Potential society effects of regulation tyre/road noise
– Summary report of the NordTyre projects
This report summarizes the results of the NordTyre projects. The report has a special focus on the effects to society of regulating tyre/road noise by using the quietest tyres available on the market together with road surfaces with reduced noise emission. The report includes the main results on noise from passenger car tyres and truck tyres, conclusions and recommendations of the NordTyre projects. Labelling of new tyres became mandatory in all EU and EEC countries in 2012. Nordic road administrations work on reducing traffic noise exposure by applying noise reducing road surfaces, by building and maintaining noise barriers etc. There is a need to know how “less noisy” tyres and road surfaces could contribute to traffic noise mitigation. The main objects of the NordTyre projects project were to:

- Clarify the “real” influence of the new tyre noise labelling of passenger car and truck tyres
- Establish scientific evidence on the tyre/road contribution to noise emission from roads in the Nordic countries
- Generate a basis for qualified decision making concerning actions to mitigate traffic noise in the Nordic countries
- To define realistic new tyre noise limits for use in a future revision of the EU tyre labelling and the tyre noise limits, including rolling resistance and supplementing the labelling of wet grip with labels of snow and ice grip
- Demonstrate the usefulness or necessity of a second “roughly textured” ISO reference test track for tyre noise testing and labelling, hence creating scientific arguments for a short term revision of EU tyre noise regulation

31 passenger car tyres were tested on 30 Nordic road surfaces and two ISO test surfaces using the CPX trailer method. 30 truck tyres have been tested on 4 road surfaces including a SMA (Stone Mastic Asphalt) surface and an ISO test surface using the cost by test procedure.

For both truck and passenger car tyres there is a difference between the measured noise levels at ISO surfaces and labelled values. For passenger car tyres there is no correlation at all between measured and labelled noise levels. For truck tyres it is not possible to conclude that there is a difference between the measured and the labelled noise levels.
The total range of noise levels encountered between the least noisy passenger car tyre on the least noisy pavement (excluding the ISO tracks) and the noisiest tyre on the noisiest pavement was almost 11 dB. For the calculation of national scenarios of potential noise reduction it was assumed that only tyres labelled 69 dB remain in the tyre population. This implies a tyre/road noise reduction of 1.4 dB.

The measurements of truck tyre noise showed a difference between the noise levels from steer axle and drive axle tyres, whereas all the trailer axle tyres yielded almost the same noise levels. Both the steer and drive axle tyres displayed a range of 6 dB and a potential of 0.4-0.5 dB tyre/road noise reduction using only the 25-33 % tyres with the lowest noise levels, whereas the trailer tyres had a range of only 1 dB and a potential of just 0.1 dB tyre/road noise reduction using only the 25-33 % least noisy tyres.

For both passenger car and truck tyres, replacing noisy surfaces with less noisy surfaces was found to potentially yield more reduction in traffic noise levels than the noise reduction obtained by regulating tyre use, but the additional noise reduction which could be obtained by using less noisy tyres is significant.

If a successful regulation of the noisiest tyres can be implemented in combination with changing to a less noisy road surface, both the noise from passenger cars and trucks can be reduced. If all road surfaces in Denmark and Norway could be changed from standard surface to Stone Mastic Asphalt with 8 mm maximum aggregate size and all but the least noisy 25-33 % of the tyres could be removed from the vehicle fleet, then annoyance from traffic noise could be reduced by 24 % in Denmark (Danish SBT) and by 11 % in Norway (Norwegian SPI).

Both the measurements at passenger car tyres and truck tyres illustrate a big need for a test surface representing the Nordic road surface types and a special noise label for Nordic conditions. If the labelling system would be improved there is a big potential in the system for reducing noise. A series of research needs have been identified.

Keywords
Passenger car tyres, truck tyres, noise measurements, noise labelling, Nordic road surfaces, noise reduction, scenarios

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Potential effects on society of regulating vehicle tyre/road noise

– Summary report on the NordTyre projects

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Preface

This report summarizes the results of the NordTyre projects. The report has a special focus on the effects to society of regulating tyre/road noise by using the quietest tyres available on the market together with road surfaces with reduced noise emission. The report includes the main results, conclusions and recommendations of the NordTyre projects. The target group for the results of the NordTyre projects is road and transport administrators and environmental protection agencies.

One of the purposes of the NordTyre project was to analyse the effect of the latest EU noise limits and noise labels for type approval of passenger car tyres and truck tyres. The results for passenger car tyres are documented in the final report on part 2 of the NordTyre project [2] and the results on truck tyres are documented in the final report on part 3 of the NordTyre project [3].

The investigation of noise from new passenger car tyres and truck tyres have been based on a series of measurements on different road surface types including typical Nordic types and ISO reference test surfaces [10].

This report is the final deliverable of the NordTyre projects initiated by NordFoU, which is a research and development framework for the Nordic state road administrations (see: www/nordfou.org/). The NordTyre projects have been funded by NordFoU with contributions from:

- Danish Road Directorate (Vejdirektoratet)
- Norwegian Public Roads Administration (Statens vegvesen, Vegdirektoratet)
- Swedish Transport Administration (Trafikverket)
- Norwegian Climate and Pollution Control Agency

Steering group members were:

- Espen Andersson (Chair from April 2013), Norwegian Public Roads Administration (Statens vegvesen, Vegdirektoratet)
- Ingunn Milford (Chair until April 2013), Norwegian Public Roads Administration (Statens vegvesen, Vegdirektoratet)
- Jannicke Sjøvold, Norwegian Public Roads Administration (Statens vegvesen, Vegdirektoratet)
- Nina E. Landvik (observer until 2016), Climate and Environmental Directorate (Klima- og forurensningsdirektoratet), Norway
- Jakob Fryd, Danish Road Directorate (Vejdirektoratet)
- Martin Hellung-Larsen, Danish Transport Authority (Trafikstyrelsen) until 2016
- Kjell Strömmer (until December 2013), Swedish Transport Administration (Trafikverket)
- Peter Smeds (from January 2014 until 2016), Swedish Transport Administration (Trafikverket)
- Julia Bermlid (from 2017), Swedish Transport Administration (Trafikverket)

Advisory group members were:

- Luc Goubert, Belgian Road Research Centre
- Ulf Sandberg, Swedish National Road and Transport Research Institute, VTI
- Ingunn Milford (from May 2013), Multiconsult, Norway
- Roger Williams (until 2015), independent tyre expert, United Kingdom
- Jan Boe Kielland, independent noise expert, Norway
- Panu Sainio, Aalto University, Finland
The NordTyre projects have been carried out by the Danish Road Directorate which has leading the projects. The project group members were:

- Jørgen Kragh (until May 2016 when he retired), Danish Road Directorate
- Rasmus Stahlfest Holck Skov (until autumn 2017), Danish Road Directorate, from November 2017 DELTA a part of FORCE Technology
- Jens Oddershede (until October 2017), Danish Road Directorate, from November 2017 DELTA a part of FORCE Technology
- Hans Bendtsen, Danish Road Directorate

The following subcontractors have contributed to the projects:

- SINTEF, Norway
- Testworld Ltd, Finland
- Technical University of Gdansk, Poland
- M+P Consulting Engineers, The Netherlands

The main authors of this summary report are Hans Bendtsen and Rasmus Stahlfest Holck Skov with contributions from Jørgen Kragh. The final editing was performed by Hans Bendtsen.
Forord


Undersøgelserne af støj fra nye dæk til personbiler og lastbiler er baseret på en serie af støjmålinger på forskellige vejbelægninger inklusiv typiske nordiske belægningstyper samt ISO-testbelægninger [10].

