels, possibly with metal frames. • Sound-absorbing noise barriers mostly consist of fiberglass, mineral wool or foam inside perforated (aluminium) enclosures. • 'Green' barriers exist that are made of natural materials, such as moss, coconut mats, or substrates with growing vegetation. These materials are mostly used to cover a concrete core that is the functional barrier.
Lifespan / Maintenance	Barriers have a lifespan of up to 50 years without losing acoustic performance. Maintenance is limited to graffiti removal, or ground improvements if the soil below settles. Wooden barriers and/or panel constructions need to be checked every few years for gaps and cracks, which should be closed.
Regulatory Status	CE-certification applies following EN 14388 ⁽¹³⁸⁾

Effectiveness

Noise reduction

Typically 5 to 20 dB at the receiver, influenced by:

- height of the barrier, with respect to the direct line of sight between source and receiver (higher = more reduction)
- the distance between the source and the barrier (larger distance = less reduction)
- the distance between the barrier and the receiver (larger distance = less reduction)
- the barrier material and thickness:
 - if the mass exceeds 40 kg/m² surface area, transmission through the barrier is negligible; lighter barriers (e.g. glass or polycarbonate) may let through some sound
 - noise may leak through metal posts and frames, as well as through gaps and cracks

¹³⁸ EN14388:2015, *Road traffic noise reducing devices – Specifications*

- wind: noise reduction is less in downwind conditions (wind blowing from source to receiver)

Other acoustic effects

Non-absorbing (reflective) sound barriers will reflect sound waves back to the direction of the source. In case of noise-sensitive buildings on the opposite side, e.g. the other side of the road or railway, barriers should be constructed at both sides and/or should be sound-absorbing. Alternatively, backwards-tilted barriers can be used which reflect the sound skywards.

Impact area

Noise is only reduced behind the barrier, corresponding approximately with receiver locations where there is no direct line of sight to the source. The reduction decreases with increasing distance from the barrier: more than ca. 250 m away from the barrier the reduction will be considerably less, limited to only a few dB.

Advantages

- High noise reduction
- Long lifespan with low maintenance
- Visual separation from the source may enhance the perception of quietness and safety
- May be combined with photovoltaic panels for energy harvesting

Limitations

- Space requirements, certainly in urban environments
- Access requirements, i.e. flight doors, animal passings
- Requirements for soil foundation, potentially conflicting with ground cables and pipes;
- Relatively expensive, compared to other noise measures
- Visual intrusion for nearby residents, as well as on the source side (road and rail users)

Costs

Approximate costs

Cost figures range from approximately €1000 to €3000 for a 4-meter-high noise barrier ⁽¹³⁹⁾, adjusted to 2024 price level, varying between countries and depending on what costs are included in such figures.

Detailed cost calculations

A complete cost calculation for noise barriers should include:

- materials and construction
- yearly maintenance and cleaning
- design and engineering
- traffic measures during construction
- project management

Noise modelling

Noise barriers are included in END Annex II (CNOSSOS-EU) and implemented in common noise assessment software such as SoundPLAN or CadnaA.

Information is required on:

- horizontal location
- height, with respect to local ground
- sound-absorption or reflection coefficient

To calculate the effect of reflections, slanted (non-perpendicular) noise barriers are considered as perpendicular if the angle with respect to the vertical is $< 15^\circ$. For more than 15° angles, reflections are not taken into account. CNOSSOS-EU also allows for more complex propagation situations, such as multiple diffracting objects or retrodiffraction.

Other national noise assessment methods also include the effect of noise barriers, although the implementation details will slightly differ.

Doc29 for aircraft noise ⁽⁹⁹⁾ and the IMPACT and AEDT ⁽¹⁰¹⁾ software implementations do not natively include noise barriers. For ground-borne airport

¹³⁹ Conference of European Directors of Roads (CEDR), Vanhooreweder B et al., *State of the art in managing road traffic noise: noise barriers*, Technical Report 2017-02, 2017-01, <https://www.cedr.eu/download/Publications/2017/CEDR-TR2017-02-noise-barriers.pdf>

noise, additional calculations using the methods mentioned above should be used.

Implementation

Considerations

- Land must be available or acquired for barrier placement.
- Public communication and consultation regarding the barrier placement are advised, beyond the regular noise action planning consultation. Management of expectations is important: residents may think the noise source will no longer be audible, which is not the case.
- EN standards to specify and measure the acoustic insulation, absorption and diffraction properties of noise barriers exist, for road (¹⁴⁰) and railway (¹⁴¹) barriers.
- Barrier construction contracts should include a check for compliance with requirements, including acoustic performance, shortly after installation. Also, monitoring of acoustic performance over the barrier lifetime is advisable. This may include visual checks as well as acoustic measurements (¹⁴²).

Timeline

Several months up to 2 years for planning, engineering and consultation. Several weeks or months for construction, depending on barrier complexity, local circumstances and terrain.

Stakeholders

Depending on the source: road, rail or airport authority, municipality and nearby residents, contractors, designers and acoustic consultants.

¹⁴⁰ EN1793-1 to EN1793-6: *Road traffic noise reducing devices - Test methods for determining the acoustic performance*

¹⁴¹ EN16272-1 to EN16272-7: *Railway applications – Infrastructure – Noise barriers and related devices acting on airborne sound propagation. Test method for determining the acoustic performance*

¹⁴² Conter M et al., *SOPRANOISE – a New Quick Method for Measuring the Acoustic Quality of Noise Barriers In-Situ*, Transportation Research Procedia, 2023, <https://www.sciencedirect.com/science/article/pii/S2352146523007482>

7.3. Receiver measures

7.3.1. Acoustic building insulation



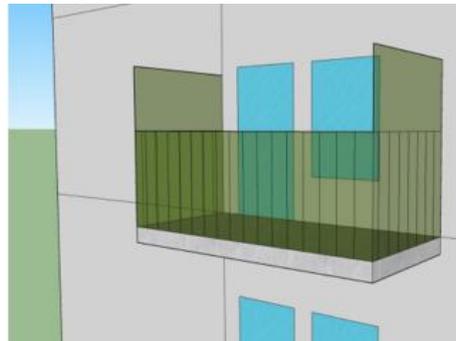
Source: Rijkswaterstaat
Roof insulation



Source: wikihow.com
Additional window pane installation



Source: Neuffer
Triple-glazing windows



Source: City of Gothenburg
Transparent balcony noise screens

Noise reduction mechanism

The indoor acoustic environment, inside houses or other noise-sensitive buildings (e.g. schools, hospitals) can be improved by keeping the outdoor noise from passing the façade. Usually, the weakest acoustic insulation points are windows, doors, ventilation ducts and roofs. In some cases, insulation of façade walls can lead to additional improvement. Bedrooms are particularly relevant to avoid sleep disturbance. To block exterior noise, airborne sound insulation is of particular interest, whereas impact sound insulation, such as from footsteps or equipment, is mainly relevant to block noise from one room to another or from neighbour to neighbour.

