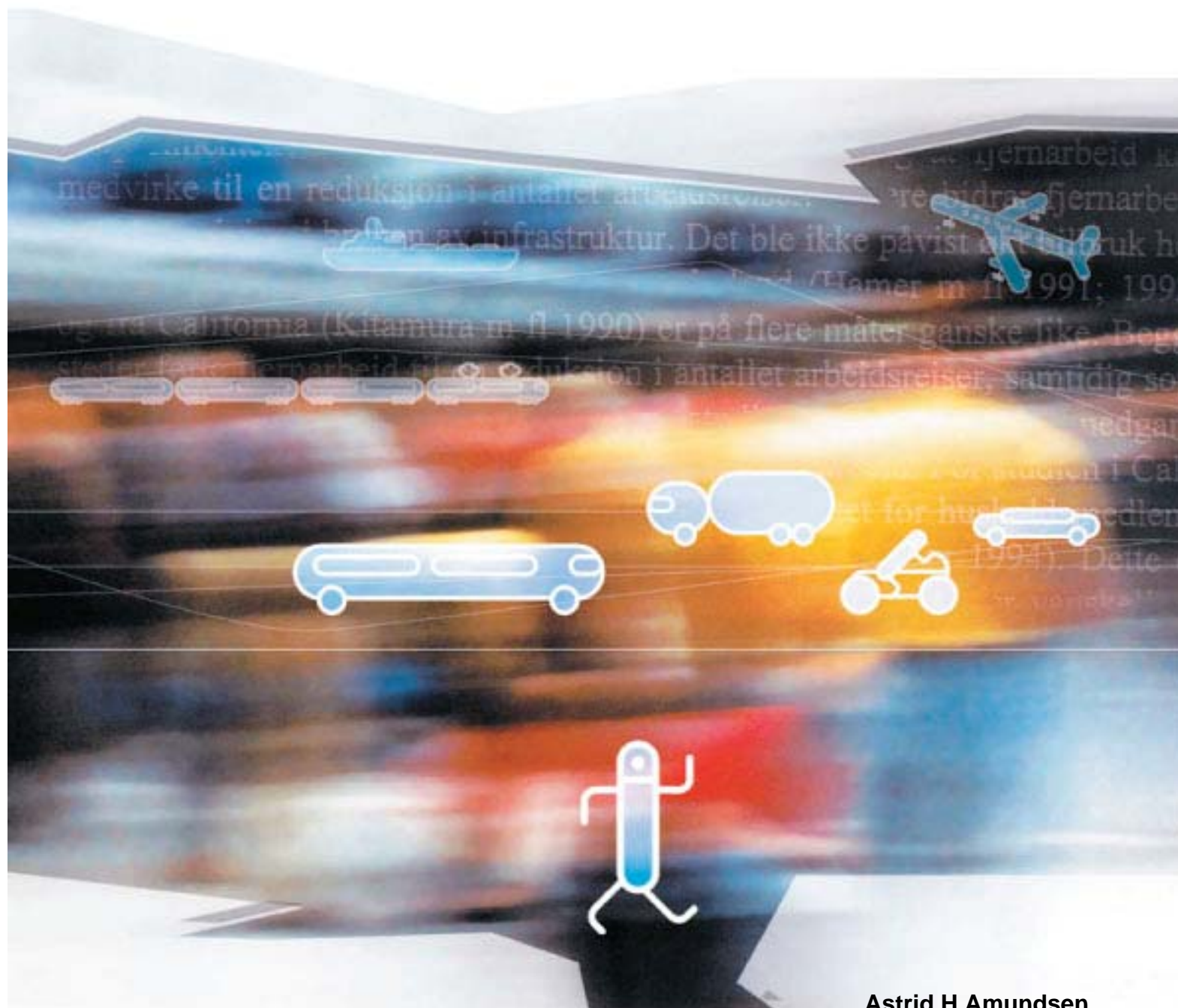


A Nordic perspective on noise reduction at the source



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Astrid H Amundsen
Ronny Klæboe

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The European Commission has estimated that about 80 million Europeans are exposed to unacceptable noise levels. Road traffic is the main source to at-the-source-noise.

The report provides an overview of what is known about different types of noise abatement efforts (on vehicles, tyres, road surface and speed). Some tentative suggestions on what to do under Nordic conditions are given.

Tittel: Nordisk perspektiv på støyreduksjon ved kilden.

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Rundt 80 millioner europeere er eksponert for uakseptable støynivåer i følge EU. Veitrafikken er en av hovedkildene til dette problemet. Denne rapporten gir en oversikt over potensialet for støyreduksjon ved kilde. Støyreduksjon fra kjøretøy, dekk, vegdekke og ved å senke fartsnivået har vært i fokus. Rapporten oppsummerer kunnskap om slike tiltak.

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Preface

It is estimated that over 100 million Europeans are exposed to unacceptable noise levels. Noise from road transport is the major source. Measures to reduce road traffic noise exposure encompass noise reduction at the source, measures addressing noise propagation, and measures at the receiver. As witnessed in the area of vehicular air pollution, reducing a pollutant at the source can be an effective measure. Noise reduction measures at the source can consist of speed reductions, reducing noise emitted from vehicle propulsion systems, and noise from tyre-road surface interactions. Due to the Nordic climate, the use of studded tyres, and winter maintenance practices, measures to reduce tyre-road surface interactions that have been proven effective in the rest of Europe, may be in viable in Norway, Sweden and Finland.

On assignment of the Nordic Council of Ministers, the Institute of Transport Economics has been asked to make an overview of current research in the area. The report is meant to serve as a common Nordic basis for forward testing and implementation of at-source measures especially designed for the Nordic conditions.

The working group on sustainable transport in the Nordic Council of Ministers has been our contact with the Council. Members of the working group are as follows:

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Oslo, November 2005
Institute of Transport Economics

Lasse Fridstrøm
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Summary:

A Nordic perspective on noise reduction at the source

This report serves a dual purpose – the first is to summarize research on noise reduction at the source, including low noise road surfaces, tyres with improved noise emitting properties, and reductions in engine and power train emissions. The second is to assess the maturity of the research, identify areas where promising results need to be corroborated, and where new research initiatives are warranted. The project is commissioned by the Nordic Council of Ministers.

Significant noise reductions at the source ten years away

In areas where Nordic researchers could reach consensus on noise reduction and mitigation measures and their expected effects, the idea was to provide the Nordic authorities with clear advice on

which measures could be deployed with a reasonable probability of success.

However, with the exception of Denmark, Nordic research activities feature few longitudinal studies and lack maturity. For Norway, Sweden and Finland not having a continental climate, research results on low noise road test surfaces need to be adapted to, and validated under several years of Nordic winter conditions. We therefore assess that it will take at least ten years before industry and the authorities in Norway, Sweden, and Finland have developed low noise surfaces suitable for our Nordic winters and can start deploying them.

The types of tyres that have the best noise emitting characteristics depend on road surface type. This may imply that European standardisation is not only a question of stricter limits, but also of necessary regional (Nordic) adaptations.

Table S.1: At-source noise reduction in dB(A). Possible effects and barriers.

	Vehicle		Speed reduction	Road surfaces	
	Engine	Tyres		Thin/Dense	Porous
<i>Noise reduction :</i>					
Existing technology/ knowledge based on:					
- 5 year perspective	1-2	1-2	1-3	1-3	2-4
- 10 to 15 years perspective	2-4	2-4	-	3-5	6-8
<i>Durability:</i>	15-20 years	3-5 years	-	7-15 years	3-10 years
<i>Economy:</i>					
- costs (investment, maintenance)	Medium	Medium	Low	Medium	High
- who pays	Consumer	Consumer	Road owner/ consumer	Road owner	Road owner
- socio-economic	+	++	++	+++	+++
<i>Feasibility:</i>					
- politically	Time consuming	Time consuming	-	+	?
- producers	Possible	Possible		Possible	Possible

Source: TØI report 806/2005

That research into the durability of new types of road surfaces, and adaptation of low noise tyres to Nordic conditions will take time, does not mean that noise reduction is not needed. Neither does it mean that we lack solutions that show considerable promise of being able to provide significant noise reductions.

Lowering the speed on important ring roads, and main roads going through densely populated areas could provide a stopgap cost efficient intermediary measure to reduce noise emissions at the source.

Noise from road transport a persistent problem for Europe

80 million Europeans are exposed to unacceptable noise levels. Road transport is one of the major sources of the noise, and about 70 percent of the noise annoyance in Nordic countries is attributed to road traffic.

While regulations of air pollution emissions have led to improved air quality, regulations have not had the same positive effect. This is due to the increased level of transport, heavier vehicles with more engine power, certification test not comparable enough to real traffic situations, and insufficiently strict noise regulations.

Europe and the Nordic countries all have ambitious targets when it comes to noise reduction. To reach the targets, at-source noise reduction will be necessary.

Noise reduction at-the-source

Research on noise reduction at the source has increased lately, but not all results are transferable. Nordic climatic conditions, with the use of studded tyres require a somewhat different approach than in the rest of Europe. Therefore, a common Nordic approach to the problem is desirable.

We are in this study looking at the possible effects of the following at-source measures:

- Noise reduction due to speed reductions
- Low noise road surfaces
- Reducing noise from vehicles
- Reducing noise from tyres

The literature review undertaken as part of this report is based on newer European studies. It provides an overview of what is known about the different types of noise abatement efforts. It focuses on the potential for noise abatement measures at-the-source, achieving noise reductions in real traffic and real operating conditions, life time cycle, costs and modifying factors of the measures.

A 10 dB(A) noise reduction may be possible by combining measures

By combining different measures a noise reduction of about 10 dB(A) may be possible in a 10-15 years perspective, see table S.1. If noise reduction of this size is demanded, cooperation between the Nordic countries on developing and testing of different surface types is necessary.

Research show that Nordic winter conditions demand somewhat different types of low noise surfaces, than southern parts of Europe. Different types of porous surfaces need further testing under Nordic conditions before they can be used on a more full-scale basis (arterial-roads near urban/residential areas, on roads with speed level above 50 km/h). Use of low noise dense surface types, are less problematic and can be implemented as of today. To optimize the noise reduction from surface/tyre, surface types and tyre types adequate for Nordic conditions need to be matches as good as possible.

Using speed reductions as a noise reducing measure is a measure with instant impact both on noise and air quality, and it is cheap to implement. But it may be politically hard to get acceptance fore this type of measure. If given priority, it is important to use the measure on roads with high speed levels in areas with high density of residents or high numbers of pedestrians/cyclist. This to reduce the negative response from the public.

At-source noise reduction

The limits imposed through the EU tyre directive need to be made stricter if new technology is to be promoted. Financial advantages or reduced taxes on certain vehicle and tyre types could be implemented. This will probably have a limited effect on noise reduction unless a majority of the cars are induced to actually change tyre types.

Use of low noise surfaces has the greatest potential effect on noise, see table S.1. It is a measure for urban areas, and for major high speed roads close to residential areas. With today's knowledge, thin surfaces are probably the best alternative to pursue for the Nordic authorities. These surfaces have a somewhat longer durability, are cheaper, have better friction, and are easier to maintain than porous surfaces. But the noise reduction possibility is also somewhat limited, about 2-4 dB(A) is feasible. Compared to conventional surface types in Europe, Nordic surface types emit more noise. It is therefore

possible that the effect of thin surfaces can be higher in the Nordic countries.

To reduce the noise level further, use of porous/or poroelastic surfaces may be necessary. Further testing needs to take place before these surfaces can be employed on Nordic roads. But it is possible, with current knowledge to lay these kinds of surface on high speed road stretches close to residential areas. The investments and maintenance costs are higher, and the lifespan is shorter than conventional surfaces and thin surfaces. For road owners to choose a more expensive and more difficult surface to lay and maintain, governmental demand for this kind of noise reducing measures is necessary.

Measures with long and short impact time

When it comes to possible noise reductions with existing technology (5 year perspective), the potential effects are based on:

- Low-noise zone (restricted access for heavy vehicles), new vehicles or encapsulation of engines.
- Financial advantages for persons buying tyres scoring high on environmental qualities. Information.
- Reducing speed from 80/90 to 60/70 km/h on major arterial road near residential areas.
- Use of thin surface, and better conventional road surfaces.

Possible long time effects (10-15 year perspective) are based on:

- A major part of the vehicle fleet is replaced with new-technology vehicles.
- Improved tyre technology in production. Financial advantages for persons buying tyres scoring high on environmental qualities.
- Use of twin layer-porous or poroelastic surface on high speed arterial roads/urban roads near residential or recreational areas.

Conventional road surfaces must be given priority

The noise properties of road surfaces that are currently employed in Norway, Finland and Sweden have not been an issue in road surface laying contracts, and the

road surface layers have unknown noise emission properties.

Limited testing in Norway suggests that the focus on durability, safety and good winter properties may have led to the production of dense road surfaces that produce 2-4 dB(A) more than the normal dense asphalt types that are in regular use in Europe. If the standard Nordic dense asphalt surfaces are equally inferior with respect to noise emissions (compared to what is common in the Netherlands and Denmark), priority should be to investigate why the differences between conventional road surfaces laid in Finland, Sweden and Norway and the rest of Europe are so large.

Potential noise reduction from low noise road surfaces

Unlike vehicle and tyre noise, there are no EU regulations for surface type. Choosing which type of road surface to use is up to the road owner.

Low noise road surfaces can be divided into three types:

- Thin/dense surfaces
- Porous surfaces
- Poroelastic surfaces

Tyre-road noise reductions are dependent on a match between road surface and tyre properties.

Thin surfaces are being tested out in several countries, including the Nordic. A noise reduction of 2-4 dB(A) is commonly achieved on the different test sections. The advantages of thin surfaces are mainly due to durability and costs.

Noise reduction of 4-6 dB(A) are achieved on tests in real traffic situation, with 2-layer porous asphalt. The problem with porous surface today, and especially in the Nordic countries, are clogging and freezing of ice in the drainage systems. Poor friction and adhesion problems are other problems with today's porous surfaces. The surface type is usually used on high speed roads, where the high speed seems to prevent some of the clogging. High pressure water spraying and sucking can reduce the clogging somewhat, and the cleaning technique for these kinds of surfaces is improving.