Denne rapport er den afsluttende leverance fra NordTyre-projekterne. Disse projekter blev igangsat af NordFoU, der er en ramme for forsknings- og udviklingssamarbejde for de statslige nordiske vejadmini-­strationer (se: www/nordfou.org/). Dette NordTyre-projekt blev finansieret af NordFoU med tilskud fra:

- Vejdirektoratet i Danmark
- Statens Vegvesen i Norge
- Trafikverket i Sverige
- Miljødirektoratet i Norge

Projektets styregruppe havde følgende medlemmer:

- Espen Andersson (formand fra maj 2013), Statens Vegvesen i Norge
- Ingunn Milford (formand indtil april 2013) Statens Vegvesen i Norge
- Jannicke Sjøvold, Statens Vegvesen i Norge
- Nina E. Landvik, Klima- og forurensningsdirektoratet i Norge, (observatør) indtil 2016
- Jakob Fryd, Vejdirektoratet i Danmark
- Martin Hellung-Larsen, Trafikstyrelsen i Danmark indtil 2016
- Kjell Strömmer (indtil december 2013), Trafikverket i Sverige
- Peter Smeds, Trafikverket i Sverige indtil 2016
- Julia Bermlid, Trafikverket i Sverige fra 2017

Projektets rådgivende ekspertgruppe bestod af:

- Luc Goubert, det belgiske vejforskningscenter, BRRC
- Jan Bo Kieland, selvstændig støjekspert, Norge
- Ingunn Milford, Multiconsult i Norge fra maj 2013
- Panu Sainio, Aalto Universitet, Finland
- Ulf Sandberg, Det nationale svenske vej- og transportforskningsinstitut, VTI
- Roger Williams, selvstændig dækekspert, England indtil 2015
NordTyre-projekterne er udført af Vejdirektoratet i Danmark, som også har ledet projekterne. Projektgruppens medlemmer var:

- Jørgen Kragh, Vejdirektoratet i Danmark, projektleder indtil maj 2016 hvor han gik på pension
- Rasmus Stahlfest Holck Skov, Vejdirektoratet i Danmark indtil efteråret 2017 og efterfølgende DELTA a part of IFORCE Technology
- Jens Oddershede, Vejdirektoratet i Danmark indtil oktober 2017 og efterfølgende DELTA a part of FORCE Technology
- Hans Bendtsen, Vejdirektoratet i Danmark

Følgende underleverandører har bidraget til projektet:

- SINTEF i Norge
- Testworld Ltd Finland
- Det tekniske Universitet Gdansk, Polen
- M+P Consulting Engineers Holland

Summary

The NordTyre projects have been carried out in order to clarify the possibilities of reducing traffic noise in the Nordic countries by regulating the use of vehicle tyres and road surfaces. This report summarizes the results of the NordTyre projects on noise from passenger car tyres [2] and truck tyres [3].

The objectives

Labelling of new vehicle tyres became mandatory in all EU and EEC countries by November 2012 [1]. The tyre label includes classes or values of three parameters: wet grip, rolling resistance and noise. The Regulation is used in the type approval process for new tyres on the European market. Nordic road administrations work on reducing traffic noise exposure by applying noise reducing road surfaces and by building and maintaining noise barriers which require significant economic resources. There is a need to know how “low noise” tyres could contribute to traffic noise mitigation and to clarify how this contribution can be optimized. The main objectives of the NordTyre projects project have been to:

- Clarify the “real” influence of the new tyre noise labelling of passenger car and truck tyres
- Establish scientific evidence on the tyre/road contribution to traffic noise emission from roads in the Nordic countries
- Generate a basis for qualified decision making concerning actions to mitigate traffic noise in the Nordic countries
- Define realistic new tyre noise limits for use in a future revision of the EU tyre labelling and the tyre noise limits, including rolling resistance and supplementing the labelling of wet grip with labels of snow grip and ice grip
- Demonstrate the usefulness or necessity of a second “roughly textured” ISO reference test surface for tyre noise testing and labelling, hence creating scientific arguments for a short term revision of EU tyre noise regulation.

A representative set of 31 passenger car tyres was selected and these tyres were run on 30 selected representative Nordic road surfaces and on two ISO test surfaces using the CPX trailer method. A sample of 30 sets of truck tyres representative for the Scandinavian truck tyre population has been tested on four road surfaces including an SMA surface (Stone Mastic Asphalt) and an ISO test surface using the coast-by test procedure.

Main conclusions

As clearly illustrated this has not been a simple task to investigate the possibilities of reducing traffic noise by regulating the use of vehicle tyres and road surfaces. One of the big challenges in basing such evaluations on the tyre noise labelling system is that the label values are measured on a relatively smooth ISO surface, which does not represent typical Nordic surfaces types having a rougher surface texture.

For both truck and passenger car tyres there is a difference between the measured noise levels on ISO surfaces and the labelled values. For passenger car tyres there was no correlation at all between measured and labelled noise levels. The reasons for this lack of correlation are discussed in the NordTyre part 2 report, and the authors believe that the main reason is variation in test track surface properties, although it cannot be ruled out that differences in test conditions during labelling measurement and the measurements carried out in the NordTyre project also contribute to this unfortunate fact. It is also a fact that tyre manufacturers do not test all tyres, but tyres representative for a tyre family. It is not known to the NordTyre project group how large variations one can expect within a tyre family.
For truck tyres the analysis of the noise levels show big differences between labelled noise levels and noise levels measured in the NordTyre project. However, the test method described in R117 [9] allows truncation and deduction, and applying this method would explain most of the difference. After applying the method with up to 0.9 dB truncation of the measurement results and 1 dB deduction combined with a large allowed temperature span without any corrections for the temperatures, it is not possible to conclude that there is a difference between the measured and the labelled noise levels for truck tyres.

The total range of noise levels encountered between the least noisy passenger car tyre on the least noisy surface (excluding the ISO tracks) and the noisiest tyre on the noisiest surface was almost 11 dB. After removing extreme values for two tyres (one high and one low), the range of labelled noise levels for the studied tyres was 5 dB. Leaving only the quietest tyre (except the one that were removed) the change in energy average noise level was 3.9 dB. The average noise level from tyre/road noise can be reduced by 1.7 dB if only the six quietest types of tyres are in use. For the calculation of national scenarios of potential noise reduction it was assumed that only tyres labelled 69 dB remain in the tyre population. This implies a passenger car tyre/road noise reduction of 1.4 dB.

The measurements of truck tyre noise showed a difference between the noise levels from steer axle and drive axle tyres, whereas all the trailer axle tyres yielded almost the same noise levels. Both the steer and drive axle tyres displayed a range of 6 dB and a potential of 0.4-0.5 dB tyre/road noise reduction using only the 25-33 % tyres with the lowest noise levels, whereas the trailer tyres had a range of only 1 dB and a potential of just 0.1 dB tyre/road noise reduction using only the 25-33 % quietest tyres. Therefore, there is a potential for reducing the noise, by regulating the use of steer and drive axle tyres to only the quietest tyres.

The NordTyre project only focussed on tyre/road noise. If it was also possible to reduce the propulsion noise from trucks, the potential for noise reduction would be higher. If electrical trucks were introduced, it would most likely increase the noise reduction potential obtainable by using less noisy tyres.

Measurements performed with retreaded tyres showed that retreaded tyres were noisier than the original tyres. On the SMA surface the drive axle tyres were on average 0.5 dB noisier than the originals, whereas the retreaded trailer axle tyres were only 0.1 dB noisier than the originals. If the retreaded tyres were subject to regulation as the new tyres are, the potential for noise reduction would be greater. Even if the retreaded tyres were subject to only using the 33 % least noisy tyres there would be a potential. The retreaded tyres constitute a significant part of the truck tyre population (40-65 %), and the potential for reducing truck tyre noise therefore is considerably limited by the fact that retreaded tyres being noisier than the originals and at the same time not being part of the labelling system.

For truck tyres, the tyre/road noise levels at the SMA surfaces (Stone Mastic Asphalt) were higher than on the other surfaces, and the range between lowest and highest level was smaller. The potential reduction of truck tyre/road noise when replacing SMA 16 by SMA 11 is 1.3 dB; and when replacing SMA 11 by SMA 8 it is 0.7 dB. For passenger cars, the potential when changing from SMA 16 to SMA 11 is 1.5 dB and from SMA 11 to SMA 8 it is 1.9 dB.

The Nordic countries are mainly using SMA surfaces. For both passenger car and truck tyres, replacing noisy surfaces with quieter surfaces was found to potentially yield more reduction in traffic noise levels than the noise reduction obtained by regulating tyre use, but the additional noise reduction which could be obtained by using the least noisy tyres is significant.

If successful regulation of the noisiest tyres can be implemented in combination with replacing the road surface type by a less noisy surface, both the noise from passenger cars and trucks can be reduced. If all road surfaces in Denmark and Norway could be changed from the standard surface to SMA with 8 mm
maximum aggregate size and all but the least noisy 25-33 % of the tyres could be removed from the vehicle fleet, then annoyance from traffic noise could be reduced by estimated 24 % in Denmark (Danish SBT indicator) and by estimated 11 % in Norway (Norwegian SPI indicator). This is a significant potential for noise and annoyance reduction in the Nordic countries. The difference between Denmark and Norway is mainly caused by the different indicators used for noise annoyance.