Airborne sound insulation can be improved by various techniques, such as double or triple window glazing, or applying cavity wall or roof insulation materials. Specialized ventilation systems exist that allow ventilation while limiting sound passing through. Balconies can be shielded with transparent screens, reducing also indoor noise.

Key Characteristics

Property	Value
Type of Measure	receiver
Typical Scale / Dimensions	<ul style="list-style-type: none"> Insulation measures affect the indoor sound quality of a single house or other noise-sensitive building, or parts of it Insulation programs are typically bound to the vicinity of infrastructure projects, airports, etc., up to several 100 m to multiple km away Some Member States have national noise sanitation projects in place that include building insulation grant schemes
Typical Materials / Tools	Insulation addresses the acoustically 'weakest' points where exterior noise passes indoor: <ul style="list-style-type: none"> window replacements by double / triple glazing windows retrofitting of windows and ventilation openings using additional soundproofing panes or sound-absorbing ventilation ducts improved sealing, to resolve acoustic leakages isolation of existing roofs and facades, e.g. using absorbing materials in wall cavities, retrofitting soundproofing roof layers
Lifespan / Maintenance	> 30 years
Regulatory Status	Many European countries have national regulations that mandate acoustic building insulation measures around infrastructure, airports or within certain noise zones. ISO- and EN-standards exist for specification and measurements of building elements and materials used for airborne sound insulation, including ISO 717-1 ⁽¹⁴³⁾ , ISO 10140 series ⁽¹⁴⁴⁾ , ISO 12354-3 ⁽¹⁴⁵⁾ and ISO 16283-3 ⁽¹⁴⁶⁾

¹⁴³ ISO 717-1:2020, *Acoustics — Rating of sound insulation in buildings and of building elements — Part 1: Airborne sound insulation*

¹⁴⁴ ISO 10140-1 to ISO10140-5, *Acoustics — Laboratory measurement of sound insulation of building elements*

¹⁴⁵ ISO 12354-3:2017, *Building acoustics — Estimation of acoustic performance of buildings from the performance of elements, Part 3: Airborne sound insulation against outdoor sound*

¹⁴⁶ ISO 16283-3:2016, *Acoustics — Field measurement of sound insulation in buildings and of building elements, Part 3: Façade sound insulation*

Effectiveness

Noise reduction

A sufficiently insulated façade can attenuate the exterior airborne sound by over 45 dB $D_{nT,w}$ ⁽¹⁴⁷⁾, whereas a poorly insulated façade (i.e. single glazing, poor sealing) may only attenuate 25 dB. The effect of the measure can lead, therefore to up to 20 dB indoor noise reduction, depending on the baseline insulation quality, which is typically lower for older buildings.

Other acoustic effects

Low frequency noise is more difficult to keep out than higher frequency noise. The $D_{nT,w} + C_{tr}$ value, which includes the C_{tr} spectrum correction factor accounting for low frequency noise, may therefore be better suited for sounds with higher low frequency content.

Impact area

Façade insulation only works to reduce indoor noise. The effect on overall annoyance and health is therefore smaller than for source or propagation measures, as people are annoyed also in outdoor private or public spaces.

Advantages

- Targeted solution: effective and efficient in cases where a small number of buildings is affected by the noise.
- Can be applied if further source and propagation measures are not possible or not sufficient.
- Acoustic building insulation also improves thermal insulation, leading to improved building energy efficiency.

Limitations

- For newer or retrofitted buildings that are already well (thermally) insulated, there may be little room for improvement, or only with more invasive measures such as additional window panes.

¹⁴⁷ $D_{nT,w}$ = single number value of the airborne sound insulation between room, used to characterize the sound insulation between rooms in buildings, based on ISO 16283-3 ⁽¹⁴⁶⁾ and ISO 717-1 ⁽¹⁴³⁾ standards.

- Relatively costly when applied to larger residential areas, as costs scale directly with the number of buildings to be insulated.

Costs

Approximate costs

Costs for acoustic insulation of a building vary widely depending on what actual measures are needed, for example:

- Window replacement: €250 – €500
- Door replacement: €750 – €1000
- Acoustic vents: €300 – €400
- Wall and ceiling insulation: €100 – €150 per m²

Several governmental insulation programs provide financial aid for insulation of buildings, including costs for acoustic advice, design and installation. Some recent examples of budgets per building found in existing programmes:

- Province of Zuid-Holland (NL), Noise Action Plan 2024-2029 ⁽¹⁴⁸⁾: €1.240 to €15.307 depending on the reduction objective in dB
- Luxembourg Airport: actual costs up to maximum €16.000 for a house and €8.000 for an apartment ⁽¹⁵¹⁾
- Berlin general window insulation programme, based on noise mapping results: maximum 90% of actual costs up to €15.000 ⁽¹⁴⁹⁾
- Munich general insulation programme: up to €150 per m² of improved living space ⁽¹⁵⁰⁾

Detailed cost calculations

Detailed cost calculations require the number of noise-sensitive objects to be insulated, which could include a noise map analysis to obtain the number of objects above the minimum threshold. Additionally, information about the current state of insulation for each building would increase the accuracy.

¹⁴⁸ https://lokaleregelgeving.overheid.nl/CVDR742136/1#cmp_A_content_o_5

¹⁴⁹ <https://www.berlin.de/sen/uvk/umwelt/laerm/schallschutzfensterprogramm/>

¹⁵⁰ <https://stadt.muenchen.de/service/en-GB/info/funding-for-noise-protection-living-without-noise/10439427/n0/>

Noise modelling

The effect of façade insulation on health and sleep disturbance is difficult to quantify as most exposure-response functions, including END Annex III, are based on outdoor noise levels. WHO-recommended indoor noise levels ⁽¹⁵¹⁾ are

- $\leq 30 \text{ dB(A)}$ L_{Aeq} average in bedrooms at night, to prevent sleep disturbance
- $\leq 35 \text{ dB(A)}$ L_{Aeq} average in living rooms to avoid annoyance and cognitive effects
- $\leq 45 \text{ dB(A)}$ L_{Amax} for short-term events (e.g. aircraft flyovers)

The implementation of façade insulation schemes does require noise modelling to determine outdoor noise exposure levels, in order to determine which noise-sensitive buildings are eligible. For this purpose, regular noise assessment methods such as those used for strategic noise mapping can be used. Existing noise mapping data may suffice, depending on the implementation goals.