According to producers, noise reduction of 8-10 dB(A) will be possible when the technology has improved further. At present this type of surface is expensive (costs at least 50 percent more than conventional surfaces), and has a short life-span, but even with this taken into consideration, these kinds of

surfaces are usually cost-effective (if used on high speed roads in areas highly populated).

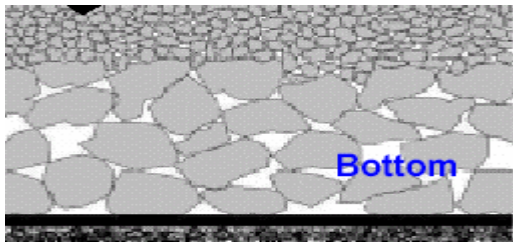


Figure S.1: Twin layer porous asphalt. Source: Berengier and Licitra 2003.

Poroelastic surfaces have an even higher possible noise reducing effect than porous surfaces. Noise reduction of 6-12 dB(A) are measured on new surfaces. The elasticity in the surface is based on rubber granules, sometimes made out of old tyres. Problems with adhesion, poor friction, and short life span are prominent at present, but these types of surface are improving.

Low noise surfaces under Nordic winter conditions

Norway, Sweden and Finland experience more adverse winter conditions than Denmark and use studded tyres during winter time. It is not reasonable to expect that improved conventional or brand new types of low noise surfaces can be deployed within a reasonable time frame.

Before deployment it is necessary to lay test-surfaces along stretches of roads that are typical for the application area (high speed roads in urban conditions) and to ascertain:

- The noise-emitting properties of the road surfaces that are in use, and the importance of surface texture for noise production.
- The interactions between Nordic road surfaces and tyre-thread patterns.
- The durability and maintainability of road surfaces under Nordic winter conditions.

An important task is to find out how to construct roads with drainage systems that works in freeze-melt conditions with partial ice-formation, and that can survive winter maintenance activities. Even with extra research effort, these types of surfaces are not expected to be deployable within a 10-year time frame. Denmark, having a more continental climate and having undertaken long time durability testing of some road surfaces, is already in the position to deploy low noise surfaces where this proves to be cost efficient.

Engine noise reduction

Even if there is a potential for further noise reduction from the engines, this is not likely to come through regulations, due to the fact that new vehicles already fulfil the EU requirements. While the potential for power train emission reductions is there, consumers are unwilling to pay for less noisy vehicles.

Noise reduction from tyres

When developing new tyres, safety, price and environmental properties such as noise are factors that need to be considered. Improving the quality on one of these factors does not necessarily mean that the tyre fares worse on others. However, some of the tyres most promising in respect to noise have inferior friction when the road surface is wet. With further development, it is expected that the properties with respect to friction under wet conditions will improve.

Factors influencing noise from tyres are:

- Tyre width
- Hardness of tyre
- Tread patterns
- Groove depth
- Road surface

The difference between the noisiest and least noisy tyres on today's market can be as 4-5 dB(A). The EU tyre directive is so moderate that all tyres produced today fulfil the requirements and will do so until at least 2011. The directive provides no incentive to tyre producers to improve the noise quality of the tyres.

An optimal combination of tyre and road surface properties is necessary. When different tyres are tested on different road surfaces, up to 9 dB(A) difference in noise levels are measured. For Nordic authorities, it is important to determine which tyre and surface type that is most efficient for Nordic conditions, and ensure that imposed EC-standards are not only appropriate for continental road surfaces, but also Nordic types with rougher surface texture.

To promote the use of low noise tyres, different financial incentives might be considered.

Noise reduction from speed reductions

The most promising measure to achieve at-the-source noise reduction in the short term is environmentally motivated speed reduction. Noise emitted from vehicles increases with their speed. It is mainly tyre-

road surface noise that is reduced. Apart from reducing noise, speed reduction will:

- Improve traffic safety
- Reduce amount of combustion particles (down to a certain speed level)
- Reduce road surface wear, and particle emission
- Reduced resuspension

When reducing the actual speed by 10 km/h, a noise reduction of about 2-3 dB(A) can be achieved. Reducing speed limits alone is not enough, because driver compliance with the new levels is low. Different types of traffic enforcement are therefore necessary. The political acceptance for the measure is often low. 2/3 of the respondents in a local survey in Oslo stated that they were positive to reduced speed level, if this meant that the air quality improved. It might thus be possible to gain local acceptance for this measure, provided there is a noise problem. The advantage of this measure is that it is efficient from the first day of implementation, and cheap compared to other measures.

Nordic low-noise-surface research should be coordinated

Research activities need to be coordinated between the Nordic countries, to make optimum use of the scarce resources that are allocated to this research area. The

laying of test surfaces and establishing multi year measurement and monitoring programs is costly, and funds need to be allocated in a more efficient way.

Here the extensive knowledge from researchers in Denmark and Netherlands should be utilised by enlisting their researchers into sustained efforts of adapting the surfaces to Nordic conditions. In other words, their general competence on such surfaces should be utilised in cooperative sustained efforts together with experts on Nordic winter conditions in order to solve the winter condition and maintenance problems.

Purchasing competence and Nordic standard road surfaces needed

To promote use of low noise surfaces, contractors should ideally be presented with performance contracts. For example, the contract can include a part where the contractor is paid per reduction in the number of annoyed persons and the pay is reduced if the noise emission properties deteriorates over time.

If possible the Nordic countries should specify one or a few common Nordic standard surfaces. This could act as a baseline for further testing, designing common quality contracts for contractors, and help to promote production of surface types adapted to Nordic climatic conditions, winter maintenance and vehicle fleet (tyre types etc.).

1 Introduction

1.1 Little progress in noise emissions reduction

While exposure to air pollution in Europe has benefited from Auto Oil and other programmes to reduce vehicular air pollution, the same downward trend has not been observed for road traffic noise.

Noise is thus one of the most persistent environmental problems in Europe. It is estimated that about 80 million Europeans are exposed to unacceptable noise levels, leading to sleep disturbances and other health effects. A further 170 millions are seriously annoyed by the noise level in their residential area. The economic costs of noise to society are estimated to more than 12 billion euros each year (European commission 2002). These figures have increased further, after the inclusion of the new member states.

Road traffic is the major source of environmental noise exposure. In Sweden and Norway about 80 percent of the accumulated annoyance in the population is attributed to road traffic noise.

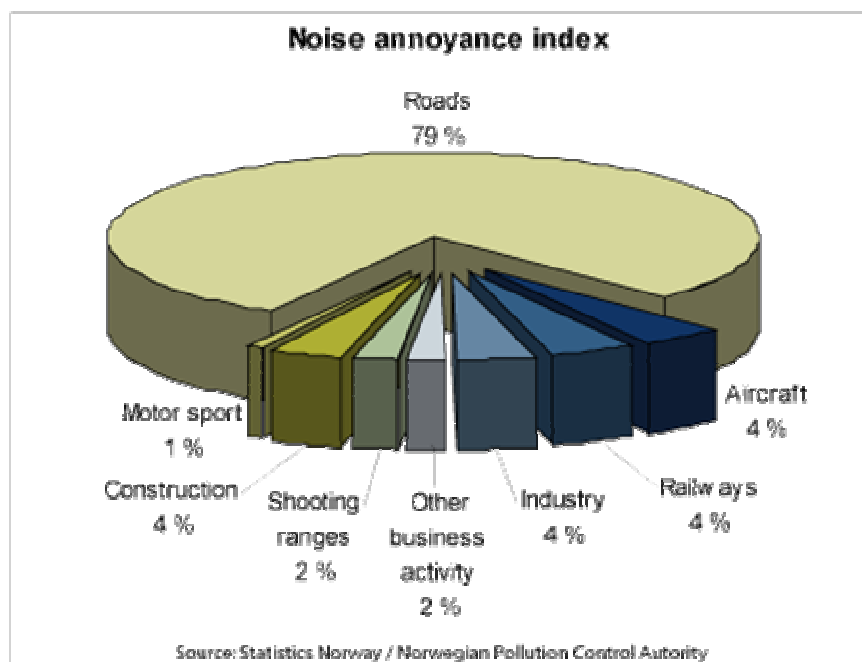


Figure 1.1 Distribution of noise annoyance according to noise source. Norwegian environmental authorities 2002

An important reason for Europeans being exposed to the same amount of road traffic noise today as 20 years ago is increasing levels of traffic. However, the reductions in air pollution levels have been attained in spite of heavier vehicles,

more engine power, rapid growth in the number of vehicles, and large increases in person and tonne kilometres.

Some specific reasons that noise abatement has been inefficient are:

Certification procedures have tested vehicle engine emissions in situations, “driving cycles”, that are not representative for actual city driving conditions. Car manufacturers may therefore have the possibility to optimize their vehicles for the certification situation and not for lowering noise emissions in real life. This may have slowed down the reduction of propulsion noise especially for passenger cars.

An even more important factor has been the failure to address tyre-road surface noise interactions that dominates at speeds over 30 and 55 km/h for passenger cars and heavy vehicles respectively see figure 1.2. While there have been comprehensive programs to reduce engine noise, tyre-road surface noise has not been addressed with the same aggressiveness.

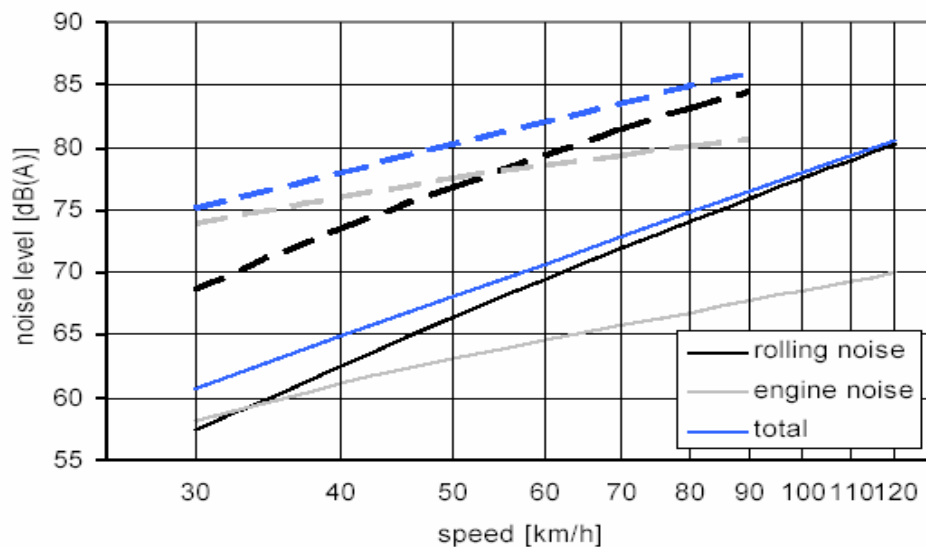


Figure 1.2: Rolling noise (tyre-road surface interaction) and engine noise as a function of vehicle speed. Relationships for passenger cars are indicated by unbroken lines while those for heavy vehicles are indicated by dashed lines. Source: Dijkink and Keulen 2004

Low noise surfaces have been tested out for the last 20 years, and drainage/porous asphalt is in regular uses in some countries (e.g. The Netherlands, Belgium, France, Austria, England, Japan and Italy). However, there is no EC directive regulation implemented to promote the use of low noise surfaces.

1.2 New optimism with respect to noise reduction

The last couple of year, there has been an increased interest in noise reduction at the source measures, both in the EU and nationally. Ongoing EU projects such as SILVIA, HARMONOISE and CALM develop new road laying technologies, noise measurement and calculation methods and accumulate knowledge. In the SILVIA project, new low-noise-surface combinations are tested out in Sweden, Denmark, and other European countries. In the upcoming EU-project SILENCE

work with low noise surfaces will be continued, together with other efforts to reduce noise.

Maintenance (sucking and high pressure hosing) of road surfaces is an important part of a road laying strategy. The aim is to reduce clogging of porous asphalt types and increase the lifespan of the surfaces. Removing road surface dust particles contribute to reduce resuspension of particles, and thus improve air quality.

Low durability of the surfaces has been an objection against the use of porous and poroelastic surfaces, especially in countries allowing use of studded tyres during the winter season. The lifespan for low-noise-surfaces are shorter by approximately half or 1/3 lower than that of conventional surfaces. Durability has improved because of improved surface laying methods and the use of better maintenance technology.

However, a specific problem in Norway, Finland and Sweden is our winter conditions/climate. Road surfaces have to perform adequately with snow and ice, and withstand studded tyres in addition to winter maintenance activities, sanding (sandpaper effect), salt and road machinery (ploughs). Wear and tear of the road surface result in a rapid degradation of road surface texture quality, leading to increased noise emissions and large quantities of road dust that clog porous asphalt. This reduce their beneficial effect on noise production, and noise absorption properties. Alternate melting and freezing of water trapped in the road surface layers, especially porous surfaces, reduce the durability of these types of surfaces.

A third hindrance has been industry opposition to stricter environmental restrictions. The life spans of tyres are shorter than for vehicles, so in principle it should be one of the fastest ways to achieve noise reductions. However, 99 percent of commercially available tyres already satisfy upcoming regulatory noise emission levels. Therefore, even if the tyre producers could produce tyres that emit less noise, they have no incentives to do so.

There is a difference of about 3-5 dB (A) between tyres that are in production that might have been utilised, but there is no noise labelling of tyres and information of noise reduction properties is not available (Morgan et al 2003).

1.3 Categories of noise abatement measures

Before discussing the research on noise reduction measures at the source, it may be useful to briefly position these measures from other noise abatement initiatives.

We distinguish between different classes of noise abatement measures.

- *Long and short term measures to reduce road traffic flows (financial methods, integrated transport-area planning, policies for transferring road traffic to public transport, freight traffic to rail etc.*
- *Local measures that, given the amount of traffic and residential locations, seek to reduce noise conflicts through construction of bypasses and traffic management schemes.*

- **Noise reduction at the source.** Measures aiming at reducing the noise level emitted from the noise source. These include measures as: encapsulations of noise engines, use of sound absorbing materials in the vehicles, use of road surfaces that emit less noise than conventional surfaces and reducing vehicle speeds. Certification procedures, standards etc that affect the environmental properties of new vehicles and replacement parts/maintenance also fall into this category.
- Measures affecting the propagation path such as environmental tunnels, noise reflection and absorption screens, absorbing road side surfaces, active noise suppression, and façade insulation.
- Measures affecting people's perception of and ability to cope with noise. Reducing danger to self, children and others, visual intrusion, and addressing other stressors such as air pollution enable people to cope better with noise stress.