Measured rolling resistance coefficients for passenger car tyres were found to be uncorrelated with measured tyre/road noise levels. The same applies to most measured data on road grip. A trend was found for less good braking performance on ice and snow the better the labelled wet grip for all-season and winter tyres, which was as expected. For truck tyres the correlations between the labelled rolling resistance and the measured noise level was modest ($R^2 = 0.5$) for the ISO surface and low ($R^2 = 0.2$) for the SMA surfaces. The drive axle tyres had the highest rolling resistance and also yielded the highest noise levels.

**Perspectives**

These conclusions imply the following perspectives.

The labelled noise values do not represent tyres operating on typical Nordic road surfaces. Since road surfaces in Denmark are comparable to many other countries in Europe, the labelling values are probably not very representative for most road surfaces in use. Both the results of measuring noise from passenger car tyres and truck tyres clearly illustrate a need for a supplementary test surface representing Nordic road surface types. The reference surface described in the CNOSSOS-EU noise prediction method [15] is not a relatively smooth textured ISO reference surface but a rougher textured virtual road surface consisting of an average of a dense asphalt concrete (DAC 11) and an SMA 11 surface.

Further, the results indicate that the test method has other issues in representing the situation at real roads, so there is a need to work on:

- A test surface that represents the Nordic road surface conditions
- A test surface that represents conditions of road surfaces used in other European countries
- A special noise label for Nordic conditions, reflecting the tyre/road noise on typical rougher surfaces used in Nordic and other countries
- A temperature correction of noise measurement results for all tyre types including truck tyres
- The reduction of the allowed range of temperatures for performing noise testing of tyres in order to reduce the uncertainty caused by temperature
- Inclusion of retreaded truck tyres in the labelling system, as well as the introduction noise limits for retreaded tyres
- Considering the need for a higher noise limit for winter tyres. Winter tyres may, according to the limit values, be 1 dB noisier than summer tyres but the measurements show that summer tyres usually are noisier than winter tyres
- For winter tyres there is a need for labelling of snow grip and ice grip. Many other European countries could have an interest in this (such as Poland, the Baltic states, and the Alpine regions).

If the labelling system would be improved there is a significant potential for making use of the system in many ways to reduce noise from road traffic:

- Campaigns and maybe tax incentives encouraging car owners to buy the least noisy tyres possible
- Encouraging public organizations and private companies with a green profile to require the use of the least noisy while at the same time safe tyres; e.g. publicly procured bus transportation, taxi approvals,
and cooperating with large transportation companies to have them favour the use of least noisy and safest tyres. Rolling resistance might also be included

- In time: Further limit the allowed tyres on the market, as proposed in the scenario calculations by decreasing the limit noise levels in the tyre type approval system
- Expand the labelling value to represent the tyres during their lifetime, and not only in new condition.

The following important research needs have been identified throughout the project:

- Further investigations of the reasons for the poor correlation between labelled values and measured values on actual road surfaces, applicable to both noise and rolling resistance
- Following the previous bullet suggestions on how to improve the labelling system to obtain an acceptable correlation between labelled values and measured values on actual road surfaces, applicable to both noise and rolling resistance
- Develop a second and more rough-textured reference surface, for use in tyre noise regulations as well as for tyre labelling. Such a surface would be more representative of Nordic roads than the present ISO 10844 reference surface, but would also be of interest for many other European countries
- Establish stricter specifications of test track properties
- Development a procedure for inter-calibration of test tracks
- Investigate the variation of noise levels within tyre families
- Investigate how tyre/road noise develops over time as tyres get older and worn
- Investigate tonality of truck tyre noise emission and tonality perceived by road neighbours.

Baggrund, formål og metode

De nordiske vejadministrationer har længe arbejdet med at reducere støjen bl.a. ved brug af støjreducerende slidlag og ved at opføre og vedligeholde støjskærme mv. og der anvendes markante økonomiske ressourcer til dette.

Man har derfor set et behov for at undersøge om mindre støjende dæk kombineret med mindre støjende slidlag kan bidrage til støjbekæmpelsen samt undersøge, hvordan et sådant bidrag kan optimeres.

NordTyre-projekternes hovedformål har været følgende:

- At klarlægge den reelle betydning af den nye støjmærkningsordning for dæk til personbiler og lastbiler
- At etablere en videnskabelig forståelse for dæk/vejbane-støjens betydning for trafikstøj-emissionen fra veje i de nordiske lande
- At etablere et grundlag for kvalificeret beslutningstagen om aktiviteter til at bekæmpe trafikstøj i de nordiske lande
- At definere realistiske nye dækstøj grænseværdier, som kan anvendes ved en fremtidig revision af EU’s mærkningsordning for dæk og grænseværdier for dækstøj inklusiv rullemodstand samt supplering af mærkningen for vådt vejgreb med mærkning for vejgreb i både sne og is
- At demonstrere behovet for en ekstra ISO-reference vejoverflade med en grov tekstur til brug ved støjtestning og mærkning af dæk, herunder at skabe videnskabelige argumenter for på kort sigt at revidere EU’s dækstøj regulerling.

Et repræsentativt nordisk udvalg på 31 dæk til personbiler blev indkøbt, og dækkene blev testet på 30 udvalgte slidlag, som er repræsentative for de nordiske lande samt to ISO-tests slidlag. Testene blev udført ved brug af CPX-støjtrailermetoden. 30 lastbildæk repræsentative for de dæk som bruges i norden er blevet indkøbt og testet på fire slidlag inklusiv et SMA-slidlag (Skærve Mastiks) og et ISO-tests slidlag ved hjælp af den såkaldte ”coast-by” test procedure.

Hovedkonklusioner
Det har ikke været nogen simpel opgave at klarlægge mulighederne for at reducere støjen ved brug af mindre støjende dæk kombineret med mindre støjende slidlag. En af de store udfordringer ved at basere sådanne vurderinger på systemet for støjmærkning af dæk er, at de mærkede støjniveauer er målt på et relativt jævnt ISO-tests slidlag, som ikke repræsenterer typiske nordiske slidlag, der har en væsentlig grovere overflade tekstur.

For både personbil- og lastbildæk er der en forskel mellem de støjniveauer, som i dette projekt er målt på en ISO-tests slidlag og de mærkede støjniveauer. For personbildæk var der slet ingen korrelation mellem
de målte og de mærkede støjniveauer. Årsagerne til denne manglende korrelation blev diskutert i rapporten fra NordTyre del 2 [2]. Forfatterne mener, at den primære årsag er en variation i overfladeteksturen på de forskellige ISO-testslidlag, men det kan ikke udelukkes at forskelle i testbetingelserne under målingerne af de mærkede støjniveauer og under målingerne i dette NordTyre-projekt også kan bidrage til forklaeringen. Det er ligeledes at fremsætte, at de målte støjniveauer ikke er repræsentative for dæk familier. Det er ikke kendt for NordTyre projektet, hvor stor en variationen i støj, der kan forventes inden for dæk familier.

For lastbildæk viser analyserne af støjniveauerne store forskelle mellem de mærkede støjniveauer og de støjniveauer, der er mål i NordTyre projektet. Men anvendes den metode, som er beskrevet i R117 [9], kan det meste af forskellen forklares. Trods en gennemsnitlig forskel på 2 dB efter nedrunding til nærmeste heltal og fratrækning af 1 dB, er det, på grund af det tilladte interval for lufttemperatur, ikke muligt at konkludere, at der er en forskel mellem de målte og de mærkede støjniveauer for lastbildæk.

Det totale interval for støjniveauer for personbil dæk lægger det mindst støjende dæk på den mindst støjende slid lag (eksklusiv ISO-testslidlagene) og det mest støjende dæk på den mest støjende slid lag er på næsten 11 dB. Ved at fjerne to dæk med "ekstreme" støjniveauer (et med højt og et med lavt støjniveau) reduceres intervallet til 5 dB. Hvis den gennemsnitlige energiækvivalente støjniveau for alle de resterende dæk sammenlignes med det mærkede niveau for det mindst støjende dæk, er der en forskel på 3,9 dB. Hvis man fjerner alle undtagen de 6 mindst støjende dæk, ligger det gennemsnitlige energiækvivalente støjniveau for disse 6 dæk 1,7 dB under gennemsnittet for alle dækene. Ved beregning af nationale støjscenarier for potentialet for støjreduktion er det antaget, at kun dæk mærket med "69 dB" findes i dækpopulationen. I dette tilfælde er der tale om en reduktion af dæk/vejbane-støj for personbiler på 1,4 dB i forhold til den samlede dækpopulation.