Implementation

Considerations

- To identify which buildings are eligible for façade insulation, a minimum outdoor threshold value (L_{den} or L_{night}) may be established. Often this is combined with a maximum indoor threshold value, which then requires a certain minimum façade attenuation.
- Façade insulation is used in national noise regulations for several Member States as a 'last resort' measure in case source and propagation measures are not possible, not sufficient or considered too expensive given a limited number of affected people.
- Information about the current state of acoustic building insulation may be lacking: the national property register often does not provide information whether or not a building was previously insulated. Inspection of individual buildings may then be required to identify eligible insulation candidates. When implementing this measure, registration of buildings that undergo acoustic insulation measures is important.
- Also, installation of insulation measures requires permission and cooperation of building owners. Buildings whose owners choose to waver

¹⁵¹ World Health Organization (WHO), *Guidelines for Community Noise*, 1999, <https://www.who.int/publications/i/item/a68672>

their rights for government-sponsored insulation should also be registered.

Timeline

For a single building:

- Design and planning: 1 - 3 months.
- Installation of measures: one to several days.

For larger scale projects: in infrastructure projects, façade insulation is generally integrated as part of project planning. Building insulation as part of a governmental noise sanitation program may take one or several years depending on scale.

Stakeholders

Local or national government, municipalities, individual citizens, designers / architects, building contractors. If related to infrastructure or airports, also the road, rail or airport authorities.

Further documentation

Some examples of recent insulation programmes:

- Luxembourg airport provides financial aid to for advice and installation of insulation measures for residential buildings built before 31 August 1986 ⁽¹⁵²⁾. Similar schemes exist for Dublin airport ⁽¹⁵³⁾, Schiphol airport ⁽¹⁵⁴⁾ and many others, some of which are also described in case study descriptions from the ANIMA project ⁽¹⁵⁵⁾.
- Munich ⁽¹⁴⁹⁾ and Berlin ⁽¹⁴⁸⁾ provide general insulation aid based on noise mapping information. Residents can check for eligibility by looking at the map or entering their address.

¹⁵² <https://guichet.public.lu/en/citoyens/aides/logement-construction/aides-capital/isolation-acoustique-bruit-aerien.html>, 2023-12-22

¹⁵³ <https://www.dublinairport.com/corporate/environmental-social-governance/noise/mitigation-schemes/residential-noise-insulation-schemes>

¹⁵⁴ <https://zoek.officielebekendmakingen.nl/stcrt-2023-26407.html>, 2023-09-28

¹⁵⁵ <https://anima-project.eu/noise-platform/protect-people-from-noise-exposure.html>

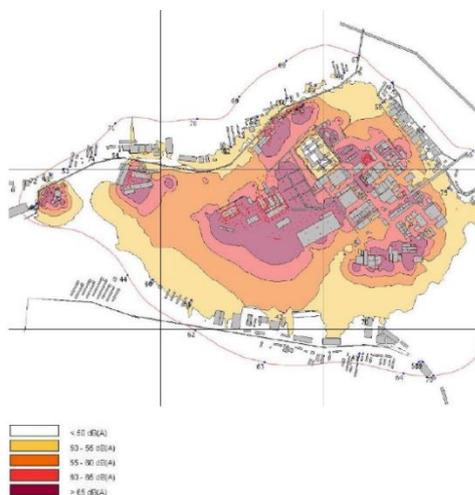
- National Highways in the UK have implemented a noise insulation scheme, limited to Noise Important Areas (hotspots) identified by the Department for Environment, Food and Rural Affairs ⁽¹⁵⁶⁾.
- A Dutch startup, DeNoise, is developing active noise cancelling window systems that actively reduce the vibrations of the window glass ⁽¹⁵⁷⁾.

7.4. Urban planning measures

7.4.1. Noise zoning



Source: <https://www.wijnenstael.nl/>
Urban planning



Source: M+P
Noise contours around industrial zones

Noise reduction mechanism

A good principle in urban planning is to separate areas with high noise exposure, such as close to roads, railways, airports and industrial activities, from residential areas with housing, schools, hospitals and parks. This principle can be formalised in regulations by means of *zoning*. This involves the designation of geographical zones in which only certain types of activities or buildings are allowed, e.g.:

- *inward zoning*: noisy activities are restricted within a certain distance from residential areas;

¹⁵⁶ <https://nationalhighways.co.uk/our-work/environment/communities/noise/noise-insulation-scheme/>

¹⁵⁷ <https://www.denoize.com/>

- *outward* zoning: residential development is restricted within a certain distance from infrastructure, airports or industrial sites.

Restrictions for activities may be defined in different ways. Zones may be limited to certain functional activities, e.g. industrial, commercial or residential zones where only specific functions are allowed. They may also be defined based on the calculated or prognosed noise emission or immission level, either for individual companies or installations, or as a 'noise budget' for the zone as a whole which allows for more dynamic noise control and management.

Acoustic zoning is often combined with other environmental zoning, such as for air quality, odour or external safety.

Key Characteristics

Property	Value
Type of Measure	planning
Typical Scale / Dimensions	Zone sizes vary from several hundred m ² to multiple km ² .
Typical Materials / Tools	<ul style="list-style-type: none"> • local or national regulations to allow restrictions on use functions for designated areas • noise calculation and mapping tools, including prognostic input data • measurement and calculation tools and standards for monitoring the actual noise levels in or around zones • enforcement processes and sanctions
Lifespan / Maintenance	Acoustic zones may need regular evaluation and processes for adapting them to follow urban or industrial developments.

Property	Value
Regulatory Status	<p>Zoning regulations including noise zones exist in many EU Member States, for example:</p> <ul style="list-style-type: none"> • Germany: the TA Lärm sets noise limits for different land-use zones ⁽¹⁵⁸⁾, e.g. residential, mixed-use, industrial • Italy: the law no. 447/1995 ⁽¹⁵⁹⁾ requires municipalities to adopt acoustic zoning, defining six noise classes ranging from quiet, residential and mixed-use up to strictly industrial areas • Netherlands: for roads, railways and industrial areas, ‘noise attention areas’ have recently replaced regulatory zoning. In these areas, residential developments are subject to noise impact assessments and restricted to maximum immission levels ⁽¹⁶⁰⁾ <p>For aircraft noise, the EU Balanced Approach Regulation 598/2014 ⁽⁹²⁾ encourages Member States to use acoustic zoning tools to guide urban development around airports. ICAO Doc 9184 provides guidance regarding acoustic zoning in airport planning ⁽¹⁶¹⁾.</p> <p>Various ISO-standards exist to support monitoring of environmental noise in acoustic zones, see below.</p>

Effectiveness

Noise reduction

Most national examples of acoustic zoning include definitions of maximum noise exposure levels in terms of L_{den} and L_{night} , or similar long-term average metrics.