In this report, we focus on measures affecting noise emissions at the source. However, it should be kept in mind that it may be necessary to employ a combination of different types of noise abatement measures in order to obtain the desired results.

Full benefits of rolling noise reductions will for example not be achieved if there remains a significant amount of propulsion noise from heavy vehicles (speeds around 50 km/h).

1.4 The aim of noise reduction at the source

The aim of noise reduction at the source is – given the amount of traffic of different types – to reduce noise emissions. They are directed towards reducing the noise emitted from engines, power train¹, tyre-road surface interaction etc.

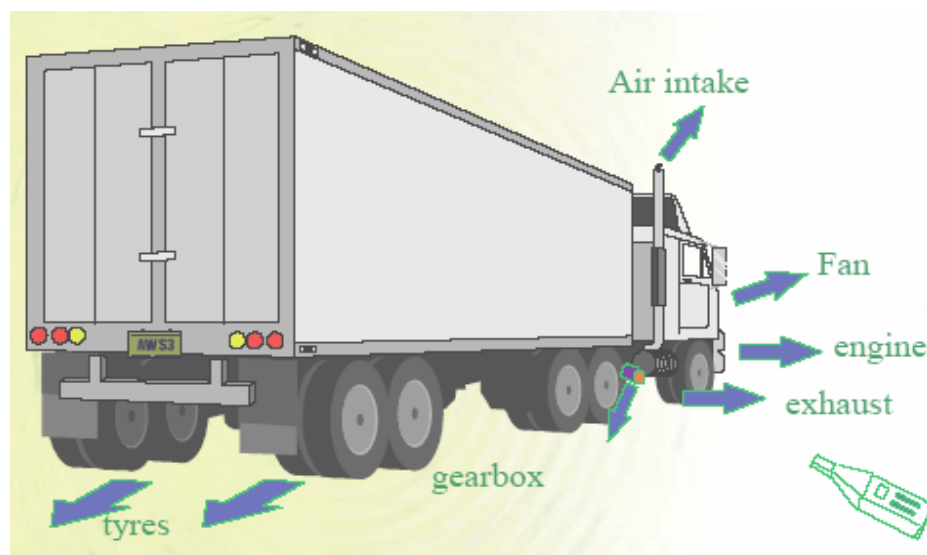


Figure 1.3: Noise sources

¹The intervening mechanism by which power is transmitted from an engine to a propeller or axle that it drives: Encyclopedia Britannica

Certification procedures where noise emissions are tested, and procedures to check that limits are not exceeded when in operation, fall into this category, as well as measures to ensure that environmental standards are maintained when original parts such as the car tyres are replaced.

Some porous road surfaces are laid not on the road itself, but along pavement areas and other areas between the roadway and residential areas etc. Strictly speaking, such surfaces are not measures affecting noise emissions but noise propagation. These types of measures are usually parts of a comprehensive road surface laying policy and are described as a part of noise abatement at the source initiatives.

1.5 Cost benefit analyses of noise abatement efforts

Impact analyses of reduced vehicle speeds list the number of lives saved and reduce accident costs as main benefit. Porous road surfaces have initially had a quite different purpose than noise abatement, namely to reduce the amount of surface water associated with rain, reduced splash and higher vehicle speeds.

All impacts of a given policy should therefore be considered and viewed as a whole. Maintenance cost, operating costs, and interruption costs are thus integral part of the socio-economic evaluation of these types of measures. Such analyses are not part of this project.

Many of the measures that are considered for employment are still at the drawing board. In many cases, there are only laboratory studies, and there are no data with respect to durability and potential side effects. One should be careful not to introduce measures where real life testing has not been performed over several years, and where there is insufficient data on durability and side effects.

1.6 Method

The work that is documented here is mainly a literature review, based mostly on newer European studies. It provides an overview of what is known about the different types of at the source noise abatement efforts. It focuses on the potential for achieving noise reductions in real traffic and real operating conditions, life time cycle, costs and modifying factors.

In addition, some tentative conclusions have been reached with respect to which areas where it is possible to conclude from current knowledge, to what might be appropriate noise abatement policies.

2 Geographical aspects

The adverse impacts of road traffic noise affect mainly the black and grey areas of European city areas. Black areas are defined to be areas exposed to L_{den} values of 65 dB or more, while grey areas cover the noise exposure range from 55-64 dB. These areas are often “belts” along the main road system, and where the black areas are closest to the road while the grey areas are areas that are shielded from the main road system by distance, intervening buildings or noise screens.

2.1 Noise abatement efforts at the source: global or local?

Noise reductions at the source come in two flavours, **local** noise abatement measures and **global** noise abatement measures:

- Examples of **local** noise abatement measures at the source are “silent” road surfaces and environmentally motivated speed reductions. Such measures have specific local impacts. Their aim is to reduce noise emissions, whereas noise screens, façade insulation etc. are local noise abatement measures targeting the propagation path.
- Noise reductions such as less noisy engines, noise reductions of power trains, or low noise tyres, can be characterized as **global** measures, as these measures will reduce noise emissions everywhere the vehicles are employed and where operating conditions are favourable. These measures thus have a potential of benefiting a very high number of people.

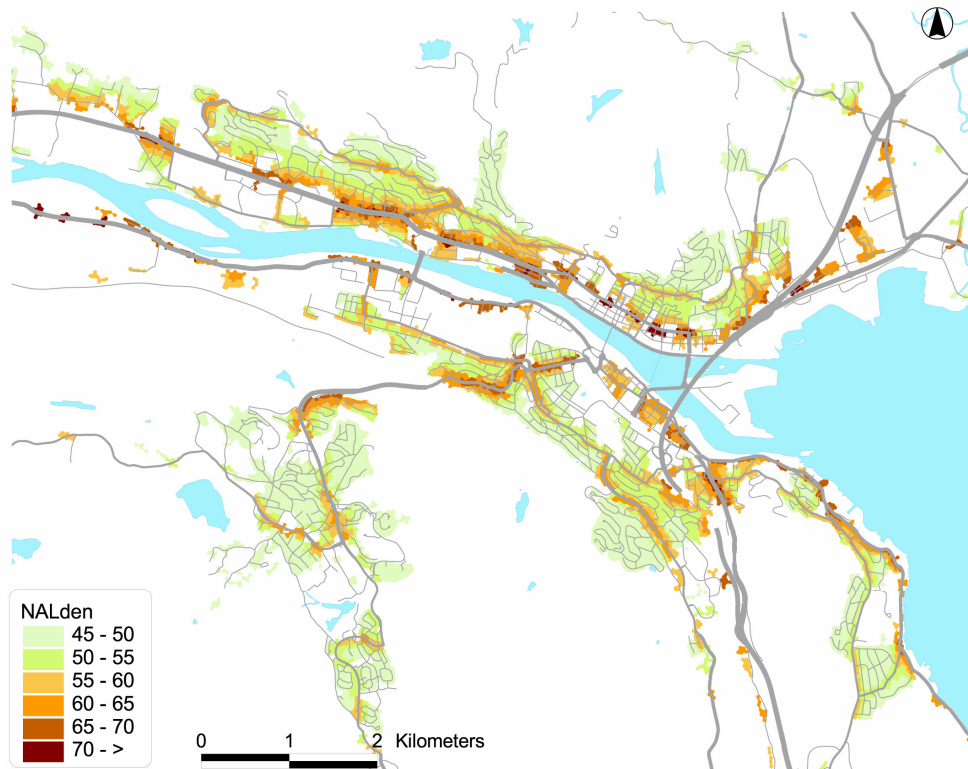
Both local and global noise abatement measures at the source have **local** impacts in that noise only becomes a problem where there are people. It is the road stretches that affect a large number of residences, workplaces or other locations where people become exposed to noise that are critical. For urban life quality the noise quality of residential neighbourhoods are especially important.

2.2 A limited number of road stretches need to be considered

As a platform for discussing the deployment of local noise abatement measures, and for mapping the impacts of local and global noise abatement measures, noise impact maps may be of utility. Such impact maps highlight geographical conflict areas where road traffic noise emissions affect many people. The maps describe impacts in terms of general noise annoyance or as specific noise impacts such as sleep disturbances, behavioural adaptations such as sleeping with windows shut at night etc.

The advantage of impact maps is that these better than exposure map isolate the road stretches that have the greatest impacts on the population. These are the areas where noise reduction measures have the most effect.

It follows that only **limited stretches** of the road network need be considered as targets for local noise abatement measures. These are the road stretches where noise emissions affect many residents living near the road. Focussing on particular stretches means that local noise abatement measures are employed where they have the greatest benefit.



Noise impact map for the small city of Drammen. Conflict areas are clearly depicted along the major road system. A minor part of the road system is responsible for a large part of the environmental problems. (Map through the courtesy of Statistics Norway).

2.3 Noise impact maps should indicate efficient measures

For deployment of noise abatement measures, it is necessary to be aware of the current situation along various parts of the road network. There is no utility in reducing vehicle speeds from 80 to 70 km/h if the current local speed limit already is 70. The reduction in noise from laying road surfaces with improved environmental properties depend on the quality of those already in place, as will the profitability of the exercise.

The efficacy of different noise abatement strategies depends on the urban situation where the measures are to be applied. To reduce noise in inner city areas, with speed below 40 km/h, engine noise reduction is typically more effective than reducing rolling noise. Measures for even speeds, engine-encapsulation or environmental zones to limit older/heavy vehicles are types of measures suitable

in these areas. On urban/village roads with higher speed levels, other types of measures are more effective. Reducing the rolling noise by use of low-noise tyres or surfaces, limiting the use of studded tyres, or reducing the speed can be very effective under these conditions. In areas where vehicle speeds are in the 50-60 km/h range there will be both engine noise from heavy vehicles and rolling noise from light and heavy vehicles. In such mixed situations where restrictions on heavy vehicles are not an option, it may be necessary to employ absorption-mats embedded in the road surface, noise screens adapted to shield right lane for heavy traffic to reduce engine noise in order to profit from the noise reductions attained with respect to rolling noise.

2.4 Optimal noise reduction efforts achieved by cooperation

The optimal mixes of noise abatement measures are difficult to achieve without cooperation between road owner, central government, municipalities, building owners and transport users. Some sort of clearing house or allocation mechanism needs to be developed for urban situations involving several parties.

Environmental zones may be one type of solutions, but the question is then who is in charge of the planning, operation and monitoring of environmental zones.

3 Action plans, strategies and targets

3.1 The Dutch noise innovation program (IPG)

The Noise innovation programme was a result of the target set in the Dutch national Traffic and Transportation plan (NVVP 2001-2020). Noise ambitions where as follows (Inland et al 2003):

“Decreasing the number of houses exposed to a noise level of > 70 dB(A) by 100 percent, the number > 65 dB(A) by 90 percent, and the number > 60 dB(A) by 50 percent. To be realised in 2030”.

The Dutch noise innovation programme has a budget of 50 million Euro, and its goal is to investigate the effect of different measures to reduce noise from road traffic (road surfaces, tyres, vehicles and noise barriers), and initiate new research needed to reach the goals, and at last to develop the technologies and products needed.

In the innovation programme, different measures will be evaluated. Different types of road surfaces will be tested out, and new improved types will be developed. The goal is to reduce the noise emitted from road traffic with 8 dB(A) within 2006 and 12 dB(A) within 2010, se table 2.1.

Table 2.1: Expected noise reduction in 2006 and 2010, according to type of measure. Source: Nijland et al 2003

2006		2010	
Road surfaces	4 dB(A)	Road surfaces	6 dB(A)
Tyres/vehicle	2 dB(A)	Tyres/vehicle	3 dB(A)
Barriers	2 dB(A)	Barriers	3 dB(A)
Total	8 dB(A)	Total	12 dB(A)

3.2 Germany’s research programme “Mobility and traffic”

The research programme has a budget of 55 million euros each year, and the basic objectives are (Heinemann 2004):

- Sustainability
- Efficiency
- International competitiveness

The programme activities are focused on noise abatement (road-, rail-, and air traffic) at the source, because this is considered most sustainable and efficient for solving the noise problem from traffic (Heinzelman 2004).

To reduce road traffic noise emissions tyre design, sound absorbing materials (including road surfaces) and low-noise wheelhouses are focussed.

As a part of the research programme the research network *Leise Verkehr* (quiet transport) was established in 1999.

3.3 Finnish guidelines and action plan for noise abatement

The group working with the Finnish action plan for noise abatement has proposed the following targets for 2010 (Ministry of Transport and Communications 2005):

- Reduce the number of people living in areas subjected to noise levels above 55 dB(A) by 20 percent by 2020 (2003 level).
- To reduce the number of people living in areas subjected to road traffic noise levels above 55 dB(A) by 15 percent.
- When building new housing and other noise sensitive activities, they should not be constructed and established in noise areas, and noise producing activities should not be brought to these areas without proper noise abatement measures.
- If the guideline value of 55 dB(A) cannot be reached e.g. in densely populated and highly trafficked areas, at least outdoors in internal yards the guidelines should be reached.

Main instruments in reducing road noise:

- Noise abatement programme for Road Administration (about 10 million euros/year). To be used on noise walls, porous surfaces and façade insulation if necessary.
- Research and development on porous surfaces and low-noise tires.
- Give priority to porous asphalt, low-noise tires and quiet vehicle procurement.
- Enforcing inspection of noise emissions of vehicles.

To meet the targets, 33 different measures are proposed, among these are measures to reduce road traffic noise emissions. Speed limits, low-noise road surfaces, silent tyres and propulsion noise reduction measures are among the measures considered.

It is estimated that speed limits can reduce noise with 0-3 dB(A), improved tyre can reduce noise with 0-3 dB(A) and low noise surfaces can reduce noise with 3-7 dB(A). Low noise surfaces have a potential of about 9 dB(A), but this require expensive testing and willingness to prioritise this kind of research and testing.

The cost of implementation of the programme is calculated to be around 30 million euros each year. Since welfare costs due to noise annoyance are estimated

to 380 million euros a year, the programme is considered to be socio-economic profitable.

3.4 Noise strategy for Denmark

In Denmark, the governmental initiated working group on road noise published their proposal for noise strategy in November 2003. Noise reduction at the source is one of their recommendations.