Målingerne af støj fra lastbildækkene viste forskelle i støjen for dæk til styreakslen og til trækakslen, mens dæk til trailerakslen havde næsten de samme støjniveauer. Støjniveauerne for dæk til både styreaksel og trækaksel lå inden for et interval på 6 dB. Der var et potentiale til en reduktion på 0,4-0,5 dB af dæk/vejbane-støj ved kun at beholde de 25-33 % mindst støjende dæk i forhold til det gennemsnitlige energiækvivalente støjniveau for alle dækene. For dæk til trailerakslen var der derimod kun et tilsvarende potentiale på 0,1 dB. På den baggrund, er der et potentiale for støjreduktion ved at regulere brugen af dæk til styreaksel og til trækaksel således at det kun er de mindst støjende dæk som anvendes.

Hvis det var muligt også at reducere motorstøjen fra lastbiler ville potentialet for støjreduktion være større. Hvis der blev indført elektriske lastbiler med lav motorstøj, kan det formodentlig forøge potentialet for reduktion af støj ved anvendelse af de mindst støjende dæk.

Målinger udført på regummierede dæk til lastbiler viste, at denne dækktypen er mere støjende end de originale dæk. For et SMA-slidlag har regummierede dæk til trækakslen som gennemsnit et støjniveau der ligger 0,5 dB over niveauet for et tilsvarende nyt originale dæk. For dæk til trailerakslen er forskellen dog blot 0,1 dB. Regummierede dæk udgør 40-65 % af populationen af dæk til træk- og traileraksler og er dermed en signifikant del af den samlede dækpopulation. Hvis der blev indført en regulering af støj for regummierede dæk, ville der være et potentiale for at opnå en yderligere støjreduktion.

For lastbildæk ligger niveauet for dæk/vejbane-støj på SMA-slidlag højere end for andre typen slidlag. Potentialet at reducere dæk/vejbane-støj for lastbildæk ved at udskifte et SMA 16 slidlag med en SMA 11 er 1,3 dB og ved at skifte fra et SMA 11 til et SMA 8 slidlag er støjreduktionen 0,7 dB. For personbil- dæk er der et potentiale på 1,5 dB ved at skifte fra en SMA 16 til en SMA 11, mens, ved et skifte fra en SMA 11 til en SMA 8, er potentialet 1,9 dB.
I de nordiske lande anvendes primært SMA-slidlag. For dæk til både personbil og lastbil vil et skift til mindre støjende slidlag give mere støjreduktion end ved at sikre en anvendelse af de mindst støjende dæk. Men den ekstra støjreduktion, som kan opnås ved brug af de mindst støjende dæk er under alle omstændigheder vigtig.

Hvis en regulering af de mest støjende dæk kan indføres sammen med udskiftning af slidlag til mindre støjende typer, kan støjen fra både personbiler og lastbiler reduceres. Der er for Danmark og Norge foretaget beregninger for et scenario, hvor alle standardslidlag udskiftes med SMA 8 slidlag, og hvor kun 25-33 % af de mindst støjende dæk anvendes. I dette scenario vil generatorne fra vejtrafikstøj i Danmark bliver reduceret med 24 % (udtrykt som det danske støjbelastningsstal SBP). I Norge vil generatorne blive reduceret med 11 % (udtrykt som det norske støjplageindeks SPI). Dette viser, at der er signifikante potentioler for reduktion af støj og støjgener i de nordiske lande. Forskellene mellem Danmark og Norge skyldes primært, at der anvendes forskellige indikatorer for støjgene.

For dækkene til personbiler er der foretaget målinger af rullemodstandskoefficienten. Målingerne viste, at der ikke var nogen korrelation mellem rullemodstand og de målte støjniveauer. Det samme gjorde sig gældende for de fleste målinger af vejgreb under vådt føre. Der blev ligeledes fundet en tendens til, at for mindre gode bremseegenskaber på is og sne jo bedre et mærket niveau for vejgreb under vådt føre for helårs- og vinterdæk, hvilket også var forventeligt.

For lastbildæk blev der fundet en moderat korrelation mellem den mærkede rullemodstand og de målte støjniveauer for ISO-slidlaget ($R^2 = 0.5$) og en lav correlation for SMA-slidlaget ($R^2 = 0.2$). Dækkene til trækakslen havde den højeste rullemodstand og de højeste støjniveauer.

**Perspektiver**

På baggrund af konklusionerne kan der opstilles følgende perspektiver.

De mærkede støjniveauer er ikke repræsentative for dæk som anvendes på typiske nordiske slidlag. Da de slidlag, der anvendes i Danmark, er sammenlignelige med slidlag som anvendes i mange Europæiske lande, er de mærkede støjniveauer formodentlig ikke repræsentative for de fleste slidlag som anvendes.

Målingerne for både personbil- og lastbildæk illustrerer klart, at der er et behov for et supplerende testslidlag, som repræsenterer situationen på typiske nordiske veje. Det referenceslidlag, som er foreskrevet i EU’s støjberegningstegnemte CNOSSOS [19], er ikke et ISO-referenceslidlag med en jævn overfladetekstur, men et virtuelt slidlag med en mere grov overfladetekstur, der består af et gennemsnit af en tæt asfaltbeton (AB 11t) og en SMA 11.

Desuden indikerer resultaterne, at testmetoden har flere problemstillinger i forhold til at repræsentere forholdene på virkelige veje i Norden. Der er således behov for at arbejde mod følgende:

- Udvikling af en test-vejoverflade til at repræsentere forholdene på nordiske vejoverflader
- Et specielt støjmærke til at repræsentere nordiske forhold, og som refleksrer støjen på et slidlag med en mere grov overfladetekstur som typisk anvendes i de nordiske lande
- At der udføres temperaturkorrektioner for støjmålinger til tests for alle dæktyper inklusiv lastbildæk
- At reducere det tilladte temperaturinterval ved teststøjmålinger for derved at reducere usikkerheden som skyldes varierende temperatur
- At inkludere regummierede lastbildæk i mærkningsordningen samt introducere støjgrænser for disse dæk
- Overvejelser over behovet for højere støjgrænser for vinterdæk. Vinterdæk må ifølge grænseværdii være 1 dB mere støjende end Sommerdæk, men målingerne viser, at Sommerdæk normalt er mere støjende end Vinterdæk.
• Der er under nordiske forhold et behov for en mærkning af vejgreb på is og sne. Dette vil også være relevant for andre Europæiske regioner som Polen, de Baltiske lande samt alpeområderne.

Hvis støjmærkningssystemet blev forbedret, er der et signifikant potentiale for at anvende systemet på mange måder:

• Der kan etableres kampagner og evt. afgiftsdifferentiering for at motivere bilejere til at vælge de mindst støjende dæk, som det er muligt at anvende
• Motivere offentlige organisationer og miljøbevidste private firmaer til at kræve, at der anvendes de mindst støjende dæk fx ved offentlig bustransport, godkendelse af taxer, varetransport mv. samt samarbejde med store transportfirmaer for at få den til at anvende de mindst støjende og mest sikre dæk. Rullemodstand kunne ligeledes inkluderes
• Over tid yderligere at begrænse de tilladte dæk på markedet, som foreslået i de scenarioberegninger som er udført i NordTyre-projektet ved at reducere grænseværdierne for støj i dækgodkendelsesystemet
• At udvide de mærkede støjniveauer til at repræsentere dækkene under hele levetiden – ikke kun, når de er helt nye.