For areas that are dedicated to residential use, maximum façade exposure levels are typically 55 to 60 dB(A) L_{den} or L_{day} . For areas with higher levels, such as mixed-use or commercial areas, there are often requirements for façade insulation or quiet building sides. Within industrial zones or zones close to transport infrastructure or airports, which may allow exposure levels of 70 dB(A) or more, residential buildings are typically not allowed. However, the limit values

¹⁵⁸ *Technische Anleitung zum Schutz gegen Lärm – TA Lärm*, https://www.verwaltungsvorschriften-im-internet.de/bsvwbund_26081998_IG19980826.htm

¹⁵⁹ *Legge quadro sull'inquinamento acustico*, no. 447, 1995-10-26, <https://www.isprambiente.gov.it/files/temi/legge-447-95.pdf>

¹⁶⁰ <https://iplo.nl/thema/geluid/geluid-regelgeving/geluidaandachtsgebied/>

¹⁶¹ ICAO Doc 9184, *Airport Planning Manual – Part II – Land Use and Environmental Management*, Fourth Edition, 2018

that apply, as well as the consequences of exceeding these limits, vary widely between countries (¹⁶²).

Other acoustic effects

In some national zoning regulations for industrial areas there are additional requirements for tonal, impulsive or musical sounds. Penalty factors often apply to such sounds to account for their higher noticeability and disturbance.

Besides long-term average exposure levels, there are also examples of restrictions for short-term events. German regulations for aircraft noise, for instance, allow no more than six events with a $L_{A,max}$ above 72 or 68 dB(A) (¹⁶⁰).

Impact area

Acoustic zones may be defined as noise contours, following a noise mapping calculation, that limit the exposure level within that area. For zones that are not defined based on functional activities rather than noise levels, the impact reaches up to several 100 m or a few km around the zone.

Advantages

- Clear separation of activities improves general liveability of residential areas.
- Can be integrated with other environmental zones or zone criteria such as air quality, odour and external safety.

Limitations

- Requires monitoring and enforcement of actual activities and noise levels to guarantee compliance with zone restrictions, as well as a complaints management process.
- Difficult or not possible to implement for existing situations, where noisy activities and residential areas are already close together. Retrofitting existing situations may require relocation of existing activities or houses.
- May have little political support in locations with significant housing shortages.

¹⁶² EPA Network Interest Group on Noise Abatement, Peeters B, Nusselder R, *Overview of critical noise values in the European Region*, 2019-10-09, https://epanet.eea.europa.eu/reports-letters/reports-and-letters/ig-noise_critical-noise-values-in-eu.pdf/view

Costs

Approximate costs

Direct costs associated with implementing noise zones include:

- Noise mapping calculations and consultancy: €10.000 to €50.000 depending on size and complexity;
- Noise monitoring measurements: €5.000 to €15.000 for permanent installations, or €1.000 to €3.000 per individual case. May be partially funded by financial sanctions in case of offences.

Indirect economic effects include changes in land and property value, which could be negative, i.e. less space available for industrial or residential developments, or positive, i.e. increase of land and housing prices in residential areas, or more room for industrial activities if well separated from noise-sensitive areas.

Noise modelling

Noise mapping calculations may be done with any commonly used noise calculation method and software capable of calculating noise exposure from the relevant sources. Several national noise assessment methods exist, and END Annex II (CNOSSOS-EU) can also be used for this purpose.

For standardisation of such software, the ISO 9613 ⁽¹⁶³⁾ and ISO 17534 ⁽¹⁶⁴⁾ are important standards describing how outdoor sound propagation should be implemented. ISO 17534 Part 4 specifically covers implementations of CNOSSOS-EU.

¹⁶³ ISO 9613, *Acoustics – Attenuation of sound during propagation outdoors*, Part 1 and 2

¹⁶⁴ ISO 17534, *Acoustics – Software for the calculation of sound outdoors*, Parts 1 - 4

Implementation

Considerations

- For noise monitoring in and around acoustic zones, ISO measurement standard 1996 ⁽¹⁶⁵⁾ is of particular relevance, as well as ISO 20906:2009 ⁽¹⁶⁶⁾ for airport noise.
- Acoustic zoning is often connected to acoustic building insulation schemes (see § 7.3.1), where requirements and subsidies for insulation apply to zones where higher noise levels are permitted (i.e. mixed-use or commercial zones, zones closer to airports and transport axes).

Timeline

- 1 – 2 years for noise impact assessments, planning and design, stakeholder participation and legal implementation
- continuous monitoring and enforcement

Stakeholders

Municipalities, citizens, local businesses, urban planners, environmental consultants

¹⁶⁵ ISO 1996, *Acoustics – Description, measurement and assessment of environmental noise*, Part 1, 2 and 3

¹⁶⁶ ISO 20906:2009, *Acoustics - Unattended monitoring of aircraft sound in the vicinity of airports*, 2009-12

8. Agglomerations

8.1. Overview

Road, rail and air traffic are main sources of noise-related annoyance and health impact both in- and outside agglomerations. In addition, industrial installations are important urban noise source, which in recent years include an increasing contribution from wind turbines. And for those agglomerations that contain or fall within a port area, shipping movements as well as noise from moored ships and port activities (e.g. loading and unloading) may be a considerable noise problem.

This chapter does not contain further noise fact sheets regarding additional noise measures for agglomerations, because:

- many of the noise measures for road, rail and air traffic described in the previous chapter also apply to agglomerations, albeit with some implementation differences;
- for industrial installations, source measures are so specific to each individual installation that a generic description of such measures is not feasible;
- many agglomerations will implement generic (horizontal) noise measures, such as façade insulation and noise zoning, which are described in Chapter 7;
- for shipping and port noise, not enough information is available for complete fact sheets. Some available information is given further below.

In the paragraphs below, source-specific noise measures are shortly described, with reference to factsheets in earlier chapters where appropriate. For measures where complete factsheets are not available, general information and references to other available materials are given.