Different proposed measures (Miljøstyrelsen 2003) and their potential for noise reduction, are:

- Intensifying the requirements on noise emitted from vehicle (presumed noise reduction caused by EU directive: 1 dB within 2020).
- Promote further use of low noise tyres (potential reduction: 0,7-1,3).
- 2 layer porous surface (drensasfalt) (potential reduction: 3-5 dB).
- Thin asphalt (potential reduction: 1,5-2 dB).
- Speed reduction (speed reduction of 10 km/h presumed to reduce noise with 0,5-2 dB).
- Banning trucks on some roads.

The figures for potential noise reduction are based on current knowledge (tested in traffic) of noise reduction. To reduce noise emissions to a satisfactory level, combination of different measures have to be implemented. None of the current measures is alone sufficient.

3.5 Noise targets in Sweden

In Sweden about 1,46 million inhabitants are exposed to road traffic noise levels exceeding 55 dB(A)(Odebrant 2002). This number relates to 2000 and has been about the same since 1995. The Swedish government has a target to reduce the number of people exposed to noise levels above national requirements with 5 percent within 2010 (1998 as basis year). As the 5 percent figure affects both new buildings, buildings where noise levels are excessive and noise problems in existing areas exposed to intermediate noise levels, several types of efforts are necessary. However, the 5 percent figure is not particularly ambitious.

Boverket focuses on ensuring adequate attention during the planning and renovation processes. Noise abatement at the source is explicitly mentioned as a supplementary method for noise reduction, but there seems to be no provision for such measures in the initiatives taken by Boverket.

3.6 Noise targets in Norway

In Norway about 1,4 million persons where exposed to noise levels above 55 dB(A) in 2003 (Statistisk sentralbyrå 2005). The number of people exposed to noise at this level is about the same as measured in 1999. About 300 000 (Statens forurensningstilsyn 2000) persons where highly annoyed.

In Norway, the government have set a goal to reduce the noise annoyance in Norway by 25 percent within 2010 (Miljøverndepartementet 1999). The noise annoyance figures for 1999 serve as baseline. The authorities have proclaimed that a substantial part of these reductions is to be achieved by noise abatement at the source. The status of these efforts in the beginning of 2005 is that there has been made little progress. This is not remarkable as there has been allocated virtually no money to sustain national noise abatement at the source efforts.

The government confess that it will be difficult to reach the targets.

With respect to more traditional noise abatement efforts targeting the black spots (over 42 dB indoors with closed windows and ventilation openings also closed), a comprehensive and costly effort is well under way. The aim is that all apartments exposed to such excessive noise levels (estimated at about 8000 for whole of Norway) should be remedied before 2005.

4 Propulsion noise

4.1 Different types of propulsion noise

Under the term propulsion noise, we distinguish between noise contributions from the engine, powertrain, exhaust and intake systems.

EC Directive 70/157/EEC regulates the technical approval of new vehicles. New passenger cars and heavy vehicle have to emit less than respectively 74 and 80 dB(A) to be approved for sale in Europe. There is a tendency towards optimizing the results for test conditions rather than for real life traffic situations. However, regulations on heavy vehicle have had a somewhat better effect in reducing noise emissions in real life situations.

A number of vehicle components emit noise. The distribution of emitted noise from a passenger car in a test situation is depicted in figure 4.1. The noise emitted from passenger cars in normal traffic situations can be quite different from the test situation. ISO and UN-ECE are therefore working on new test procedures to close the gap between test situation and reality.

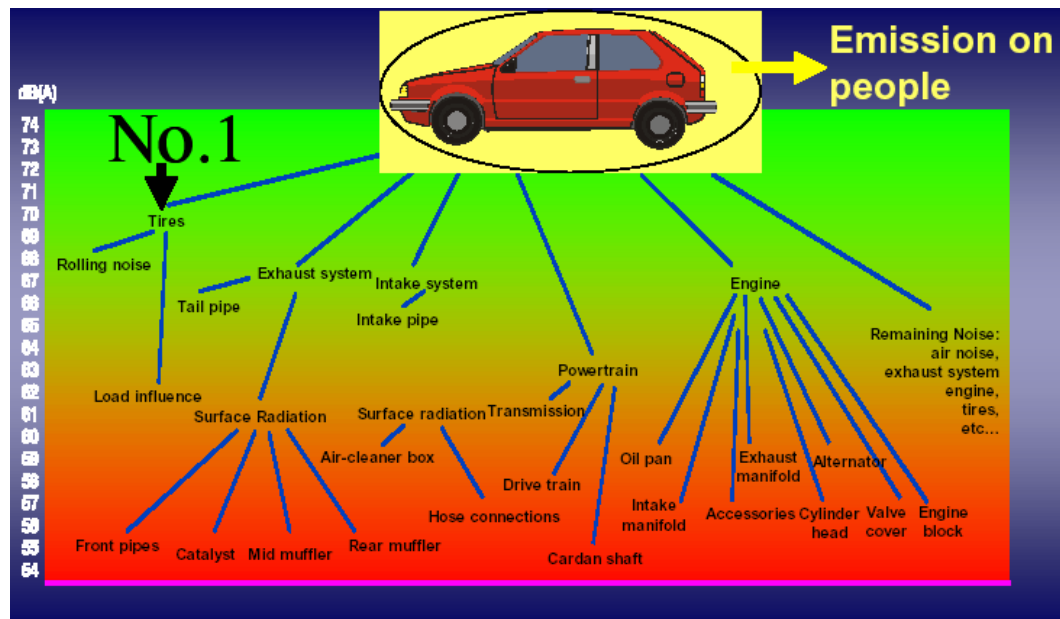


Figure 4.1: Noise source distribution by a passenger car meeting the 74 dB(A) limit, test situation. Source: Gerhard 1999

Depending on vehicle speed and the associated choice of gear, not only the absolute noise levels emitted vary, but also the relative contribution from the different vehicle noise emissions sources will vary. The relative contribution of different vehicle parts to emitted noise from a vehicle driving in 2nd and 3rd gear and from a heavy vehicle is shown in table 4.1.

Table 4.1: Typical distribution of propulsion noise, percentages from different units. In percent. Pass-by. Source: Rust 2001

Noise from:	Engine	Intake system	Exhaust system	Gearbox and driveline	Cooling system	Total
Pc in 2 gear	51	14	21	14	0	100
Pc in 3 gear	35	11	31	23	0	100
Hv	32	15	16	27	10	100

According to Morgan et al (2003), about 50 percent of the noisiest cars running on the streets possess engines that no longer can be considered state-of-the-art. If “outdated” engines were replaced with new ones, a noise reduction of about 3 dB(A) should ensue.

There is also a potential for reduced noise emissions if customers could be persuaded to purchase the less noisy cars. The difference in noise emitted from the noisiest and the least noisy vehicles on the market is about 7 dB(A) (Morgan et al 2003).

4.2 Propulsion noise from heavy vehicles

One manufacturer of heavy vehicles has demonstrated the possibility to reduce the noise with a further 10 dB(A) compared to today’s level (Morgan et al 2003). But it is not realistic that noise from all heavy vehicles can be reduced this much. The main problem is the price increases following from such efforts. In specific noise sensitive areas for example in connection with the introduction of Environmental Zones (Miljøsoner) or Low Emission Zones, additional noise insulation may be required for vehicles that serve the areas.

Powerful heavy vehicle engines yielding more than 320 kW are today encapsulated to reduce emitted noise levels with about 3 dB(A) (Morgan et al 2003). Without encapsulation, the 80 dB(A) EU-requirement for heavy vehicles would not have been met.

4.3 Measures to reduce propulsion noise

The most commonly used methods for reducing propulsion noise are (Rust 2003):

- Controlling the powertrain by low-noise design (optimising structure dynamics, use of low-noise materials etc.).
- Specific injection and combustion characteristics, to control combustion under cold running conditions and low idle (common rail injection system, pilot injection, exhaust gas recirculation, electronic powertrain management).
- Encapsulation/acoustic shielding.
- Multiple muffler system for control of exhaust noise.
- Noise-optimised layout for intake system (designed using advanced simulation tools and implemented using resonators and broadband dampers).

5 Tyres and vehicle speed

5.1 Factors that affect noise emissions

The amount of noise emitted from tyres is among other dependent on:

- Tyre width (wide tyres are noisier than narrow ones, at least up to a certain width).
- The hardness (a hard tyre are noisier than a tyre constructed using soft materials).
- Tread pattern (for example: rib pattern is sometimes noisier than block pattern).
- Groove depth (deep patterns are noisier than surface pattern, studded tyres are noisier than non studded tyres.).
- Road surface and the interaction between tyres and road surface.

Contrary to noise emitted from the engine, tyre noise emissions have increased over time. This is mainly caused by the use of wider tyres (Philips and Kingsley in Berge 2001). In the last 15 years, the width of the tyres used has increased by approximately 2 mm yearly (Morgan et al 2003).

A test of 29 different types of tyres performed by Phillips et al (2001) suggest a increase in the noise level by 0,2-0,4 dB(A) per 10 mm increase in tyre width (depending to a certain degree on the type of tyre).

A huge amount of different tyres are available today, and these tyres can differ about 4-5 dB(A) in noise emitted (Kragh 2003, Berge and Ustad 2004a and 2004c). Another factor is choosing the right kind of tyre for the road surface most common in your district. According to tests preformed by Morgan et al (2003) as much as 9 dB(A) noise differences can occur when different kinds of tyres are tested on different kind of road surfaces. Choosing the right match between tyre and road surface alone can reduce much of the noise problems.

According to Rust (2003) a further 5 dB(A) reduction is possible compared to today's technology, Sandberg claims that 10 dB(A) reduction is possible with a newly developed compression tyre (Sandberg and Ejsmont 2002).

Sandberg et al (2005b) has also tested a porous tread tyre. The tire is made of rubber granules bound with polyurethane, and is placed on top of conventional tire carcasses. A porous structure is created, and noise reduction of about 7 dB(A) was achieved on a typical Swedish road texture (SMA16). On smoother surfaces (SMA8) the noise reduction was 2-3 dB(A). The noise reduction was measured using the CPX method, in 50 and 80 km/h, and Nokian tyre was used as reference tyre (Sandberg et al 2005b). Two different tyre widths and two different surfaces

was tested. Rolling resistance was very much like that of the reference tyre, but the wet friction was poorer and needs to be improved.

One of the major problems concerning tyre noise is the EU directive from 2001 (EU directive 2001/43/EF). The noise limits agreed upon in the directive are so moderate that a major part of the tyres produced today already fulfil the limits, and will do so until at least 2011. Therefore, the directive gives no incentive to the tyre producers to improve the noise qualities of their tyres in the near future.

Figure 5.1 is an example of this. In Germany 82 different aftermarket tyres were tested, and all of them fulfilled the proposed EU directives requirements for 2009 and 2011 respectively.

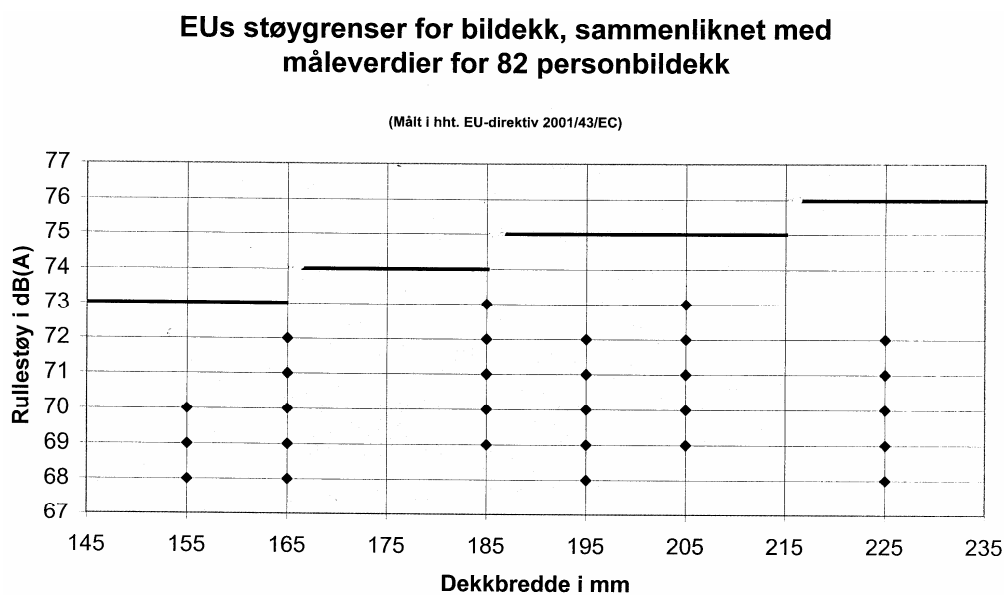


Figure 5.1: Noise measures of different tyres, compared to EU requirement for 2009-2011. Source: Reithmaier and Salzinger 2002, data modified by Kielland, SFT (Norway)

5.2 Tyres must fulfil several requirements

When developing tyres, safety, price and environmental factors are important. Reithmaier and Salzinger (2002) has tested different types of tyres, and scored them after how they satisfy these factors. Optimization of the relative weight allocated to these three variables is important. However, environmental needs do not always reduce friction properties of the tyres. Providing detailed specification of tyre properties makes it easier for the customer to chose a tyre better equipped for their needs, and may make the tyre industry more willing to develop low noise tyres (if they see that customers and politicians want this kind of tyres).

5.3 Vehicle speed

Noise emitted from vehicles increase with increasing vehicle speed, see figure 5.2. Reducing speed (mainly within the 40-90 km/h speed level range) results in: reduced noise levels, reduced amount of combustion particles, reduced road surface wear, and fewer and less severe road accidents. As resuspension of particles depend on the speed winds from cars and trucks passing by, reduced vehicle speeds can reduce resuspension when road dust has accumulated along the roadside. Such situations occur especially after snow melting during early spring. Reducing the average vehicle speed by 10-20 km/h can reduce the noise level by 2-4 dB(A) depending on the percentage of heavy vehicles (Bendtsen et al 1998, Amundsen and Ragnøy 2002, Paikkala et al 2003).