Gennem projektforløbet er der blevet afdækket en række vigtige forskningsbehov:

• At afdække årsagerne til den dårlige korrelation mellem de mærkede niveauer og de niveauer, som måles på rigtige veje. Dette gælder både for støj og rullemodstand
• At udvikle forslag til, hvordan mærkningssystemet kan forbedres for at opnå en acceptabel korrelation mellem mærkede og målte niveauer på virkelige slidlag. Dette gælder både for støj og rullemodstand
• At udvikle en anden referenceoverflade med en mere grov tekstur til brug for regulering af dækstøj samt ved støjmærkning af dæk. En sådan vejoverflade vil være mere repræsentativ for nordiske veje end den nuværende ISO 10844 reference overflade og den vil have interesse for mange europæiske lande
• At udvikle nogle mere præcise specifikationer for testslidlag
• Undersøge intervallet for støj inden for dæk familier
• At udvikle en procedure for fælles kalibrering af strækninger med testslidlag
• Undersøgelse af hvilket støjinterval dækkene i dækfamilier ligger inden for
• At undersøge, hvordan støjen fra dæk udvikles over tid, mens de bruges og slides
• At undersøge betydningen af toner i støj fra lastbildæk – herunder undersøge, hvordan dette påvirker menneskers opfattelse af støjen.
## 1 Abbreviations

Abbreviations used in the report

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
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<tr>
<td>CEDR</td>
<td>Conference of European Directors of Roads (see: <a href="http://www.cedr.fr">www.cedr.fr</a>)</td>
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<tr>
<td>ERGA</td>
<td>Evolution of Regulation – Global Approach (EU Commission ad hoc group on a method for measuring tyre/road noise)</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
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<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>SINTEF</td>
<td>Independent Norwegian Research Institute</td>
</tr>
<tr>
<td>NordFoU</td>
<td>A research and development framework for the Nordic state road administrations (see: <a href="http://www.nordfou.org">http://www.nordfou.org</a>)</td>
</tr>
<tr>
<td>NordTyre</td>
<td>Joint Nordic project on tyre noise (see: <a href="http://www.nordfou.org/knowledge/Sider/default.aspx">http://www.nordfou.org/knowledge/Sider/default.aspx</a>)</td>
</tr>
<tr>
<td>C1</td>
<td>Tyre class for car tyres</td>
</tr>
<tr>
<td>C2</td>
<td>Tyre class for light truck tyres</td>
</tr>
<tr>
<td>C3</td>
<td>Tyre class for heavy duty vehicle tyres</td>
</tr>
<tr>
<td>CPX</td>
<td>Close-Proximity method according to ISO/DIS 11819-2</td>
</tr>
<tr>
<td>SPB</td>
<td>Statistical Pass By method according to ISO 11819-1</td>
</tr>
<tr>
<td>A-G</td>
<td>Classes of fuel efficiency and wet grip for tyres</td>
</tr>
<tr>
<td>TPG</td>
<td>Twente Proving Ground, also denoted Twente Test Track in the Netherlands</td>
</tr>
<tr>
<td>SMA</td>
<td>Stone Mastic Asphalt</td>
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<td>DAC</td>
<td>Dense Asphalt Concrete</td>
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1 Background and aim

The steadily increasing traffic noise has caused administrations in Denmark, Norway and Sweden to set national targets for reducing noise annoyance, including working internationally to influence decision-making in European forums like CEDR/EU/ERGA on noise from vehicles and tyres.

An EU Regulation (EC) No 1222/2009[1] and labelling of new vehicle tyres came into force by November 2012 and became mandatory in all EU and EEC countries. The tyre label includes classes or values of three parameters: wet grip, rolling resistance and noise. The Directive is used in the type approval process of new tyres for the European market. Nordic road administrations work on reducing traffic noise exposure by applying noise reducing road surface and by building and maintaining noise barriers which require significant economic resources. There is a need to know how “low noise” tyres could contribute to traffic noise mitigation and to clarify how this contribution can be optimized.

The objectives of the NordTyre project were to:

- clarify the “real” influence of the new tyre noise labelling
- establish scientific evidence on the tyre/road contribution to traffic noise emission from roads in the Nordic countries
- identify combinations of tyres and road surfaces which yield the lowest noise emission throughout their lifetime and thereby influencing the environment along roads and highways as little as possible
- generate a basis for qualified decision making concerning actions to mitigate traffic noise in the Nordic countries
- to define realistic new tyre noise limits for use in a future revision of the EU tyre labelling and the tyre noise limits, including rolling resistance and supplementing the labelling of wet grip with labels of snow grip and ice grip
- demonstrate the usefulness or necessity of a second “roughly textured” ISO reference test track for tyre noise testing and labelling, hence creating scientific arguments for a short term revision of EU tyre noise regulation.

The NordTyre part 1 and 2 is about the impact and possibilities of regulating passenger car tyres, and the NordTyre part 3 is about the impact and possibilities of regulating truck tyres. Most but not all the objectives of the NordTyre projects have been fulfilled. A lifetime investigation of noise from tyres has not been performed.

This report is a summary of the combined effect of regulating the passenger car tyres and truck tyres. Detailed descriptions can be found in the NordTyre part 2 report [2] and NordTyre part 3 report [3].
2 Regulation of tyre noise

In 2009, new European tyre noise limits were introduced in the Reg. (EC) No.661/2009 [1]. This regulation also includes requirements for wet grip and rolling resistance. The new noise limits entered into force beginning 1\textsuperscript{st} of November 2012. The noise level is given by a symbol, in addition to a measured noise level, i.e. the type approval noise level at 70 km/h (for class C2 and class C3 tyres) or 80 km/h (class C1 tyres). Figure 1 shows a tyre label. One black “bar” indicates a noise level which is 3 dB or more below the limit value, 2 bars a noise level 1-2 dB below the limit value and 3 bars indicate a noise level on (or above) the limit. For snow tyres, for extra load tyres and for reinforced tyres, the limits are 1-2 dB higher than for normal tyres. Retreaded tyres are not subject to noise labelling according to [1].

The type approval noise measurements are performed on an ISO test track with a smooth dens graded surface. During type approval of tyres, a measured tyre/road noise level, before comparing with the noise limit, shall be truncated (i.e. rounded down to the nearest integer decibel value) and 1 dB shall be subtracted to account for the measurement uncertainty [9]. Thus, a noise label value is a “nominal” noise level. The noise level measured during the type approval testing may exceed the noise label value by up to 1.9 dB.

![Figure 1: Example of a tyre label.](image)
3 Method applied

3.1 Measurements on passenger car tyres
The NordTyre project was initiated by producing a report on the State-of-Art concerning the testing of tyre/road noise on various road surfaces [4]. Then a representative set of car tyres was selected and these tyres were run on selected representative road surfaces. Noise levels were measured using CPX-trailers where the tyre/road noise is measured close to the tyre. The CPX measurements are only measuring the tyre/road noise, and therefore the influence from differences in propagation and weather conditions are minimized when comparing the tyres. These measured noise levels were compared with the noise labels issued by tyre manufacturers and with noise levels measured on ISO test tracks using the Coast-By method and a measurement distance of 7.5 m. From many previous measurement series the Danish Road Directorate (DRD) have found a very good and stable correlation between CPX measurements and road side Statistical Pass-By (SPB) measurements which are similar to the Coast-By method [13].

The measurement results were used to derive potential noise reductions that could be obtained by replacing existing road surfaces with quieter surfaces and by regulating the use of noisy car tyres. These potentials were used to calculate the potential effects on the annoyance experienced by the populations in Denmark and Norway (see Chapter 4 and 5).

3.1.1 Road surfaces
The intention was to select a suitable number of road surfaces representing the spectrum of wearing courses encountered on Nordic roads, with slightly higher representation of road surfaces with reduced noise than of road surfaces known to be associated with high traffic noise levels.

In Denmark 16 road sections located at state roads were used for the tests, in Norway 10 road sections were used for the tests, and in Sweden 5 road sections were used for the tests. Different sections with Stone Mastic Asphalt (SMA) have been included.

The measurements of passenger car tyre/road noise were performed during the summer 2012 and supplementary CPX noise levels were measured in July 2013 on a second ISO test track.

3.1.2 Selected tyres
The overall intention was to select an appropriate number of passenger car tyres to represent the tyres applied on Nordic cars. Based on interviews with tyre companies and on the availability of tyres from different tyre lines at the beginning of the project a total of 31 tyre lines were procured representing a cross-section of:

1) Small / Medium / Large tyres
2) Summer / All-year / Winter tyres
3) Premium / Medium / Low price tyres

The tyre price ranged between 54 € and 139 € per tyre, excluding V.A.T and rim. The sizes investigated were:

1) “Small” (typically 175 mm wide on 14” rim)
2) “Medium” (205 mm wide on 16” rim) and
3) “Large” (225 mm wide on 16” rim)
The range of labelled noise levels was 66-75 dB. The labelled rolling resistance classes were B-F, and the labelled wet grip classes were A-E [1].

During these CPX noise measurements the tyre load was 300 kN (326 kg) and the tyre inflation pressure was 200 kPa in compliance with the CPX measurement standard. These conditions differ from those prescribed in procedures for tyre noise labelling, and it has been argued that CPX measurement results cannot be expected to correlate with tyre noise labels. This is discussed in [2] and from that it can be concluded that the tyre noise labels do not reflect passenger car noise levels measured in real traffic, when combining with the fact that CPX measurement results do indeed correlate well with noise levels from passenger cars [13]. Changing tyre load/pressure conditions from CPX standard to tyre labelling conditions was shown only marginal to improve the fraction of explained variance ($R^2$) in the (lack of) correlation between tyre labels and measured CPX noise levels from $R^2 = 0.008$ to just $R^2 = 0.033$ [2].