Table 6 – Overview of noise measures for agglomerations

Noise measure	Section(s)
Road traffic noise	
Promotion of low noise tyres	§ 4.2.1 and § 8.2.1
Low noise pavements	§ 4.2.2 and § 8.2.2
Pavement maintenance and discontinuities	§ 4.2.3 and § 8.2.3
Lower speed limits for urban roads	§ 4.2.5
Promotion of electric vehicles	§ 8.2.4

Noise measure	Section(s)
Urban railway noise	
Curve squeal	§ 8.3.1
Parked trains	§ 8.3.2
Shipping and port noise	
General description incl. onshore power supplies	§ 8.4
Aircraft noise	
General aircraft noise measures	§ 6.2
Drones (Unmanned Aviation)	§ 6.3
Propagation, receiver and planning measures	
Noise barriers	§ 7.2.1
Acoustic building insulation	§ 7.3.1
Noise zoning	§ 7.4.1

8.2. Urban road traffic noise measures

8.2.1. Promotion of low noise tyres

See § 4.2.1 for the fact sheet on low noise tyres.

Implementation

For cities, promotion of low noise tyres should focus on communication campaigns on a regional scale.

- Cities should target local garages, tyre businesses and lease companies by communication campaigns to raise awareness of their role in environmental noise reduction.
- Financial incentives for local businesses could include discounts on low noise tyre brands and types, as well as procurement advantages, such as for the city-owned vehicle fleet, for public transport services and in taxi licensing systems.
- Cities are in a better position than national authorities for communication campaigns targeting tyre buyers, as they operate closer to citizens. Cities should use existing communication channels, such as local news, newsletters, roadside billboards, etc. to raise awareness and promote any financial incentives.

- Some cities have financial support available for low-income households, which could also be used to enable these citizens to buy new low-noise tyres, allowing them to participate in environmental improvements.

Noise reduction and scale of impact

City traffic also consists of people from outside the city who cannot be targeted by such measures, which limits the noise reduction effect on a local scale. There will be, however, a positive aspect beyond the boundaries of the city when citizens travel further away.

8.2.2. Low noise pavements

See § 4.2.2 for the fact sheet on lower speed limits for urban roads.

Urban roads typically have lower driving speeds (30 – 80 km/h) and more acceleration, deceleration and cornering which puts more horizontal stresses on the pavement. This makes such roads less suitable for (highly) porous, sound-absorbing pavements, as these are more vulnerable to such stresses leading to shorter lifespan and more maintenance, resulting in higher costs and more roadworks.

However, low-noise pavement types certainly exist that are suitable for urban roads, usually based more on texture optimisation than on sound absorption. In the Netherlands, acoustically optimised Stone Mastic Asphalt (SMA) variations have been developed, and in Switzerland the SDA4 pavement with small stone aggregates is a common example.

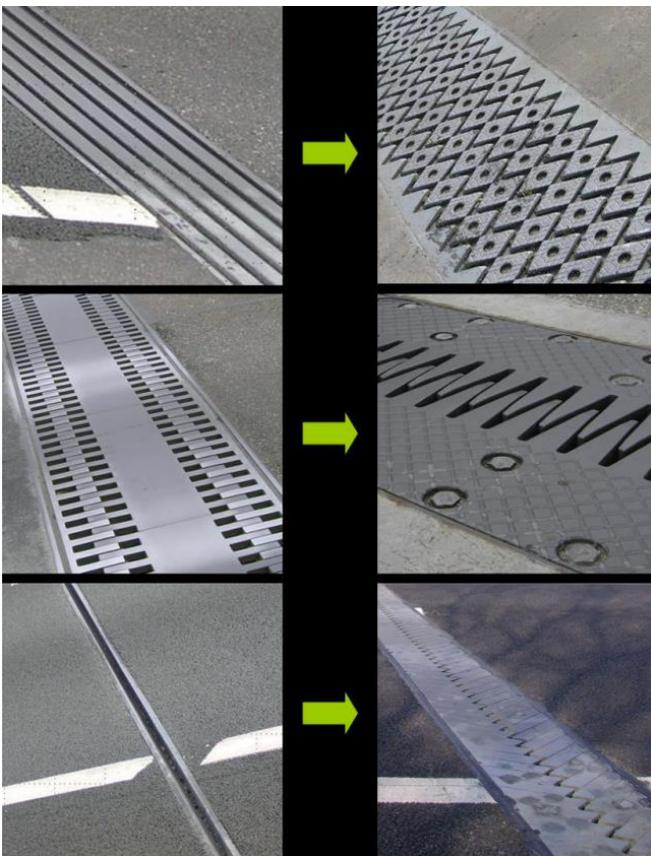
For urban roads where paving blocks are preferred, low-noise paving block variations with optimised surface texture and joints as well as porous paving blocks are available. These are not as quiet as a low-noise asphalt, but do provide a noise reduction of 3 to 4 dB(A) compared to regular paving blocks. Also, paving blocks should be placed at slanted (45°) angles (in 'herringbone' patterns) to lower the tyre excitations.

8.2.3. Pavement maintenance and discontinuities

See § 4.2.3 for the fact sheet on pavement maintenance.

For urban roads, it is particularly important to also take into account other road discontinuities, such as manhole covers, drainage grates, tram rails, speed bumps and road markings. In general, it is advisable:

- to avoid discontinuities in the wheel tracks: covers and grates should be placed in between traffic lanes, or in the lateral lane middle between the wheels, to minimise drive-overs;
- for tram rails and bridge joints, to place these at a slanted angle rather than perpendicular to the road. Slanted angles lead to less abrupt tyre impacts and therefore lower noise peaks. For bridge joints, low-noise alternatives exist, designed to minimise tyre impacts, see figure below;
- for any road discontinuity, it is important to minimise the height difference during construction. Also during the road lifetime, pavement rutting or compaction from traffic and soil settling may lead to increased height difference, which should be resolved by maintenance of the pavement or the other road elements.



Source: M+P

Traditional joints (left) vs. low-noise alternatives (right)

8.2.4. Promoting electric vehicles

Noise reduction mechanism

Electric vehicles (EVs) have quieter drivelines (i.e. engine, exhaust, etc.) than vehicles with internal combustion engines (ICEs). Although tyre noise

dominates the road noise traffic immissions in most situations, the driveline is relevant in particular situations:

- for passenger cars at low vehicle speeds (≤ 30 km/h);
- in situations with accelerating traffic, such as at crossings and speed bumps;
- for waiting traffic with stationary running engines, although many modern combustion engine vehicles have automatic start/stop systems;
- for buses, distribution vans and trucks, where the driveline noise contributes also at higher constant driving speeds, up to 70 or 80 km/h;
- for motorcycles and other exceptionally loud vehicles.

Electrification of vehicles, in all vehicle categories, will reduce the driveline noise in such situations and therefore will contribute to urban road traffic noise reduction.