In Oslo, Norway the speed limits was lowered by 20 km/h on one road section during the winter season of 2004/2005(November – April). The speed reduction was environmentally justified, and led to reduction of PM10 as well as a 2 dB(A) reduction of the noise level (Statens vegvesen 2005). 4/5 of the respondents to a local survey stated that they were positive to a continuation of the speed reduction, if it proved to improve the air quality (Statens vegvesen 2005). The environmentally based speed limits are therefore to be implemented for the winter of 2005/2006. The measure might also be implemented on other major high speed roads in residential areas.

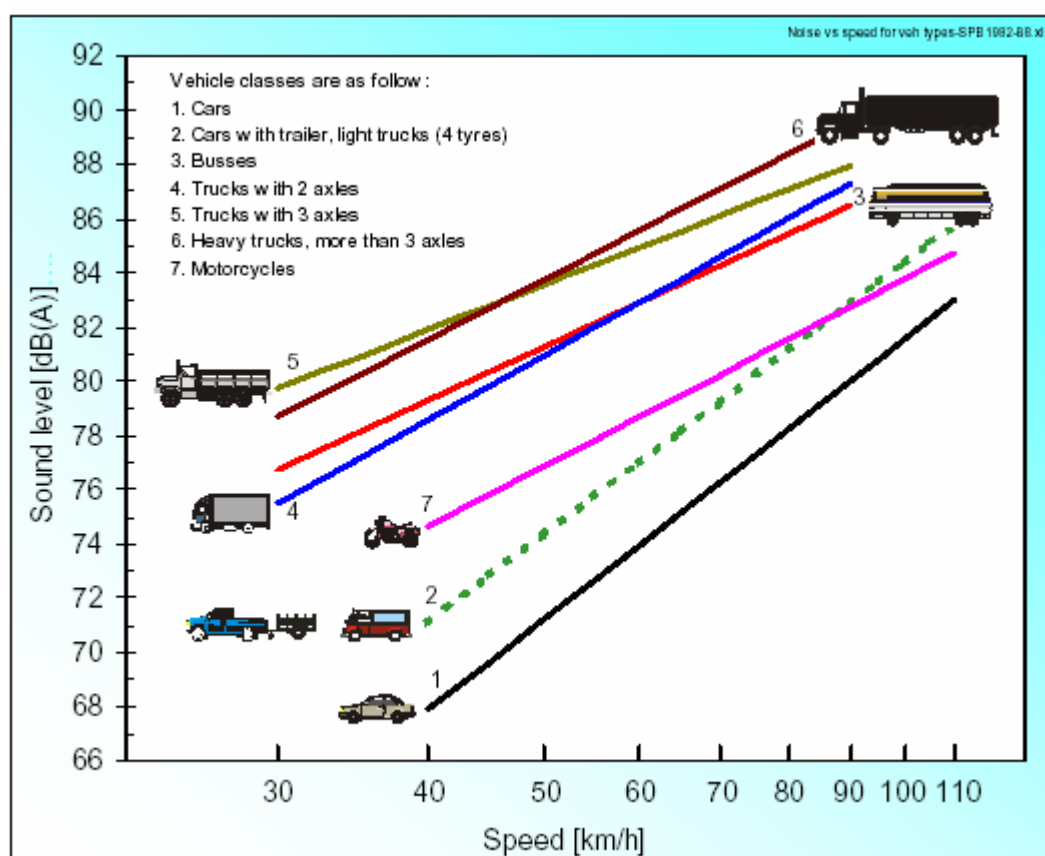


Figure 5.2: Noise from different types of vehicles, depending on speed-level. Source: Sandberg 2003 (p. 17)

One of the greatest advantages of reducing vehicle speeds compared to other means of reducing noise emissions is that implementation time is short. The

potential noise reduction is not as high as the long-time potential for other measures, but it is a relatively cheap measure and can get effects quickly. The problem is the poor compliance with speed limits in general. Increased speed surveillance (police/camera/ISA) is often necessary, and is generally not popular among the public or the politicians.

Nevertheless, on some stretches of radial or circular roads in cities/villages it may be possible to gain support for reduced vehicle speeds if the particular road is close to residential areas or popular recreational areas. In addition to noise reduction, traffic safety benefits are often substantial and air quality in the area is somewhat improved.

Noise reduction of up to 3 dB(A) can be achieved by choosing a constant as possible and a optimal speed level (depending on gear) based on the driving situation and vehicle type (Paikkala et al 2003).

Speed reductions should also be considered specifically for uphill versus downhill conditions. Propulsion noise from heavy vehicles can dominate in uphill situations and speed limits may thus need to be different in the two situations.

The injury accident rate and the fatal accident rate increase with about the 2nd and 4th power of the mean traffic speed (Nilsson 2000). Reduced speed will reduce suspension of particles, but may have an adverse effect on pollution from the combustion. This depends on temperature, type of vehicle and speed interval. Reducing speed from 90-80 km/h to 70-60 km/h has a positive effect on safety and the environment (Amundsen and Ragnøy 2002, European commission Transport RTD 1998).

6 Road surfaces

6.1 Different types of road surfaces

The specifications of different road surfaces vary between countries. This makes it difficult to compare them to each other. There are many possible combinations of minerals, aggregate sizes, chemicals, number of layers and thickness of layers that can be employed for obtaining road surfaces with different qualities. Depending on climatic conditions, AADT, speed level and types of vehicles the best possible combination has to be chosen.

Some Norwegian test results show that what is thought to be typical road surfaces after a winter season, emit about 7-8 dB(A) more than the ISO-surface (Berge and Ustad 2004a and 2004b). Norwegian road surface types are mainly chosen for their ability to withstand the use of studded tyres during winter, and increased wear during winter.

Low-noise road surfaces are mainly suitable in densely populated areas with speed levels above 40 km/h. At lower speed levels other measures e.g. directed at engine noise especially from heavy vehicles, is more suitable to reduce noise. Motorways, main connecting roads, and other roads in urban or densely populated areas are roads where choosing the right type of road surface can have a good effect.

Generally speaking: rough surface is noisier than smooth surfaces. Porous surfaces are less noisy than non-porous surfaces, and elastic surfaces are less noisy than non-elastic surfaces. However, there are also interactions between the type of tyres that are used and the road surface. Tyre-road noise reductions are dependent on a match between road surface and tyre properties.

The interaction between tyre and road surface is shown in figure 6.1. Right and left arrows in figure 6.1 indicate the so called horn effect. In the cavities in/between the tyre tread, air pumping will take place. The Helmholtz resonance is the air displacement into/out of connected air cavities in the tyre tread pattern (Sandberg and Ejsmont 2002). Radial and tangential vibrations both in the tyre and in the road surface occur when the blocks leave the contact patch.

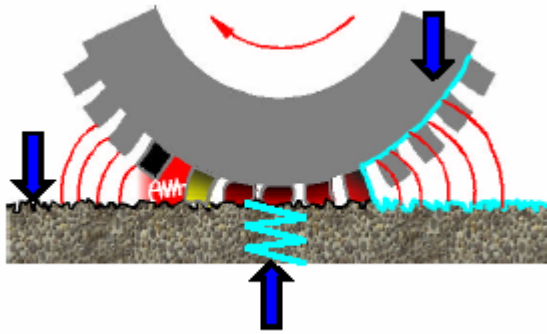


Figure 6.1: Rolling noise from the tyre/road surface interaction. Source: Dijkink and Keulen 2004

To develop the best type of surfaces other factors than just noise must be taken into consideration. Optimisation of friction properties, wear resistance (durability and air pollution), development- and maintenance cost must also be considered and the best mix of properties chosen.

Ideally, road surfaces should satisfy a number of requirements (Elvik and Greibe 2003):

- Durability: A good road surface should last long and be resistant to wear and tear.
- Skid resistance: A good road surface should provide good skid resistance and thus a high level of road safety.
- Light reflection: A good road surface should adequately reflect light without causing discomfort glare.
- Tyre and vehicle wear: A good road surface should not cause damage to tyres or cars or greatly speed up normal wear and tear.
- Rolling resistance: A good road surface should not unduly increase rolling resistance, thus leading to increased fuel consumption.
- Traffic noise: A good road surface should minimise traffic noise (due to tyre/road interaction).

The drawback with some of the road surfaces that have been tested out as having the best noise-reducing properties is their cost and inferior durability.

Most of the tests that are undertaken in Europe on low-noise surfaces are now centred on porous (twin – or multi layer) surfaces, poroelastic surfaces or thin surfaces.

6.2 Thin surfaces

As part of the EU project SILVIA various types of low-noise-road-surfaces are tested. In addition to porous and poroelastic surfaces, a new type of thin surfaces looks promising. Thin surfaces do not have the same noise reducing potential as porous or poroelastic surfaces, but are cheaper and have better durability.

The tests have just started, so there are no results yet, but experiences from the Netherlands indicate noise reductions of 1,5-2 dB(A) (Miljøstyrelsen 2003).

Thin open layer surface testing commenced in Denmark as part of the SILVIA project. The basic concept of open layer surfaces is to create a structure with as big cavities at the surface as possible. Thereby noise generated by the air pumping effect is reduced. At the same time, blends and laying techniques are optimized for producing smooth surfaces that reduce vibration from the tyres. This is an example of handcrafting the surface layer to the problem at hand (Bendtsen and Andersen 2004).

The thin layer tested out in Denmark is about 17 millimetres thick and have a aggregate size of max 6 millimetre (Bendtsen and Andersen 2004). Preliminary results show a noise reduction of about 3 dB(A) compared to dense asphalt concrete with max 11 mm aggregate size (Bendtsen and Andersen 2004).

Figure 6.2 provides an example of the potential noise reduction for thin layer compared to some other types of road surfaces.

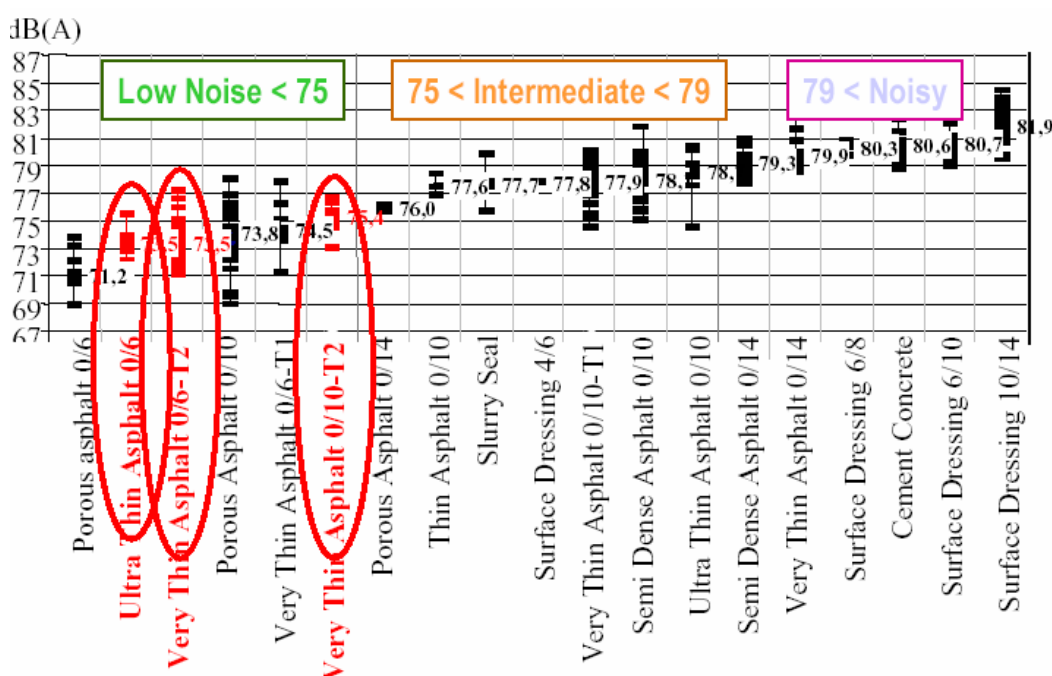


Figure 6.2: Noise levels from thin surface types compared to porous- and some other types of surfaces. Source: COLAS

The summer of 2000 low-noise stone-mastic asphalt (SMA) with 5 millimetre maximum aggregate size was laid out in Helsinki, Finland (Valtonen et al 2002). A noise reduction of 3 dB(A) was achieved on a 50 km/h road, and a 7 dB(A) reduction achieved on a 80 km/h road section. The wearing was six times as high as SMA 11 and ten times as high as SMA 16.

6.3 Porous surfaces

Generally the thicker and higher porosity the surface has, the better noise reduction is achieved (Statens vegvesen 2003). Porous surfaces are also called drainage surfaces, and drain water away from the surface. Clogging of the pores has been a problem, especially in countries using studded tires during the winter season.

Porous surfaces tested out now, usually have two layers. The twin layer porous surfaces, see figure 6.3, have a fine-grained top layer, a coarser grained bottom layer on top of a thin impenetrable layer (preventing the water to penetrate further down). The top layer usually has aggregate size of 4-8 millimetres and a thickness of 20-25 millimetres. This gives the surface an even surface, which reduce the rolling noise and the penetration of water, and act as a filter against some of the dust particles. The bottom layer has aggregate size of 11-22 millimetres and a thickness of 35-65 millimetres. This layer makes it possible to drain away water and dust particles. Both layers have a porosity of 20-25 percent (Rust 2003, Bèrengier and Licitra 2003).

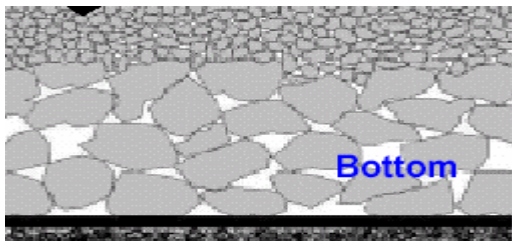


Figure 6.3: Twin layer porous asphalt. Source: Berengier and Licitra 2003

The life cycle of a twin layer is estimated to 5-8 year for the top layer, and 10-16 year for the bottom layer (Bendtsen et al 2002, Sælensminde 2002). The durability of the top layer is depending on: use of studded tyre (probably), AADT, amount of heavy vehicles and the amount of maintenance (washing, sucking e.g.) of the road surface. When the top layer has lost most of its noise-reducing effect, it can be milled away, and a new top layer can be added.

Porous surfaces are mainly ideal for ring roads or arterial roads in densely populated areas where the speed limits are higher than 70-80 km/h. In more inner-city areas with an increased level of acceleration/retardation and many curves, the increased clogging of the top layer may indicate that thin surface types are more suitable.