Figure 2: Measurement vehicle and CPX trailer used during passenger car tyre tests. Here performing measurements on an ISO test surface in Sweden.

### 3.2 Measurements on truck tyres

A sample of truck tyres representative for the Scandinavian truck tyre population has been tested. The tyres have been tested on four road surfaces with the objective to be representative for the conditions for labelling testing and for conditions similar to Scandinavian roads. The measurements have been carried out on a test track at the University of Twente, the Netherlands, called the Twente Proving Ground (TPG).
The measurements of the tyre/road noise levels have been carried out as coast-by measurements according to a procedure specified in the type approval regulation for tyres [9].

The coast-by measurement results have been analysed for the different tyres at each of the road surfaces. The results have been used to configure a standard heavy vehicle with a representative combination of steer, drive and trailer tyres, with the purpose of calculating the potential for reducing tyre/road noise and overall vehicle noise taking propulsion system noise into account.

The potential reductions of tyre/road noise have been applied in scenarios for the reduction of annoyance experienced in Scandinavian countries.

### 3.2.1 Selected road surfaces

The consortium which performed the noise measurements selected a test track at the University of Twente, the Netherlands, for measuring coast-by noise levels from a truck using one or two sets of each selected line of truck tyres. The test sections at the test track were:

- An ISO test surface complying with ISO 10844 [10]
- A SMA 16, corresponding with a new Nordic SMA 11
- A Thin Surface Layer with 8 mm maximum aggregate size and a semi porous structure (TSL 8)
- A Dense Asphalt Concrete with 16 mm maximum aggregate size (DAC 16)

### 3.2.2 Selected tyres

The tyres selected for the measurements were tyres which were considered to contribute most to the traffic noise exposure of the population living around roads in the Nordic countries. The tyres are truck tyres (category C3) of different tyre lines and sizes, covering drive axle tyres, steering or trailing axle tyres. The selection of the tyres were based on surveys on parking areas nearby Trondheim, Norway and at a custom border station between Sweden and Norway, combined with contact with e.g. truck tyre importers.
The majority of tyres in the Norwegian surveys were from major tyre brands. Major brands were therefore selected in order to represent the practice of “serious” transport enterprises.

Retreaded tyres are a significant part of the tyres in Europe: approximately 40 % in middle Europe and 65 % in Sweden and Finland [5]. Retreaded tyres are used as drive and trailer tyres but not as steer tyres. A few tyre lines of the chosen tyres therefore were tested as original tyres and retreaded tyres, respectively, in order to be able to take the influence of retreaded tyres into account. At the same time this makes it possible to isolate the effect of the retreaded tyres.

The tyre sets chosen for the project were: 8 steering axle, 12 drive axle (9 original, 3 retreated) and 10 trailer axle (6 original, 4 retreaded).

![Illustration of the different tyre types at a truck](image)

**Figure 4:** Illustration of the different tyre types at a truck; Steering (S), Drive (D)- and Trailer (T) tyres. A truck with this tyre configuration has been used for the scenario analysis in Chapter 4.
4 Measurement results

A large number of measurements have been carried out in both the NordTyre part 1, 2 and 3. As this report is focused on the effect on the labelling system on the annoyance in the Nordic countries, only a few measurement results are illustrated in the present report. Further results and detailed documentation can be found in [2] and [3].

4.1 Relation between measured noise levels and tyres noise labels

4.1.1 Passenger car tyres

Labelled tyre levels are measured by the tyre manufacturers at ISO test surfaces [10]. In Figure 5 the labelled noise levels are compared to measured noise levels at two different ISO surfaces in the project (#1 (DRD20) and #2 (DRD32)). The fraction $R^2$ of explained variance in the results from the two ISO tracks is 2 % and 7 %, respectively ($R^2 = 0.023$ and 0.0706). With such weak correlation there is no relation between the labelled noise levels and the measured noise levels.

It could be argued that the load and inflation pressure prescribed in the labelling procedure are not necessarily the conditions all tyres are driven with in the traffic. A tyre line may be used for a range of car models having different weight, and for a given car model a range of tyre dimensions may be used. Further could the difference be influenced by the measurements in the NordTyre project being at a specific tyre from a tyre line, where the measurements in the labelling measurements could be performed at another tyre from the tyre line.

Such variation will contribute to make the label value less representative for the noise emission on real roads. Figure 6 illustrates a similar plot where the label values are compared to the measured noise levels at a Nordic SMA. Once again the correlation is close to zero, meaning that the label values do not reflect the noise measured at Nordic surfaces.

![Figure 5: Measured CPX noise level as a function of the noise label issued by the tyre manufacturer. Left: ISO track #1 (DRD20); Right: ISO track #2 (DRD32) [2].](image-url)
4.1.2 Truck tyres

The measured noise levels and the labelled values are measured using the same method and are therefore directly comparable. Figure 7 shows the coast-by noise level measured on the TPG ISO test track (ISO#3) for each of the selected 23 tyre lines as a function of the noise level labelled by the manufacturer. Noise levels from seven retreaded tyre lines, which have not been labelled, are not shown in the figure. The left part of the figure shows the measured noise levels, while the right part shows the measured noise levels after they have been truncated and after 1 dB has been subtracted as prescribed in [1].

Figure 7: Coast-by noise level $L_{A1m}$ measured at 1.2 m height on the TPG ISO test track (ISO#3) as a function of the noise level labelled by the manufacturer (left). Same but measured noise levels truncated and subtracted 1 dB (right) [3].
The “real” measured coast-by-noise levels were higher than the labelled noise levels; see the left part of Table 1, which shows the number $N$ of tyre lines per type of tyre and the maximum, average and minimum differences between the measured coast-by level and the labelled noise level. For drive axle tyres this difference was up to 5 dB, for trailer tyres up to 4.5 dB and for steering tyres it was up to 6.0 dB. The overall average difference was 2.6 dB with a standard deviation of 1.8 dB. Part of this difference is caused by the truncation and the subtraction of measurement uncertainty from the labelling test result.

Table 1: Differences between coast-by noise levels measured on the ISO test track (ISO#3) and the labelled noise levels [3]. To the left the real measured levels and to the right the truncated and 1 dB subtracted levels.

<table>
<thead>
<tr>
<th>Position</th>
<th>Steer</th>
<th>Drive</th>
<th>Trailer</th>
<th>Steer</th>
<th>Drive</th>
<th>Trailer</th>
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<tr>
<td>$N \cdot \cdot$</td>
<td>8</td>
<td>9</td>
<td>6</td>
<td>8</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Measured noise levels</td>
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<tr>
<td>Max [dB]</td>
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<td>5.0</td>
<td>4.5</td>
<td>4.0</td>
<td>4.0</td>
<td>3.0</td>
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<tr>
<td>Avg [dB]</td>
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<td>2.3</td>
<td>2.5</td>
<td>1.5</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Min [dB]</td>
<td>-1.5</td>
<td>-0.4</td>
<td>0.9</td>
<td>-3.0</td>
<td>-2.0</td>
<td>-1.0</td>
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</tbody>
</table>

The right part of Table 1 shows the differences between measured noise levels, after they have been truncated and after 1 dB has been subtracted according to [9], and the noise label values. The overall average difference is 1.1 dB with a standard deviation of 1.9 dB. This remaining difference was explained in [11] to be caused mainly by low temperatures prevailing during the NordTyre measurement series, i.e. 6 °C - 11 °C in combination with the absence of a temperature correction in [9] for the C3 truck tyres. The temperature range prescribed for tyre/road noise measurements in [9] is 5 °C - 40 °C, with a reference temperature of 20 °C. If a temperature correction of 0.05 or 0.07 dB/°C, as can be found in literature had been applied then the normalised noise levels would have been 0.7 dB or 0.8 dB lower. This would explain about 75 % of the above mentioned 1.1 dB average difference.

4.2 Reducing tyre/road noise

As there is a range of labelled the noise levels, there is a potential for reducing the average noise level by using only the quietest tyre lines.

4.2.1 Passenger car tyres

The objective of this survey was to analyse the effect of reducing the tyre population to only the least noisy tyres. Due to the difference in inflation pressure between the measured CPX levels and the measurement procedure in the labelling system it has been decided to use label values in the following calculations.