Implementation

The use of electric vehicles in cities may be promoted by:

- mandatory criteria or financial incentives for procurement of public transport, garbage collection, licenses for taxi and distribution services, and city-owned vehicles;
- more stringent criteria for access to low emission zones, potentially blocking all internal combustion engine vehicles;
- providing sufficient vehicle charging infrastructure, such as on public parking spots;
- financial support for low-income households, for which the investment in relatively new and expensive electric vehicles is difficult or impossible;
- communication campaigns to promote electric vehicle use for private owners, and to explain the rationale behind the low emission zones.

8.3. Urban railway noise measures

8.3.1. Curve squeal noise

Noise reduction mechanism

Curve squeal is the high-pitched, tonal sound that is sometimes heard when trains pass through curves in the rail track. It occurs for heavy rail, notably around switches and on shunting yards, as well as for urban railways, i.e. trams, metro and light rail.

It is caused by the train wheels that, while following the curve, slip over the rail laterally and/or by the wheel flanges hitting and slipping against the side of the rail head. This leads to sudden intense and high-pitched noise, causing high annoyance and sleep disturbance for nearby residents. The occurrence of curve squeal is difficult to predict, as it depends on many factors including rail and wheel properties, track geometry, train speed, meteorological conditions.

Reduction measures to prevent or reduce curve squeal include ⁽¹⁶⁷⁾:

- application of lubricants or friction modifiers on the track and/or the wheels, using track- or vehicle-bound systems;
- wheel dampers;
- rail damping, although literature is inconclusive about a positive effect on curve squeal;
- improved curving behaviour, aimed to reduce the horizontal angle of attack between wheel and rail, such as by passive or active steered wheelsets;
- alteration of the lateral rail profile, or the rail material.

Noise modelling

The END Annex II (CNOSSOS-EU) includes a correction factor for curve squeal, but it is advised to use measurement data both for the levels and for the occurrence of squeal noise.

¹⁶⁷ Thompson D et al., *A state-of-the-art review of curve squeal noise: phenomena, mechanisms, modelling and mitigation*, in: Anderson D et al., *Noise and Vibration Mitigation for Rail Transportation Systems, Notes on Numerical Fluid Mechanics and Multidisciplinary Design*, 2018

A software tool to predict the occurrence of curve squeal is described in ⁽¹⁶⁸⁾. The ongoing EU research project QuieterRail ⁽⁷¹⁾ is developing further methods to predict and evaluate rail noise in curves that can be used for noise mapping.

8.3.2. Parked trains

Modern trains are generally fitted with a large number of technical aggregates (e.g. air conditioning, electric outlets) to make the train more comfortable for passengers ⁽⁷³⁾. Trains are parked in train yards that are often in or close to railway stations near residential areas. In the shoulder hours of the day, i.e. late evening or early morning, trains will stand idling with external equipment still active as they prepare for shutdown or startup, or during maintenance and cleaning activities. Compressors, cooling fans and air pumps, often mounted on top of the trains, then lead to annoyance and sleep disturbance.

Potential reduction measures for parked train noise include ⁽¹⁶⁹⁾:

- vehicle measures such as acoustic encapsulation of noisy components, exhaust silencers, acoustically optimised air intakes and reduced fan speed;
- optimised parking locations to ensure loud trains are parked far from residential buildings, and noise barriers around parking yards;
- operational procedures to limit climate control use, or limit operation times for such use, and cooperation with rolling stock manufacturers to implement low-noise parking modes for new or existing vehicles.

The UIC Noise and Vibration Sector, within the framework of their Noise and Vibration Technical Advice (NOVITÀ) project, has commissioned and published a study dedicated to noise from parked and stationary trains, including measurement data, regulatory framework examples and noise mitigation practices and solutions ⁽¹⁷⁰⁾.

¹⁶⁸ Tufano R et al., *SONIA: An engineering tool for railway curve squeal analysis*, proceedings of Forum Acusticum 2023, 2023-09, <https://hal.science/hal-04520005/document>

¹⁶⁹ Rissman M et al., *Noise from parked trains – An UIC study*, proceedings Forum Acusticum 2023, 2023-09, <https://dael.euracoustics.org/confs/fa2023/data/articles/000832.pdf>

¹⁷⁰ International Union of Railways (UIC), Sustainability, Rissman M et al., *Noise from parked and stationary trains: An analysis of operational and technical solutions*, UIC NOVITÀ project report, 2023-02, https://uic.org/IMG/pdf/noise_from_parked_and_stationary_trains.pdf

8.4. Shipping and port noise

8.4.1. Typical noise sources

For port agglomerations, that feature a harbour, specific noise issues arise from shipping and other port noise sources. These noise issues include:

- noise from ships moving in and out of the harbour area, or manoeuvring inside the harbour area to enter or leave the berth, including ship horns;
- noise from moored ships, laying still in the berth, arising from power generators, compressors, pumps, fans and other on-board machinery;
- noise from other port activities related to shipping, including noise from cranes, forklifts and other loading and unloading equipment, as well as cleaning and refuelling activities.

The noise emitted by ship and port activities is often low frequency, tonal and/or impulsive, which leads to significant complaints, annoyance and sleep disturbance for residents around the port area.

8.4.2. Available technical support

The international project NEPTUNE ⁽¹⁷¹⁾ by eleven ports from Europe, Australia and Canada, running from 2017 to 2019, focused on noise from ships at berth. The project produced some useful technical support:

- a Best Practice Guide ⁽¹⁷²⁾, including (in Chapter 6) an overview of noise measures at the source, propagation and receiver levels, as well as non-acoustic and communicative measures. Individual fact sheets for noise abatement measures are available in Annex I to the Best Practice Guide;
- a noise measurement method, in Annex II to the Best Practice Guide ⁽¹⁷¹⁾, to standardise noise measurements on different types of moored ships, e.g. container and cruise ships, tankers and bulk carriers;

¹⁷¹ NEPTUNE: Noise Exploration Program To Understand Noise Emitted by Seagoing ships

¹⁷² NEPTUNE project partners, Wolfert H et al., *Mitigation of Noise from Ships at Berth – Best Practice Guide version 1.0*, 2019, https://assets.ctfassets.net/wnob2adoewm2/3B9G8YCYmgjrEFcrkrksSN/adb72d14114243360f283fb5a53b9e6/FILE_02_ESI_Noise_-_Best_Practice_Report.pdf

- a noise label for each ship, based on the measured broadband and low-frequency noise levels, on a scale from 0 to 100. The noise label has been integrated into the wider Environmental Ship Index (ESI) ⁽¹⁷³⁾.

The Danish Environmental Protection Agency published a report on measures to reduce noise from ships in ports in 2010 ⁽¹⁷⁴⁾.