The Swedish and Danish government have estimated that porous surfaces are about 50 percent more expensive than conventional surfaces (Sandberg and Ejsmont 2002).

Under winter conditions in Norway, Sweden and Finland, where temperatures may vary a lot, porous surfaces may have disastrous effects on the durability of the surface. Normal drainage to the roadsides is often blocked due to snow and ice. There will also be situations where parts of the road surfaces are blocked by ice, and parts that have not yet frozen. When the liquid parts freeze, water expands. Suggestions for remedying this type of problem are to build in inclinations leading the water into drainage canals etc. Previous efforts from Norwegian road laying tests also suggest that satisfactory solutions to this problem may be difficult to find (Statens vegvesen 2003).

6.3.1 Danish results

In Copenhagen Denmark, three types of porous surface have been tested out in a minor street (AADT 7 000, speed limit 50 km/h) since 1999. The surfaces were twin layer asphalt with top layer with 8 or 5 millimetre small aggregate size and different thickness. This was done to evaluate the different characteristics of the surfaces (noise, clogging, friction, durability, etc). Compared to a conventional, reference surface the noise reduction was 4.5-6 dB(A), see table 6.1. After two years the noise level was about 4 dB(A) lower than the reference surface.

Table 6.1: Test results from three different types of drainage asphalt in Denmark. Source: Bendtsen et al 2002

	DA8-70	DA5-55	DA5-90
Characteristic:	Two layer Thickness 70 mm 8 mm max aggregate size	Two layer Thickness 55 mm 5 mm max aggregate size	Two layer Thickness 90 mm 5 mm max aggregate size
Noise reduction ¹ :			
- New surface	4,5 dB(A)	5 dB(A)	6 dB(A)
- After 2 years	4 dB(A)	4 dB(A)	4 dB(A)

¹ Noise reduction in proportion to "normal" asphalt, with same age and traffic.

After 2 years all three of the asphalt types had the same noise reduction, even though the thickness and aggregate size was different. Twice a year the surfaces were cleaned with high-pressure water spraying and sucking to reduce clogging. In the end of the two-year period, the clogging was somewhat higher in the surfaces with the smallest aggregate size (Bendtsen et al 2002).

Wear and tear of surface road particles and other pollution on dense asphalt layers bordering onto the porous asphalt, resulted in significant clogging of the porous asphalt in the lane where vehicles went from dense to porous layers. This means that an additional 100 meters of porous asphalt may be necessary to serve as a buffer area to reduce clogging of the road surface along the areas where the sound reduction is important.

Economical analysis (30 years perspective), indicate that a twin layer porous asphalt is 3-10 times as cost-effective as façade insulation or the use of noise barriers (Bendtsen et al 2002). The calculation is based on a lifespan of 7 year for the surfaces. Later calculations (Sælensminde 2002) indicate that even with a life expectance of 3 years for the top layer and 7 year for the bottom layer, these kinds of surfaces are cost-effective.

6.3.2 Results from the Netherlands

In the Netherlands, porous surfaces are tested out on different road sections as a part of the IPG programme (se chapter 2.1). The currently used porous asphalt is a twin layer surface with a 15-25 millimetre top layer (max aggregate size 6-8 mm) and a 45 millimetre bottom layer (max aggregate size 16 mm). Eight other types of mixtures are now also tested out on 5 different road sections (Hofman and Kojj 2003).

The currently used porous asphalt reduce the noise with 1,8-5,3 dB(A). After four years most of the test sections are well within the 4 dB(A) goal for 2006. But measurements on some of the test sections, show poor skid resistance (Fafiè 2002 in Hofman and Kooij 2003).

In the Dutch Roads to the future program (WnT), different types of 3rd generation surfaces are developed and tested. Noise reduction from 5 to 8 dB(A) are measured, se table 6.2. With a better optimizing, reductions of about 10 dB(A) seems possible (Hofman and Kooij 2003).

Heavy vehicles produce more noise than light vehicles, and modern engines are designed so that the noise is transmitted downwards (Dijkink and Keulen 2004). It is possible to produce surfaces specially designed to reduce the noise from heavy vehicles. The surface called SilentTransport (see table 6.2) is intended for lanes with a high percentage of heavy vehicles.

Table 6.2: Noise reduction, 3 generation surfaces. Measured by SPB-method, light vehicles in 100 km/h. Source: Hofman and Kooij 2003, Dijkink and Keulen 2004

Name	Characteristic	Noise reductions dB(A)
Very Silent Noise Module	Module system containing Helmholtz resonators. On top of this, thin porous layer with high skid resistance.	5
The rollable Road	3-layer, two top-layers (about 30mm), rollable, bottom layer with concrete elements (high supporting power) containing Helmholtz resonators.	6
ModiSlab	Durable (about 25 year), but expensive. Top layer with concrete (15mm), bottom layer with porous concrete (35-55mm). Varying in thickness dependent of type of vehicle using the surface – sound absorption matching the traffic on the surfaces.	6-7
The adhesive road	Prefab asphalt mat on a roll, can be bonded to/removed from the substrate with a innovative on/off-switching bonding system.	6
SilentTransport	Porous asphalt, with very silent top layer, and an acoustical dense membrane. Designed to absorb engine noise, suitable for lanes with high numbers of heavy vehicles.	8
Tapis Tolerance	Soft top layer, a perforated compression layer, an absorption layer of honeycomb profiles in mineral wool. After optimisation a noise reduction of more than 10 dB(A) could be possible.	7-8*

CPB-method

6.3.3 Results from Japan

In 2001 there was about 4 km of twin layer porous asphalt on national highways in Japan (Namikawa et al 2004). The two-layer porous asphalt has a max aggregate size of 5 mm and a porosity of 23 percent. The surface is mainly better than conventional surfaces in the octave band spectra of 700 Hz and higher (Namikawa et al 2004).

6.4 Poroelastic surfaces

Poroelastic surfaces have a porosity of about 25-35 percent, and the elasticity is created with the rubber content of minimum 25 percent of the volume (Rust 2003).

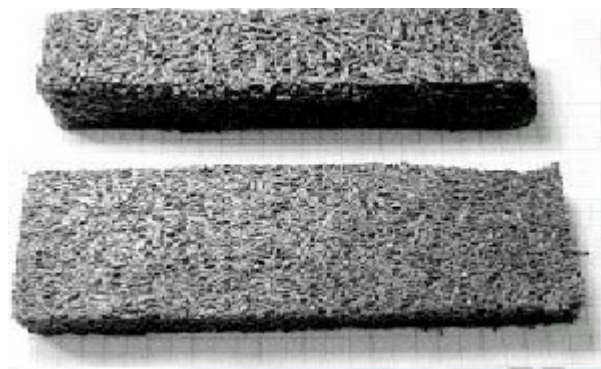


Figure 6.4: Examples of poroelastic surfaces. Source: Bèrengier and Licitra 2003

These types of surfaces have a higher noise reduction potential than porous surfaces (Sandberg and Ejsmont 2002). Clogging is a lesser problem for poroelastic surfaces than for porous surfaces, but more knowledge is still needed to make these surfaces more durable and safe (Rust 2003).

6.4.1 Norwegian experiences under winter conditions

Poroelastic road surfaces were tested out in Oslo, Norway. The surface tested out was 25 mm thick and consisted of 4-8 mm rubber granules. This was bound together by polyurethane, on a porous base (Arnevik 2000). The road had to be closed for four days when laying the surface, mainly to allow the surface to harden. This procedure took longer time than what is usually accepted for roadwork. For new types of poroelastic surfaces the construction phase is reduced, e.g. by using prefab.

5-6 dB(A) noise reductions were measured. But, the type of poroelastic surface tested did not have acceptable friction (0,36 when driving 50 km/h), and during winter-maintenance, the snow-plow ripped up parts of the surface. Costs were about five times as high as conventional asphalt (Sandberg and Ejsmont 2002).

6.4.2 Swedish and Japanese results

In Sweden, test on improved poroelastic mixes started in 1996, and noise reduction from 7 to 10 dB(A) was measured (Sandberg et al 2000). Some mixtures showed noise reductions up to 14 dB(A), but the durability of the surfaces was inadequate. Noise reduction was maintained during rainfalls.

Later tests in Japan (cooperation of Japanese and Swedish researchers) have focused on improving the poroelastic surfaces on durability, friction, fire resistance, adhesion to the base course and reducing the costs (Sandberg et al 2000). The surfaces are based on elongated fiber-like rubber particles, which seem to form a stronger surface (Sandberg et al 2000). Preliminary results show fire-resistance properties much like that of dense asphalt concrete, and acceptable wet friction (Sandberg et al 2000).

Based on laboratory tests three different types of poroelastic surfaces were tested out in the city of Stockholm in 2004. The road section had an AADT of 5400, 8 percent heavy vehicles, and a speed limit of 50 km/h (Sandberg and Kalman 2005a). Rubber from old tyres was used in all three surfaces. Noise reduction of 8-12 dB(A) was measured both with the CPX and the CPB method. The friction coefficient was about 0.6. After a couple of month the testing had to be stopped due to cracking of the underlying asphalt layer (Sandberg and Kalman 2005a).

Table 6.3: Poroelastic surfaces tested in Stockholm. CPX method. Source: Sandberg and Kalman 2005a

Name	Description	Noise reduction
Tokai	Prefab rubber panels 1*1m. 30 mm thick. 30-35 % air voids. Made in Japan.	11
Rosehill	Prefab rubber panels 1*1m. 30 mm thick. 30-35 % air voids. Made in UK.	9
Spentab	Site-constructed rubber-based mix. 25-50 mm thick. 30-35 % air voids. Made in Sweden.	12

Pavetex, an elastic non-porous surface is also being tested in Japan. The surface consists of a fibrous course material made by unwoven polypropylene fabric impregnated with chemical rubber (Iway et al 2004). This surface has kept the elastic capacity of the poroelastic surface, but is not porous, this to increase the durability of the surface. After 6 year use the surface still emitted 5 dB(A) less than ordinary dense asphalt concrete, the first year the noise difference between the two surfaces was about 8 dB(A) (Iway et al 2004). The reduction in the noise effect was considered to be due to the increased stiffness of the surface with time. Improved types of the Pavetex show noise reductions of 14 dB(A) – measured at tyre, or 8 dB(A) measured at roadside. After 40 000 vehicles the results was about the same (Iway et al 2004). The friction coefficient was lower than ordinary road surface (0.32-0.39 or 58-63 BPN). This is within the Japanese regulation for skid resistance.

6.4.3 American rubber asphalt

In Phoenix, Arizona rubber asphalt is being tested out on 130 kilometre of freeway. A layer of about 5 centimetre of open texture rubber asphalt, is placed on top of the old concrete road surface (Arizona DOT 2005). The asphalt is made of rubber from recycled old tyres, mixed with asphalt and binder. Noise reductions of about 5 dB(A) are achieved (Scofield and Donovan 2005). The surface is sensitive to temperature during paving, to achieve the best possible binding.

6.5 Costs

The costs of low noise surfaces depend on costs of construction, maintenance and the durability of the surface. This again depend on a number of factors as: type of surface material, amount of traffic on the road, the number of heavy vehicles, speed level, maintenance level and method, meteorology and use of studded tyres. The EU project SILVIA will among other calculate costs of different low noise surfaces. Today we have inadequate information on these aspects.

Preliminary results from SILVIA (Sælensminde and Veisten 2005) indicate costs and life-time expectancies as follows in table 6.4. The numbers in the table are based on Larsen and Bendtsen (2002) and the Norwegian Road Administration (1995).

Table 6.4: Average investment and operating costs for dense asphalt concrete (DAC) and two-layer porous asphalt (PA8). In €1000 per km road (4 lanes of 4 metres). Source: Sælensminde and Veisten 2005

Pavement type		Investment	Lifetime	Annual operating costs	
Dense asphalt concrete ²	Layer replacement	€ 177	7 year	Winter maintenance	€ 6,3
Two-layer porous asphalt ³	Top layer	€ 118	3 year	Winter maintenance ⁴	€ 9,3
	Bottom layer	€ 236	7 year	Pressure cleaning twice a year	€ 2,4
	Drainage pipes ⁵	€ 115	7 year	Cleaning of pipes, twice a year	€ 5,7

The top layer of porous asphalt is expected to live 3-4 years, if the maintenance is adequate both on the road and in the drainage systems. This is especially important in countries using studded-tired during the winter season.

² Based on Norwegian cost numbers (VD 1995)

³ The sum of top and bottom layer of two-layer porous asphalt is approximately twice as expensive as dense asphalt in Denmark. (Larsen and Bendtsen 2002). Preliminary Norwegian testing indicate these types of surface to be 3-4 times as high as conventional dense surface.

⁴ 50 % larger winter maintenance costs for porous compared to dense asphalt concrete (James 2003, Veisten and Sælensminde 2004).

⁵ Necessary on streets with kerbstone and sidewalks (Larsen and Bendtsen 2002). Recent experience in Copenhagen indicate somewhat lower costs.

Low noise surfaces are more expensive than conventional road surfaces, but as a noise reducing measure (used instead of for example noise barriers) it can be socio-economic profitable in some areas (Bendtsen et al 2002, Sælensminde 2002). In these calculations health is one of the benefits used.

6.6 Safety aspects

In a study by Elvik and Greibe (2003) it was concluded that increasing the friction coefficient on the road can reduce the number of accidents, but mainly accidents occurring on wet surface.

Tests of skid resistance (friction coefficient) show that some of the low noise surfaces have a lower friction coefficient than a conventional used road surface. According to Sandberg and Ejsmont (2002), it is possible to design low noise surfaces, which at the same time maintain a good friction coefficient. Results from the newest designs of low noise surface indicate that the difference in friction between low noise surfaces and conventional surfaces is reduced increasingly.

7 Summary of different studies, noise reduction potentials and barriers

7.1 Study overview

The tables 7.1-7.4 give an overview of some of the latest studies on source-noise related studies since 1995. Most of the tests are based on European studies; some preformed on test tracks, some in laboratories and some in real life situations. When concerning the road surface studies, the results are in part compared to conventional surface, which may differ from study to study. The measurement is also partly performed by different methods and varying driving conditions.

This means that the differences in noise reductions in the different studies must be evaluated carefully.