All the tyres lines included can be seen as a "typical" population of tyres. Figure 8 shows how the energy average noise level of the population of the selected summer and all-season tyres decreases when the tyres are removed one by one from the set of 22 tyre lines, beginning with the noisiest tyre as ranked by the tyre manufacturers’ labels. The numbers shown next to the data points are the ID number of the latest tyre which has been removed to reach at the energy average noise level shown by that data point. The energy average of all the tyres is 70.8 dB and for only the most quiet tyre (no 1) left it is 66.0 dB.
Figure 8: Energy average of the tyre noise labels as a function of the number of tyres removed, beginning with the noisiest tyre (No. 18) when ranked according to manufacturers’ noise labels [2].

The two most extreme labelled tyres are left out of the data (tyre no 18 labelled 75 dB and 20 labelled 66 dB) when evaluating the potential for noise reduction in the following. The range of the labelled noise levels is now 5 dB and the change in energy average noise level in Figure 8 after having removed all but the quietest tyre is 3.9 dB. After having removed all but the six quietest tyres the reduction would be 1.7 dB. For the scenarios described in the following, it was assumed that only tyres labelled 69 dB (tyre no 6, 19 and 21) remain in the tyre population. This implies a tyre/road noise reduction of 1.4 dB in relation to the energy average of all the tyres.

4.2.2 Truck tyres

For a representative truck with the chosen tyre configuration the reduction of tyre/road noise has been predicted using only the 25-33% quietest tyres instead of using an average noise level for all the tyres included in the TPG measurements.

Figure 9 illustrates the distribution of noise levels from different truck tyre types, ranked according to the measurement results from the ISO surface. The dotted part is the 67-75% noisiest tyres, solid part is the 25-33% least noisy tyres. Solid point-bound part is the retreaded tyres, which are not part of the labelling system and therefore not being affected by regulation.

The figures illustrate that there is a range of up to 4 dB in the noise levels at the ISO surface. When looking at the SMA surface, which represents the Nordic road surfaces, the range is narrower, namely 1-2 dB.
Figure 9: Distribution of noise levels from different truck tyre types, ranked according to the noise levels at the ISO surface [3]. Dotted part is the 67-75% noisiest tyres, solid part is the 25-33% least noisy tyres. Solid point-bound part is the re-treaded tyres. Top: Steer tyres; Middle: Drive tyres; Bottom: Trailer tyres.
4.2.3 Reduction potential for tyre/road noise from a truck

To describe the influence of only allowing the quietest truck tyres a “present” truck and a “quiet” truck was configured with tyres as previously described (2 Steering tyres, 2 Drive tyres and 8 Trailer tyres) (see Figure 4). 50 % retreaded tyres were used on the Drive and Trailer axles in both cases. The energy average of tyre/road noise and potential reduction of noise from a “quiet” truck based on ISO sorting is illustrated in Table 2.

The noise reduction potential for the tyre/road noise of the *Quiet* truck is 0.8 dB for the ISO road surface 0.2 dB for the SMA road surface. In these predictions the propulsion noise is not taken into account and it must be assumed to be the same for the *Present* and the *Quiet* truck. Therefore the noise reduction including propulsion noise will be less than the noise reductions given in Table 2.

If it was also possible to reduce the propulsion noise from trucks, the potential for noise reduction would be higher. If electrical trucks were introduced it would increase the noise reduction potential by using less noisy tyres.

Table 2: Energy average of tyre/road noise level from a Present and a Quiet truck, and noise reduction between the two [3] on ISO and SMA surfaces. Sorted according to ISO road surface.

<table>
<thead>
<tr>
<th>Road surface</th>
<th>ISO</th>
<th>SMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present truck</td>
<td>75.5 dB</td>
<td>77.5 dB</td>
</tr>
<tr>
<td>&quot;Quiet&quot; truck</td>
<td>74.7 dB</td>
<td>77.3 dB</td>
</tr>
<tr>
<td>Reduction</td>
<td>0.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>
4.3 Potential noise reduction obtained by changing road surface

There is a potential for reducing the traffic noise by replacing existing types of road surfaces by quieter road surfaces. As the passenger car tyres and truck tyres have different dimensions and tread patterns, the interactions between the tyres and the road surfaces are different. Therefore the potentials for reducing the noise from passenger cars and truck tyres are different. Truck tyres are generally less sensitive to the road surface texture than passenger car tyres. Therefore the potential for noise reduction by changing road surface is generally larger for passenger car tyres than truck tyres.

In the analyses the potential in Norway have been represented by replacing the typical SMA 16 surfaces with SMA 8, and in Denmark by replacing the typical SMA 11 surfaces with SMA 8. The potentials used are illustrated in Table 3, and it can be seen that the potential in Norway is larger than in Denmark because the starting point in Norway is a noisier SMA 16 road surface.

Table 3: Relative levels of tyre/road noise on different road surface types for passenger cars and multi-axle trucks, and noise reduction potentials used in this analysis [2 and 3].

<table>
<thead>
<tr>
<th>Road surfaces type</th>
<th>Relative tyre/road noise level [dB]</th>
<th>Passenger cars</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA 16</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>SMA 11</td>
<td></td>
<td>-1.5</td>
<td>-1.3</td>
</tr>
<tr>
<td>SMA 8</td>
<td></td>
<td>-3.4</td>
<td>-2.0</td>
</tr>
<tr>
<td>Reduction potential</td>
<td></td>
<td>NO: 3.4 dB</td>
<td>DK: 1.9 dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO: 2.0 dB</td>
<td>DK: 0.7 dB</td>
</tr>
</tbody>
</table>
5 Scenarios on noise reduction

5.1 Principle and Procedure

Scenarios were generated by modifying the tyre/road noise component of the passenger car noise and estimating the consequent changes in overall vehicle pass-by noise levels.

The tyre/road noise and the propulsion noise contributions to the overall passenger car noise level were calculated in the following reference cases 1) Norway: SMA 16 road surface and 2) Denmark: SMA 11 road surface. This was done by applying the Nord2000 prediction method.

To illustrate the process, Figure 10 shows the pass-by noise levels at 7.5 m distance, 1.2 m above the road surface, from a light vehicle (left) on a stone mastic asphalt (SMA 16) and a heavy vehicle (right) on dense asphalt concrete (AC 11d) as a function of the (constant) vehicle speed, according to Nord2000 [12]. The total noise level is composed of the tyre/road noise and the propulsion system noise. If we modify the tyre/road noise by selecting another road surface or another population of tyres this will result in a change in the overall noise level. The “balance” between tyre/road noise and propulsion system noise depends on the sound propagation from source to receiver and hence scenarios were calculated for different propagation situations.

![Figure 10: Pass-by noise level at 7.5 m calculated with Nord2000 as a function of the (constant) vehicle speed. Total noise and its components of tyre/road and propulsion system noise. Left: Light vehicle at SMA 16 [2]; Right: Heavy vehicle at AC 11d [3].](image)

It can be seen from Figure 10 that for passenger cars the dominant noise source for vehicle speeds over 50 km/h is the tyre/road noise whereas for heavy vehicles both the tyre/road and the propulsion noise are important for vehicle speeds over 50 km/h.

5.2 Limitations

Only tyre/road noise from new C1 passenger car tyres has been dealt with in Part 2 of the NordTyre project. Winter tyres were excluded from scenario simulations of the effect of regulating the tyre use, because it would not make sense to assume the exclusion of all summer and all-year tyres and then have a vehicle fleet equipped with only winter tyres characterised by their noise levels measured during the summer.

Only C3 truck tyres were included in the measurements performed on Twente Proving Ground and in this analysis.
5.3 Definition of scenarios

Table 4 is an attempt to illustrate the scenario calculations. First the effect of changing the road surface type is determined; then the effect on the total noise level of changing the road surface type on different road categories. Third is the effect of changing the tyres to less noisy tyres, and at last the effect of changing both the road surface and the tyres.

Table 4: Illustration of noise reduction scenarios for one propagation scenario [2].

<table>
<thead>
<tr>
<th>Road surface type</th>
<th>Tyre/road noise: Effect of replacing road surface</th>
<th>Avg. of all tyres</th>
<th>With 25-33% quietest tyres</th>
</tr>
</thead>
<tbody>
<tr>
<td>[-]</td>
<td>Road type (Speed)</td>
<td>Road type (Speed)</td>
<td>Road type (Speed)</td>
</tr>
<tr>
<td>SMA 16</td>
<td>0</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>SMA 11 –X</td>
<td>ΔL_P</td>
<td>ΔL_P</td>
<td>ΔL_P</td>
</tr>
<tr>
<td>SMA 8 –Y</td>
<td>ΔL_P</td>
<td>ΔL_P</td>
<td>ΔL_P</td>
</tr>
</tbody>
</table>

As there are differences in the noise mapping procedures used in Norway and Denmark, similar starting points for the noise propagation scenarios were calculated presuming different Danish and Norwegian weather condition.