The INTERREG Maritime programme Italy-France 2014–2020 aimed to exchange knowledge and good practices in port noise management. Under this INTERREG programme there have been several projects focusing on different types of ports and different aspects of port noise, such as modelling and measurement methods ⁽¹⁷⁵⁾. Efforts towards noise mapping of port noise have been described in an article by the project partners ⁽¹⁷⁶⁾.

Some specific material is available on onshore power supplies (OPS), which is an important measure to reduce noise from moored ships by eliminating the need for onboard auxiliary power generators, similar to ground power units (GPUs) for aircraft (see § 6.2.8):

- The Port of Rotterdam has been promoting and facilitating OPS for several years. They recently published a strategy document on OPS for 2025-2035 ⁽¹⁷⁷⁾, in Dutch.
- Much information on OPS, including case studies and implementation guidance, is given by the World Ports Sustainability Program, see <https://sustainableworldports.org/ops/>.

¹⁷³ <https://environmentalshipindex.org/>

¹⁷⁴ Danish Ministry of the Environment, Environmental Protection Agency, Lloyd's Register ODS, *Noise from ships in ports – Possibilities for noise reduction*, 2010, <https://www2.mst.dk/udgiv/publications/2010/978-87-92668-34-9/pdf/978-87-92668-35-6.pdf>

¹⁷⁵ Schenone C et al., *The Port Noise Analysis and Control in Interreg Italy-France Maritime Programme*, proceedings of Inter-Noise 2019 Madrid, 2019-06, https://www.sea-acustica.es/INTERNOISE_2019/Fchrs/Proceedings/1898.pdf

¹⁷⁶ Fredianelli L et al., *Classification of Noise Sources for Port Area Noise Mapping*, *Environments* 2021, 2021-02-09, <https://doi.org/10.3390/environments8020012>

¹⁷⁷ Port of Rotterdam, City of Rotterdam, *Walstroomstrategie 2025-2035 – Samen met volle kracht vooruit*, 2025-11-03, <https://www.portofrotterdam.com/sites/default/files/2025-11/walstroomstrategie-2025-2035.pdf>

Rijkswaterstaat, the Dutch national authorities for roads and waterways, developed a noise measurement for moving (inland) ships (¹⁷⁸), partially based on the ISO 2922:2020 method (¹⁷⁹).

¹⁷⁸ Verheijen E, Ruiter T, *A Measurement Protocol for Sound Power of Moving Ships*, proceedings of ICSV30 Amsterdam, 2024-07, https://dbvision.nl/bestanden/overons/publicaties/2024/verheijen_en_ruiter.pdf

¹⁷⁹ ISO 2922:2020, *Acoustics – Measurement of airborne sound emitted by vessels on inland waterways and harbours*, 2020-12

9. Conclusions and recommendations

9.1. Conclusions

Many Europeans are exposed to unhealthy levels of environmental noise, with road, rail, air transport and industry as the main sources. Noise Action Plans (NAPs) are a key instrument for Member States to steer the reduction of environmental noise and increase public health and well-being. Although the actual reduction only comes with actual implementation, a NAP is an essential tool to prioritise and plan the most effective noise measures, leading to more effective and cost-efficient noise policy.

A wide range of technical measures is available to decrease transport noise at the source, including quieter vehicles, quieter infrastructure or quieter operations. In addition to source-specific measures, horizontal measures are available in the propagation path (noise barriers), at the receiver side (building insulation) and during urban planning (zoning), to spatially separate noise sources from sensitive receivers.

Source measures, like low-noise pavements and tracks or quieter vehicles and components, are generally preferable to propagation and receiver measures, as they offer long-term benefits on a large scale. Propagation and receiver measures, however, remain critical where source measures are insufficient or unfeasible. As concluded earlier by the EEA and the EC, a combination of all possible measures will be needed.

For agglomerations, noise abatement is specifically challenging as urban areas are complex, with multiple noise sources in densely populated areas with limited space. Industrial sources are also relevant, and port activities are a specific concern for cities with waterway connections. Agglomerations also experience limited governance: they do not control the major infrastructure and airports, and depend on national or regional authorities to take effective source-oriented measures. However, local roads and urban railways are major sources of noise also in cities, and the reduction measures are essentially the same, including low-noise pavements, road and track maintenance and speed reduction. On the vehicle side, enforcement to avoid extremely loud vehicles is a typical local measure, and cities also have significant influence on the promotion of low-noise tyres.

The selection of the most appropriate noise measures for a given situation always depends on costs and benefits, but is constrained by other organisational, practical, socio-economic or environmental requirements. Many noise measures will also have additional co-benefits like improved air quality or safety, and may even reduce costs, e.g. through fuel reduction or improved

infrastructural asset management. An NAP with a higher chance of successful implementation therefore involves multi-criteria decision making.

This technical support document aims to provide information on the pros and cons of each individual noise measure. This includes, as far as possible, a specification of costs and noise reductions, and guidance on how to more accurately model these.

9.2. Recommendations

Competent Authorities designated to produce and update NAPs are recommended to:

- ensure consideration of all noise measures highlighted in this support document, including less common or obvious measures that may not have been considered earlier;
- prioritise source-oriented noise measures, as these tend to lead to the biggest positive impacts in terms of the number of people affected while improving also the general quality of life outdoors;
- use the information and suggestions in this document to improve the modelling of noise reductions and costs, which can contribute to more transparent decision-making and NAP quality;
- identify and exploit co-benefits of noise reduction measures, such as improved air quality, climate benefits, improved safety and passenger comfort, to strengthen the business case and increase the chance of actual implementation;
- use the provided toolbox to include also such other criteria in the decision-making process;
- implement and use existing EU Green Public Procurement guidelines, where relevant, to promote low-noise technologies in procurement of infrastructure and vehicle fleets;
- cooperate with other Competent Authorities and establish or improve coordination frameworks between different governance levels, so as to enable the noise measures that are most effective for all;
- communicate the benefits clearly to the public and to policy makers at other institutional levels, emphasizing the improvements to public health and socio-economic benefits, to increase acceptance for potentially unpopular measures like speed reductions or airport curfews;
- increase efforts towards ensuring a timely and effective implementation of the measures adopted in their NAPs, so that actual and rapid progress is made in reducing the public health burden from environmental noise;

- establish a monitoring mechanism that measures and shows which of the adopted measures have been implemented: preferably, the progress monitoring is done not only every five years with the mandatory review of an NAP , but also intermediately (yearly or biyearly).