Table 7.1: Overview of different noise related studies. Noise reductions from different types of road surfaces

Study	Type	Design	Noise reduction (dBA)	Other factors tested
Bendtsen et al 2002 (DK)	2-layer porous asphalt	Test start 1999. Tested on urban street, 3 years. Three types tested, with different thickness and aggregate size. Maintained twice a year. ⁶	4,5-6 4 (two year)	Safety, friction winter maintenance. permeability, annoyance, economy
Namikawa et al 2004 (J)	2-layer porous	Specially design vehicle, measure noise at tyres.	6-8 ⁷	
Hofman et al 2003 (NL)	2- layer porous	Used since 1994 on national and local roads. New types of low-noise surfaces tested out in labs/test tracks.	4-6 ⁸ 5-8 ⁹	
Kuijpers et al 2000 (NL)	2-layer porous	Tested in real life situations since 1994. Top grading 4/8 and bottom grading 11/16.	5 6-7 ¹⁰	

Source: TØI report 806/2005

⁶ By high-pressure water spraying and sucking. More efficient methods for maintenance of porous asphalt are tested out in the Netherlands and Germany.

⁷ No difference from 0-500 in third octave band, 6-8 dB(A) difference from 630-5000Hz.

⁸ Results from real life use. After 4 years of use, effect reduced to 1,8-5,3 dB(A).

⁹ Potential effect, compared to Dutch dense asphalt.

¹⁰ If adding a finer top layer, with grading 2/4.

Table 7.1: Overview of different noise related studies. Noise reductions from different types of road surfaces. Continued

Study	Type	Design	Noise reduction (dBA)	Other factors tested
Nilsson 2004 (SE)	2-layer porous	Test sections. 80 km/h and 110 km/h roads.	8-9 ¹¹	
Dijkink et al 2004 (NL)	1-layer porous	Partly on test tracks. Porous surface with built in absorption mat (engine noise from heavy vehicle).	8 ¹²	Dijkink et al 2004 (NL)
Baughan et al 2002 (UK)	1-layer porous asphalt	Test start 1995. Rural motorway (AADT 65 000), nearby villages. 3 km test section.	4,5 4 (four year)	Annoyance, weather
Glaeser 2004 (D)	Porous concrete	Test section on B56, federal road near Düren. VW Passat with different types of tyres used in the test.	4 ¹³	Tyre, wheel-acres.
Arnevik 2000 (N)	Poro-elastic	Test 1989-1994. Urban road (AADT 3150). Studded tyre use during winter season.	5,6 10 ¹⁴	Wear resistance, friction (0,36), fire resistance,
Sandberg et al 2000 (SE, J)	Poro-elastic	Test start in 1996, test tracks. Summary of different ongoing projects in Sweden and Japan.	12-14 ¹⁵ 7-10 ¹⁶	Durability, friction (>0,5), fire resistance, costs and adhesion.
Iwai et al 2004 (J)	Poro-elastic	Test start around 2000, test tracks. IPVTP –improved pavetex.	14 ¹⁷ 8 ¹⁸	Friction (0,39),
Sandberg et al 2005a (SE)	Poro-elastic	Tested in 2004 on real life situation in Stockholm city (50 km/h, 5400 AADT) and in laboratory. 3 different types of surfaces were tested. CPX and CPB method, ISO tyres. Compared to existing DAC11 surface.	8-12 ¹⁹	Adhesion, permeability, friction, particle emission, clogging, rolling resistance, wear.
Scofield et al 2005 (USA)	Rubberized asphalt	5 cm asphalt rubber top-layer. Tested in real life situation on about 130 kilometres of freeway in Phoenix, Arizona.	4-5 ²⁰ 6-11 ²¹	
Bendtsen et al 2004 (DK)	Thin open asphalt	Test start in 2003, part of EU project SILVIA. Urban road. Pass-by method. 6 mm aggregate size, 20 mm thickness.	2-3 ²²	Costs, durability, safety,

Source: TØI report 806/2005

¹¹ Early stages of test. Part of SILVIA.

¹² Assumed reduction with a combination of porous asphalt, ZSA layer (small grain size) and ZOAB (absorption mat) placed inside the road surface between the wheel-shafts.

¹³ Compared to conventional dense surface. Pass by test, at 80 km/h.

¹⁴ Noise reduction from rolling vehicle (no motor noise)

¹⁵ Mixture with inadequate durability

¹⁶ Expected results, mix with better durability

¹⁷ Measured at vicinity of the tyre, construction/after passing of 40 000 vehicles. Best effects between 630-2000Hz.

¹⁸ Measured at roadside

¹⁹ Depending on surface type

²⁰ Average reduction in neighbourhood

²¹ CPX method

²² Preliminary results, 6 month old pavement. Compared to AC11.

Table 7.1: Overview of different noise related studies. Noise reductions from different types of road surfaces. Continued

Study	Type	Design	Noise reduction (dBA)	Other factors tested
Berge et al 2004b (N)	Thin open asphalt	Test period 1998-2003. CPX- method, 50-70 km/h. 15 different surfaces in two different counties.	1,5-4,4 ²³	Different surface types
Meunier 2001 (F)	Thin dense/porous/elastic	Lab tests/ test tracks. Pass-by measures. Max 6 mm aggregate size, about 2,5-4 cm thick, porosity 10-20%, with polymer-modified binders.	3-4	
Vanltonen et al (FIN)	SMA5	Tested in real life situation in Helsinki, Finland. Different road sections. Compared to SMA 11 and 16.	3 ²⁴ 7 ²⁵	Different speed levels. Wearing.
Berge et al 2004a (N)	6 AC 2 SMA 1 PFC	9 different road surfaces (different surface roughness), 4-16 mm aggregate size. Noise tested in coast-by situations (engine of).	10-12 ²⁶ 7 ²⁷	Different speed levels. Tyres.
Sandberg and Ejsmont 2002	Diff. surface types	Difference between the best low-noise surfaces (porous surface) and the noisy ones (cement concrete/rough SMA).	9 ²⁸	Handbook: Surface, tyres e.g.
Spinoglio 2003 (I)	Surface treatment	Italgrip system, surface treatment (about 2,5 mm) to improve skid resistance. Tested in real life traffic since 1991. Improve friction with 0,25-0,30, somewhat reduced effect with time.	3-4 ²⁹	Friction, noise, safety

Source: TØI report 806/2005

Table 7.2: Overview of different noise related studies. Noise reductions from tyres

Study	Type	Design	Noise reduction (dBA)	Other factors tested
Sandberg and Ejsmont 2002	Tyres	Composite wheels – new technology wheels tested out by Goodyear and by VTI in Sweden. Early stages. Coast by test in 30, 50 and 70 km/h.	7-10 ³⁰	Handbook: Surface, tyres e.g.
Sandberg et al 2005b (SE)	Tyre	Porous rubber treads tyres. Indoor and outdoor tested. CPX method. Compared to Nokian NRT2 and NRVi.	7-8 ³¹ 2-3,5 ³²	Surface, tyre width, rolling resistance, wet friction
Rust 2003 (A)	Tyres	Lab tests, test tracks.	5 ³³	Surface, engines

²³ Compared to reference surface, a SMA 14 from 1996.

²⁴ Speed level 50 km/h

²⁵ Speed level 80 km/h

²⁶ Difference between a Dutch Twin-layer and a Norwegian asphalt concrete (AC14).

²⁷ Difference between a ISO layer and Norwegian asphalt concrete (AC14)

²⁸ The extremes in either direction are excluded, otherwise a difference of about 17 dB(A).

²⁹ Compared to concrete surfaces.

³⁰ Compared to the PIARC tyre, Dunlop D8 tyre and Michelin MXL tyre. Coast by method.

³¹ On rough “Nordic” surface (SMA16)

³² On smooth surface (SMA8)

Table 7.2: Overview of different noise related studies. Noise reductions from tyres.
Continued

Study	Type	Design	Noise reduction (dBA)	Other factors tested
Sandberg and Ejsmont 2002	Existing types of tyres	Measured 100 different tyres with the CPX method in 1997-99. Test performed by VTI and TUG, on dense asphalt concrete (DAC16).	9 ³⁴	Handbook: Surface, tyres e.g.
Berge et al 2004a (N)	Existing types of tyres	6 different car tyres (on the Norwegian market) tested on 9 different road surfaces (different surface roughness). Noise tested in coast-by situations (engine off).	4-5 ³⁵	Different speed levels. Surface texture.
Glaeser 2004 (D)	Existing types of tyres	Test section on B56, federal road near Düren. VW Passat with different types of tyres used in the test. 38 sets of tyres.	3-4 ³⁶	Wheel-arches, road surface
Glaeser 2004 (D)	Foam in wheel-arches	Test track with ISO requirements, modified car. Absorbing foam (30 mm thick) in wheel-arches.	0,5-2,2 ³⁷	Tyres, road surface.

Source: TØI report 806/2005

Table 7.3: Overview of different noise related studies. Noise reductions from vehicles

Study	Type	Design	Noise reduction (dBA)	Other factors tested
Morgan et al 2003 (D/UK)	Encapsulation	Encapsulations of engines in heavy vehicles.	3 ³⁸	Tyres, surfaces.
Morgan et al 2003 (D/UK)	Engine	Test of different kinds of engine types.	7 ³⁹ 3 ⁴⁰	Tyre, surface.
Andesen 2003 (DK)	Size of vehicle	On the road measurement of more than 1000 heavy vehicles. Flat road.	3 ⁴¹	Model development
Andersen 2003 (DK)	Petrol – diesel	On the road test 1999-2002. Drive by tests.	1,5 ⁴²	

Source: TØI report 806/2005

³³ Potential further noise reductions of car tyres, exclusive current knowledge and technology in use today.

³⁴ Difference between best and worst tyre on the market in 1997-99.

³⁵ Difference between best and worst tyre on the same road surface.

³⁶ Two highest and two lowest values removed (extreme values).

³⁷ Depending on type of tyre.

³⁸ Heavy vehicles

³⁹ Difference in noise level from different engines in production today.

⁴⁰ Potential reduction if using the best technology in new cars.

⁴¹ Average difference between heavy duty vehicles with 2 axels, compared to multi-axels.

⁴² Average difference between a diesel car and a petrol car.

Table 7.4: Overview of different noise related studies. Noise reductions from speed reductions

Study	Type	Design	Noise reduction (dBA)	Other factors tested
Bendtsen et al 1998 (DK)	100→80	Calculations, based on the Nordic noise-calculation model.	2	
	80→60		3,5	
	60→40		3,5	
	50→30		1,4	
Andersen 2003 (DK)	100→80	Developing noise model for light/heavy vehicles. On the road measurements, tested 2972 light vehicles and 1074 heavy duty vehicles. Tested on flat road section.	2,6	Model development
	80→60		3,4 (2,4) ⁴³	
	60→40		4,8 (3,4)	
	50→30		6 (4,3)	
Sandberg et al 2002 (SE/PL)	110→90	Model calculations, based on a combination of light and heavy vehicles. Speed coefficient = 25, measuring L _{Aeq} .	2,2	Handbook: Surface, tyres e.g.
	90→70		2,7	
	80→60		4,5	
	60→40		6,4 ⁴⁴	
Robertson et al 1998	90→40	Model calculations. For any given traffic mix, there is a difference of about 7 dBA, between the given traffic-flow driving in 90 km/h respectively 40 km/h.	7	MASTER – EU project on speed.
Amundsen et al 2002 (N)	80→60	One day test in 2000. Speed reduction of 10 km/h. Urban driveway.	3	Safety, Air pollution, Community acceptance.
Hedström 1999 (SE)	50→30	Literature review from different speed reduction measures in urban areas, combined with use of test vehicle, using different driving-cycles common to urban areas.	2 ⁴⁵	Particles
Statens vegvesen 2005 (N)	80→60	Real life testing. Part of RV4 in Oslo, reduced speed during winter mainly to reduce particle pollution. Mean speed level reduced from 77 km/h to 67 km/h.	2	Particles, Nox, community acceptance

Source: TØI report 806/2005

7.2 Noise reduction potential of various measures

The time-perspective is important when choosing which measure to implement, and to predict the potential effects of the measure. Measures that can be implemented in a 1-5 years perspective are for example: speed reduction, tyre designs, engine encapsulations, and traffic management (Wallentowitz 2003). Major changes in vehicle designs and more advanced road surfaces are usually harder to implement. This is due to investment costs and need for further technical development.

Table 7.5 give an overview of the potential effects of different noise reducing measures and some of the barriers against implementation. The potential short time

⁴³ Noise reduction for a single vehicle when reducing the speed. Light vehicle, heavy vehicles in parenthesis. Vehicles cruising by.

⁴⁴ Including noise from power unit.

⁴⁵ Average derived from different studies.

and long term effects in the table are lower than indicated in chapter 7.1, this is partly due to the uncertainties in the different studies. It is hard to compare different studies when the terms of the studies are so unequal. The noise reduction is measured by different methods, in some studies the results are compared to conventional surface/tyres, which may differ quite a lot from country to country. The speed levels in which the tests are performed vary, and in some studies, it is not specified if the noise measured is just the rolling-noise, or noise emitted from one or more vehicles. The fact that some results are from real-life situations, and some are from specific test-tracks, must also be taken into consideration.

Table 7.5: At-source-noise-reduction in dBA. Possible effects and barriers

	Vehicle		Speed reduction	Road surfaces	
	Engine	Tyres		Dense	Porous
<i>Possible noise reduction, dB(A)*:</i>					
Existing technology/ Knowledge based on:					
-5 year perspective	1-2 ⁴⁶	1-2 ⁴⁷	1-3 ⁴⁸	1-3	2-4 ⁴⁹
- 10 to 15 years perspective	2-4 ⁵⁰	2-4 ⁵¹	-	3-5	6-8
<i>Durability:</i>	15-20 years	3-5 years	-	7-15 ⁵²	3-10 years ⁵³
<i>Economy:</i>					
- costs (investment, maintenance)	Medium	Medium	Low ⁵⁴	Medium	High
- who pays	Consumer	Consumer	Road owner/ consumer	Road owner	Road owner
- socio-economic	+	++	++	+++	+++
<i>Feasibility:</i>					
- politically	Time consuming	Time consuming	-	+	?
- producers	Possible	Possible		Possible	Possible

* Basic year is January 2006.

Source: TØI report 806/2005

⁴⁶ Requiring encapsulation of engines of all old heavy vehicles.

⁴⁷ Possible if choosing the least noisy tyres on today's marked, prohibit the use of studded tyres in winter (urban areas).

⁴⁸ If speed is reduced by 10-20 km/h on certain roads in densely populated areas, and more even speed is chosen.

⁴⁹ Applying thin surfaces or 2-layer porous asphalt as tested out in Denmark and Sweden.

⁵⁰ This apply mainly for heavy vehicles, all vehicle using best available technology (encapsulation, use of low-noise materials e.g.)

⁵¹ E.g. use of new technology tyres.

⁵² Depending on traffic density, use of studded tyres, e.t.c.

⁵³ Depending on type of surface chosen, level of maintenance. Different lifespan of top and bottom layer. Improving.

⁵⁴ New signs and increased surveillance/speed camera. Increased time costs not included.

When it comes to possible noise reductions with existing technology (5 year perspective), the potential effects are based on:

- Low-noise-zone (restricted access for heavy vehicles), new vehicles or encapsulation of engines.
- Financial advantages for persons buying tyres scoring high on environmental qualities (and still score high on safety). Information.
- Reducing speed from 80/90 to 60/70 km/h on major arterial road near residential areas.
- Use of thin-surface, as tested out in Denmark.

Possible long time effects (10-15 year perspective) are based:

- A major part of the vehicle fleet is replaced with new-technology vehicles.
- Improved tyre technology in production. Financial advantages for persons buying tyres scoring high on environmental qualities (and still score high on safety). Information.
- Use of twin layer-porous or poroelastic surface on high speed arterial roads/urban roads near residential or recreational areas. Improved durability and maintenance technology.

The durability of the different measures (see table 7.2) is depending on type of change. Engines are supposed to have the same lifetime as the rest of the vehicle, even if the noise reducing effect may be somewhat reduced. The tyres ought to have the same life expectancy as is usual today. For road surfaces, the life expectancy varies between the different types of surfaces, and depends on different factors (material use, maintenance level, traffic flow e.g.). The durability of low-noise-surfaces is for most types shorter than that of conventional surfaces, but has been and is still improving.

Costs of at-source-measures vary, and are especially for surfaces, hard to calculate at this early stage of product development and testing (e.g. SILVIA). The costs of improved tyre and vehicle technology, will usually have a direct effect on the product price, and are therefore paid by the consumers. Reduced speed levels demand new traffic signs, increased surveillance especially in the beginning and information to the public (on why the speed is reduced). Laying of new road surfaces are financed by the road owner (the national or local budget). The investment costs and maintenance costs are higher than for conventional road surfaces (can be as much as 3-5 times more expensive if the more advanced surface types are chosen). However, if environmental benefits are taken into considerations, calculations indicate that the measures is socio-economic profitable.

Politically it has been difficult to promote reduced speed levels because a majority of the public is against it, but this may change if information of why the speed is reduced is spread. There is a tendency towards increased goodwill for different measures to improve the environmental quality in urban areas. Vehicle and tyre noise regulations are developed at EU-level, and may nationally be difficult to influence, especially on short time notice. At the national level, it is possible to promote the use of best available technology by information or by advantage-

programs (e.g. free/reduced entrance through toll-booths, reduced tolls for new vehicles/tyres). Types of road surfaces are decided at national/local level, and depend among other on the budget. If politicians decide that noise reduction is an important target area, this may influence the distribution of money spent on noise reducing measures in the budget. Concerning technology, the producers already have the knowledge to develop improved vehicles and surface types. However, at the time being, mainly the costs of these new products have prevented them from being mass-produced.

8 Some tentative conclusions and suggestions

8.1 Noise abatement measures at the source should be pursued

The conflict between transportation and residents in urban areas will grow stronger due to space restrictions and stricter regulations with lower environmental limits, the high cost of noise screens, noise insulation and other costly noise abatement measures such as environmental tunnels, major re-routings etc. This will increase the demand for cost-efficient and good noise abatement solutions. It is then important that such measures really are available and that the knowledge and know-how to implement them is there.

The EU directive 2002/49/EC on management of environmental noise imposes member countries to develop noise maps and action plans. Action plans for the major roads (more than 6 million vehicles a year) have to be ready within 2008 (additional regulations for major airports, railways and agglomerates), and within 2013 action plans for other major roads have to be finished.

Global measures such as reducing propulsion noise, especially of heavy vehicles, and reducing tyre-road surface noise, promise large noise reductions at relatively low cost. In urban areas with high vehicle speeds and many noise-affected people, vehicle speed reductions, possibly in conjunction with measures targeting heavy vehicle propulsion noise may be implemented with good effect. The success of speed reducing measures will depend on popular support. The efficacy of speed reductions are dependent upon whether the reductions are followed up by policing, environmental photo-boxes and other means of enforcing the reductions.

With respect to other measures, it must be realised that conditions in Denmark and the other Nordic countries may differ. Denmark has much to gain from adopting the same surface/tyre solutions already under way, as for example in the Netherlands, Germany and Austria. Finland, Sweden and Norway, however, need to develop their own, while drawing on the experiences reached elsewhere.

In connection with the authorities efforts to fulfil the directive, increased knowledge of the effect of at-source-noise-reduction is important, both at international and local level. However, Norway, Sweden and Finland may need more time in order to figure out which road surface and tyre solutions are appropriate for Nordic conditions and to make plans for implementing such efforts.

8.2 Testing and research efforts over 8-15 years period necessary

For Denmark, where there has been an extensive period of road surface testing and where environmental conditions are similar to those in middle Europe, road surface solutions already developed promise large noise reductions at relatively low cost.

However, for Norway, Sweden and Finland, the situation is different. There is insufficient data about the noise reducing properties and the durability of low noise surfaces under our winter conditions.

Sustained testing and research efforts over 8-15 years period may be necessary to produce sufficient knowledge of which types of surfaces to lay and how to produce optimal road surfaces in Norway, Sweden and Finland. The long time span is due to the need for durability testing under real life conditions.

Finland, Sweden and Norway should prepare for tests and research in two faces. First tests to find out which type of road surfaces has the best properties for our vehicle fleet and winter conditions. Thereafter trials and tests need to be undertaken in order to obtain a production, deployment and maintenance system that is adapted to our winter conditions.

8.3 Improving today's surface types important

The noise properties of road surfaces that are currently employed in Norway, Finland and Sweden have not been an issue in road surface laying contracts, and the road surface layers have unknown noise emission properties. Limited testing in Norway suggests that the focus on durability, safety and good winter properties may have lead to the production of dense road surfaces that produce 2-4 dB more than normal dense asphalt types that are in regular use in Europe. If the standard Nordic dense asphalt surfaces are equally inferior with respect to noise emissions (compared to what is common in the Netherlands and Denmark), investigation of why the differences between conventional road surfaces laid in Finland, Sweden and Norway and the rest of Europe are so large should be a priority.

The state of affairs in Finland, Sweden and Norway can host opportunities. There may be much to gain by optimising the dense asphalt used today, and prevent the rapid deterioration of road surfaces that have good initial noise emission properties.

It seems reasonable that an increased focus on the noise properties of different dense asphalt road layering solutions may produce road surface layers that

maintain good winter properties and durability while providing a substantial noise reduction. First stage tests should probably involve different types of thin asphalt and/or dense (SMA etc) asphalts depending on local conditions and needs. It is here that especially Finland, Sweden and Norway may have most to gain at least costs. Some of this testing is already taking place, but expanded testing on different climatic, level of studded tyre use and traffic density are necessary. Nordic cooperation in the test-face should be increased.

To produce conventional road surfaces that emit less noise than current road surfaces do, it is necessary to try out a variety of alternatives that can fit Nordic winter conditions and choose some that seem promising. This means that Scandinavian entrepreneurs and road authorities must cooperate to test and develop custom made surfaces. They cannot rely on ready-made surfaces designed for other conditions. Thereafter there must necessarily follow a phase where there is testing and research on the whole production process.

8.4 Parallel efforts should explore new road surface solutions

To reduce the gap in knowledge with respect to the adaptability of surfaces that have the best noise properties, efforts should in parallel be utilised to establish a competence on porous asphalt layers and other road surface technologies aimed at reducing rolling noise.

Here the extensive knowledge from researchers in Denmark and Netherlands should be utilised by enlisting their researchers into sustained efforts of adapting the surfaces to Nordic conditions. In other words, their general competence on such surfaces should be utilised in cooperative sustained efforts together with experts on Nordic winter conditions to solve the winter condition and maintenance problems.

The extensive testing and knowledge established in Denmark should in particular be utilised for laying test surfaces of porous asphalt or other low noise surface technologies. Such surfaces should specifically be laid on ring roads and main roads in city areas where there is a high volume of traffic – at least 10 000 AADT, and high speeds. Larger cities where the climatic conditions mean that the main road system is free from snow and ice most of the winter, where there are restrictions on the use of studded tyres, and where many residents are affected should be prioritized. The cities of Helsinki, Stockholm, Oslo and Gothenburg quickly come to mind. Results from testing show, that high speed levels prevent some of the clogging of the pores, and lead to prolonged durability of the layers.

However, it should be realised that such test surfaces must be part of an integrated road construction, water drainage, surface laying and relaying solution, and where possible high pressure hosing or other techniques for maintaining the porous properties are necessary. For the authorities, this means that during testing sufficient funds need to be allocated to constructing and testing road stretches with this type of layer.

In urban residential areas with lower speed levels dense-low-noise layer may be a better alternative. In uphill areas with high volume of heavy vehicles absorption mats, who absorb engine noise (tested in the Netherlands), might be a good alternative. This is an expensive measure, but is likely to be cost effective on certain road sections in urban areas.

8.5 Road surface description standard for the Nordic countries

There are no reference data on the noise emission properties of asphalt layers that are in current use in the Nordic countries. But for Norway, such data will be available later this year, based on measurement on a wide range of existing dense asphalt surface. Preliminary results show 2-4 dB(A) above equivalent conventional dense asphalt European layers, in the speed range of 50-80 km/h. It is important to find out whether these results differ from other road stretches in densely populated areas in Finland, Sweden and Norway. Denmark may need a separate road surface description standard. A measurement and testing program is therefore needed.

After establishing a data base on the properties of different surfaces, depending on different climatic conditions, different traffic volume etc, it should be possible to find some common noise emission characteristics of surfaces employed, and establish a Nordic “normal” reference road surface description. The description should contain information on the noise emission properties when new, and the deterioration and increase in noise production over time. The authorities should also consider whether a database of other road surface properties needs to be established to serve as a knowledge base and an input to road surface laying quality contracts. The Finnish, Swedish and Norwegian road authorities might have much to gain from cooperating and exchanging information on these aspects.

The purpose of the road surface reference description is to establish a common baseline against which it is possible to compare new test surfaces and production surfaces from different road laying companies. One use could be to calculate reductions in noise emissions as a basis for incentives to road laying companies.

When testing out low-noise surfaces in Finland, Sweden and Norway, the common reference surface should be employed as comparison standard. Test results will be easier to compare and the knowledge generated can be more easily shared.

A common reference road surface description should be established within a 3 year period. More than one reference surface descriptions may be required as the characteristics of road surfaces may be dependent on local situations (traffic flow, vehicle speed use of studded tyre, common tyre types, climatic condition etc.). If so, the reference surfaces could also include Danish reference road surfaces, and the knowledge base be established as a Nordic reference.

Such a Nordic reference may have to be updated each 5th to 10th year to take into account changes in vehicle fleet composition and especially the types of tyres that are employed.

8.6 Incentives should be built into road surface laying contracts

A standard road surface contract with minimum standard concerning: noise quality, friction coefficient, durability under certain conditions (specified level of maintenance and use of studded tyre) should be developed.

To exploit the competence and knowledge that road-laying companies possess with respect to optimising the properties of current non-porous road surface layers, they should be provided with an incentive for laying road surfaces that have good properties. This means contracts that focus on performance and quality rather than obtaining the best price for a pre-specified road-layering job. As the noise reduction properties deteriorate over time, the incentives should depend on the lifetime properties and have a specified price per person affected. There would thus be an incentive for utilising somewhat higher quality materials, more frequent top-layer refreshment or higher quality maintenance may be implemented for those specific stretches where people are affected by the noise emissions.

There is no utility in noise abatement where there are no people. For the larger part of the road networks, other road surface parameters are the most important.

To be able to measure the benefits from employing road surfaces that are claimed to have good noise emission properties, a standard for comparisons must be established that provide information on what is “normal” noise emission properties of a typical road surface, and the loss in dB of the noise reducing properties. There should also be guidelines as to how the benefits per person should be assessed, as noise reduction in the presence of other noise sources, below a certain noise level etc. may not be as important to reduce.

8.7 Tyre initiatives need to consider the type of road surfaces that are laid

Studded tyres, wide tyres, and tyres that have inferior noise emission properties overall may be dissuaded by increased taxation.

However, the test results with respect to noise properties of various alternative tyre solutions (tread type) are not clear enough to make an informed decision as to the optimum solution for Finnish, Swedish and Norwegian road surface conditions. There is an interaction between tread types and road surface properties, and tyre-types that are good for smooth surfaces, have inferior properties on rough surfaces.

Norway, Sweden and Finland should require that noise reduction potential information (noise labelling) is made also with respect to surfaces that are used in their countries and not only with respect to silent surfaces that may be more appropriate for Central European and Danish conditions.

If it can be shown that some tyre types have good over-all noise reduction properties, and for different types of road surfaces, these tyre types may be better for Finland, Sweden, Norway and Denmark than tyre types that only perform well for surface types not common in the Nordic countries.

8.8 The socio-economic costs of studded tyre use should be re-examined

Taxes have been levied on studded tyres primarily because they contribute to particle pollution and excessive wear and tear of the road network.

The rapid erosion of the acoustical properties of newly laid road surfaces has previously not been considered. Here the main impact may not be clogging, but texture effects (roughening of the surface) that lead to increased wheel vibrations and therefore increased rolling noise. We do not know how much of the 2-4 dB(A) excessive noise production that some Norwegian road surfaces were shown to produce over European dense asphalt, that are due to studded tyre use. A reasonable guess would be that at least 3 dB(A) of summer-time noise emissions are due to wintertime use of studded tires. If so, substantially increased taxation or stronger restrictions are warranted than those employed today.

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