Agglomerations in particular are additionally recommended to:

- prevent noise problems by integrating related considerations into urban planning, so as to keep residential and other noise-sensitive buildings away from major industry, airports and major road/rail routes, certainly when housing pressure increases;
- prioritise low-cost and high-impact road traffic noise measures as appropriate; this support document shows such measures include speed reduction (30 km/h zones) and improved maintenance also for regular (i.e. non-low-noise) pavements and road discontinuities;
- promote sustainable, efficient and healthy transportation, such as by facilitating and incentivising public transport, electric vehicles and walking and cycling;
- prepare for noise impacts by unmanned aviation (drones) as a future form of urban mobility with potential noise implications, by starting discussions and policy development, as well as development of data and modelling tools needed to include these in future NAPs;
- for port areas, consider effective reduction measures for moored ships, such as onshore power supplies, as well as incentivisation of low-noise ships and onboard equipment.

For this technical support document itself, it is recommended to consider promoting the contents and the catalogue of noise measures to an online format, i.e. a website. In an online form, it could be expanded and maintained in upcoming years as new noise measures, more detailed cost factors and other information come in. The website could include an online version of the current Excel toolbox, to help competent authorities select the most appropriate noise measures given the multiple decision criteria involved.

Annex A – Airport measures and costs overview

Table 7 – Overview of noise measure costs for several EU airports

Noise Measure / Category	Dublin 2024–2028	Zurich 2024	Schiphol Airport	Frankfurt Airport	Munich Airport
Residential Noise Insulation & Home Buy-outs	>€18,000,000 total spent on homes & schools	~CHF 17,1 million: sound insulation, refurbishment and reimbursements (2024), long-term programme: ~CHF 330m since 1999	Noise insulation programmes: ~€577 m historic total	Passive noise abatement programmes: ~€60 m total	~€62 million total for noise measures since 1992 (incl. ~21,000 soundproof windows + ~20,000 ventilators)
Residential Sound Insulation Grant / SIS	up to €30,000 per home	mandatory sound insulation programme; 252 properties equipped in 2024	Part of overall insulation programme	Included in passive noise abatement programme	Part of broader noise protection programme (window & ventilators; no annual breakdown)
Community / Community Fund	€10,000,000 total fund	Zurich Airport Noise Fund finances insulation and compensation claims (no separate community grants)	Environmental Fund finances community initiatives	—	Not separately reported; engagement via statutory noise commission and stakeholder dialogue
Noise Monitoring & Track Keeping	~included in total	Continuous operational noise monitoring under SAIP; no separate cost figures published	Ongoing monitoring network	Continuous noise monitoring system	Noise monitoring via 16 measurement stations (costs as part of operational noise protection reporting, not separate)
Airspace Change / Noise Management	—	Incentive system for quieter aircraft (noise-differentiated charges)	Differentiated airport charges to incentivise quieter aircraft	Noise-related charges and incentives	Noise-differentiated landing charges and financial incentives for quieter aircraft
Noise Management / NAP Activities	—	Noise charge revenue ~CHF 16.0 million in 2024 used to fund noise mitigation measures	Broad NAP commitments	Active noise abatement measures	NAP implementation costs included in noise protection investment totals, not per action
Consultancy / Research	—	—	—	—	Not separately costed in published noise protection figures
Events & Subscriptions	—	—	—	—	Not separately costed
Publications	—	—	air	—	Annual and integrated env. reports include noise metrics (costs implicit in reporting activities)
Equipment Costs / Computer	—	Monitoring system costs implicit; not separately reported	Monitoring systems implicit	Monitoring systems implicit	Noise monitoring and data systems maintained (operational costs in broader env. protection budget)
Fines / Noise Action Line	—	—	—	—	Not explicitly included in cost reporting
Total / Approximate Annual Cost	Partial / summary only	~CHF 17.1 million direct noise mitigation spend in 2024; ~CHF 16.0 million noise charge revenue	~€50–100 million per year (indicative annualised total)	~€6–12 million per year (indicative annualised total)	~€62 million invested in noise protection programmes (1992–now); ongoing investments reported as part of sustainability performance

Table 8 – Overview of noise measure costs for UK airports (1/2)

Noise Measure / Category	East Midlands 2024–2028	Gatwick 2024–2028	Birmingham 2019–2023	Liverpool 2024	Manchester 2024–2028
Residential Noise Insulation & Home Buy-outs	£268,000	£550,000	Commercially confidential	—	—
Residential Sound Insulation Grant / SIS	—	—	£200,000 per annum	—	—
Community / Community Fund	£50,000 contribution	£1,000,000 Gatwick Area Community Trust	£84,000 per annum Community Trust Fund	—	£100,000 per annum
Noise Monitoring & Track Keeping	£200,000 equipment	£1,850,000	£6,000 per annum Other Environmental Monitoring	£20,000 NM & TKS hardware/software	£200,000 equipment / software
Airspace Change / Noise Management	—	£7,150,000 Airspace change	—	—	—
Noise Management / NAP Activities	£137,000 staff costs	£5,475,000 Noise management	£50,000 per annum Schools Environmental Improvement Scheme	£45,000 Staff Costs	£160,000 staff & training
Consultancy / Research	£42,000 research	—	—	£10,000 SIGS / Development & Contributions	£52,000
Events & Subscriptions	—	—	—	—	—
Publications	—	—	—	—	£65,000
Equipment Costs / Computer	—	—	—	£20,000 Equipment Costs	Included above
Fines / Noise Action Line	—	—	—	—	—
Total / Approximate Annual Cost	~£497,000	£16,025,000	£463,000	£101,000	£627,000

Table 9 – Overview of noise measure costs for UK airports (2/2)

Noise Measure / Category	Edinburgh 2014	Stansted 2024–2028	Glasgow 2024–2028	Heathrow 2019–2023
Residential Noise Insulation & Home Buy-outs	—	£1,000	Proposed extension for 600 properties, cost not published	£9,000,000 per annum
Residential Sound Insulation Grant / SIS	—	—	—	—
Community / Community Fund	—	£50,000	—	—
Noise Monitoring & Track Keeping	£20,000 monitors & radar	~£200,000	£65,000 Computer/Software	£1,005,000 per annum
Airspace Change / Noise Management	—	—	—	—
Noise Management / NAP Activities	£50,000 staff	£200,000 staff	£115,000 Staff	£1,300,000 staff
Consultancy / Research	—	£42,000	£30,000 Consultancy	£625,000 per annum
Events & Subscriptions	—	—	£25,000 Research, Events & Subscriptions	—
Publications	£15,000	£22,000	£25,000 Publications	£330,000 per annum
Equipment Costs / Computer	£25,000 computer / website	Included above	—	Included above
Fines / Noise Action Line	—	—	—	—
Total / Approximate Annual Cost	~£110,000	~£515,000	£260,000	~£12,260,000

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