According the Nord2000 noise prediction method [15] the source height of the tyre/road noise is mainly 0.01 m over the road surface whereas the source height for the propulsion system noise is mainly 0.30 cm for passenger cars and 0.75 cm for trucks. These different source heights have different influence on the propagation scenarios for passenger car and truck noise. The EU prediction method CNOSSOS [14] use a single source height of 0.05 m for all vehicle types. If the CNOSSOS method had been used for these predictions instead it would have changed the results to some extent.

In order to include the effect of noise propagation the starting points are calculated 100 m from the road centre line, 4 m above terrain, with 1 m hard terrain, while the rest of the propagation is over grass land. This represents the noise situation in a residential area with a 100 m distance to the road. The 4 m receiver height was chosen to represent the conditions for EU noise mapping.

For the Norwegian case the weather is no wind and moderate temperature inversion (downward curvature) with temperature gradient 1°C/100 m. For the Danish case the weather is moderate downwind which approximately represents the yearly average weather used in Danish noise mapping.

Figure 11 shows the “balance” for a vehicle speed at 80 km/h between tyre/road noise and propulsion system noise for a passenger car in the reference case with SMA 16 for both the Danish and the Norwegian case predicted at a distance of 100 m from a road. Similar calculations have been performed with typical vehicle speed combinations for three different road categories (urban road, highway and motorway), for both light vehicles and heavy vehicles, where the balance between the two components is different. These differences are mainly caused by the differences in the defined weather conditions.
The potential noise reductions for the different road categories, for passenger cars and trucks are illustrated in the following. As the total annoyance is a combined effect of the noise from passenger cars and trucks, the percentage of the total share of noise was calculated for typical percentages of passenger cars and trucks.

5.3.1 Denmark

The potential noise reduction in residential areas obtained by regulating both the road surface and the tyre use in Denmark is given for the different typical road types in Table 5. The main reason that the reductions of the total vehicle noise in Table 5 are smaller than the reduction in tyre/road noise is that now the propulsion noise is included and this component is not reduced. The reason for different reduction potentials at different road types is the balance between the tyre/road noise and the propulsion noise at different speeds (see Figure 10).

Table 5: Potential total vehicle noise reduction in residential areas around urban roads, highways and motorways, respectively, for both passenger cars and trucks in Denmark obtained by regulating both the road surface and the tyre use. The potentials are not weighted with the share of noise from passenger cars and trucks.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Urban</th>
<th>Highway</th>
<th>Motorway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>2.2 dB</td>
<td>2.9 dB</td>
<td>3.0 dB</td>
</tr>
<tr>
<td>Truck</td>
<td>0.3 dB</td>
<td>0.5 dB</td>
<td>0.6 dB</td>
</tr>
</tbody>
</table>
The percentage of the noise share based on sound energy, for the different road types is given in Table 6.

Table 6: Percentage of noise share for typical urban roads, highways and motorways for both passenger cars and trucks in Denmark [2 and 3].

<table>
<thead>
<tr>
<th>Percentage of noise level</th>
<th>Urban</th>
<th>Highway</th>
<th>Motorway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>59 %</td>
<td>52 %</td>
<td>76 %</td>
</tr>
<tr>
<td>Heavy vehicles</td>
<td>41 %</td>
<td>48 %</td>
<td>24 %</td>
</tr>
</tbody>
</table>

The weighted potential noise reduction for the different road categories in Denmark is illustrated for the passenger cars and trucks in Table 7 and at Figure 12. As seen both in the tables and at the graph the main potential comes from the passenger car noise, especially on motorways, where the passenger cars drive faster than the trucks.

Table 7: Weighted potential noise reduction in residential areas around urban roads, highways and motorways for both passenger cars and trucks in Denmark obtained by regulating both the road surface and the tyre use.

<table>
<thead>
<tr>
<th>Weighted potential</th>
<th>Urban</th>
<th>Highway</th>
<th>Motorway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>1.3 dB</td>
<td>1.5 dB</td>
<td>2.3 dB</td>
</tr>
<tr>
<td>Truck</td>
<td>0.1 dB</td>
<td>0.3 dB</td>
<td>0.1 dB</td>
</tr>
</tbody>
</table>

Figure 12: Weighted potential noise reduction for passenger cars and trucks for the different road categories in Denmark obtained by regulating both the road surface and the tyre use.

5.3.1 Norway

The potential noise reduction in residential areas obtained by regulating both the road surface and the tyre use in Norway is given for the different typical road types in Table 8. Again the main reason that the reductions of the total vehicle noise in Table 8 are smaller than the reductions in tyre/road noise is that now the propulsion noise is included and this component is not reduced.
Table 8: Potential total vehicle noise reductions in residential areas at urban roads, highways and motorways, respectively, for both passenger cars and trucks in Norway obtained by regulating both the road surface and the tyre use. The potentials are not weighted with the share of noise from passenger cars and trucks.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Urban</th>
<th>Highway</th>
<th>Motorway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>2.2 dB</td>
<td>3.5 dB</td>
<td>3.9 dB</td>
</tr>
<tr>
<td>Truck</td>
<td>0.8 dB</td>
<td>1.3 dB</td>
<td>1.3 dB</td>
</tr>
</tbody>
</table>

The percentage of the noise share based on sound energy for the different road types is illustrated in Table 9.

Table 9: Percentage of noise share typical for urban roads, highways and motorways for both passenger cars and trucks in Norway [2 and 3].

<table>
<thead>
<tr>
<th>Percentage of noise level</th>
<th>Road type</th>
<th>Urban</th>
<th>Highway</th>
<th>Motorway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td></td>
<td>81 %</td>
<td>67 %</td>
<td>74 %</td>
</tr>
<tr>
<td>Truck</td>
<td></td>
<td>19 %</td>
<td>33 %</td>
<td>26 %</td>
</tr>
</tbody>
</table>

The weighted potential noise reduction for the different road categories in Norway is illustrated for the passenger cars and trucks in Table 10 and at Figure 13. As seen both in the tables and at the graph is the main potential coming from the passenger cars. It can be seen that the noise reducing potential in Norway is a little larger than in Denmark.

Table 10: Weighted potential noise reduction in residential areas for urban roads, highways and motorways for both passenger cars and trucks in Norway obtained by regulating both the road surface and the tyre use.

<table>
<thead>
<tr>
<th>Weighted potential</th>
<th>Road type</th>
<th>Urban</th>
<th>Highway</th>
<th>Motorway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td></td>
<td>1.8 dB</td>
<td>2.4 dB</td>
<td>2.9 dB</td>
</tr>
<tr>
<td>Truck</td>
<td></td>
<td>0.1 dB</td>
<td>0.4 dB</td>
<td>0.3 dB</td>
</tr>
</tbody>
</table>

Figure 13: Weighted potential noise reduction for passenger cars and trucks for the different road categories in Norway obtained by regulating both the road surface and the tyre use.
6 Annoyance scenarios

Based on the potential for reducing the total vehicle noise by reducing the rolling noise from the passenger car- and truck tyres (including the use of less noisy tyres and road surfaces) annoyance scenarios are developed and analysed in the following.

This section describes the effects one would expect on the annoyance experienced by the populations if the noise reduction scenarios mentioned in the previous sections became reality (Table 7 and Table 10 etc.). Based on available data on the present noise mapping showing the noise exposure of the population, changes in the value of overall noise exposure indicators to be expected as a consequence of implementing the noise reduction scenarios were calculated as described in the following.

6.1 Noise annoyance indicators

In Table 11 the definitions of various noise indicators are summarised and references are given to the documents defining them. Figure 14 shows their value as a function of the noise exposure. The Danish indicator (SBT) increases exponentially with increasing noise levels while the Norwegian indicator (SPI) increases linearly, and the percentage of highly annoyed persons (% HA) following a polynomial expression increases at a rate in between those of the two other indicators. When calculating the Danish noise indicator SBT only the number of dwellings exposed to more than 58 dB is included. When calculating the reduction all the dwellings reduced to less than 58 dB are excluded and therefore giving a big reduction by not contributing at all.

Table 11: Definitions of noise indicators used in Denmark and Norway, and the percentage of highly annoyed persons according to an EU position paper.

<table>
<thead>
<tr>
<th>Country</th>
<th>Indicator / Acronym</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark - DK</td>
<td>Noise annoyance number (Støjbelastningstal) / SBT</td>
<td>SBT = ( N_{dw} \cdot G ) [6]</td>
<td></td>
</tr>
<tr>
<td>Norway - NO</td>
<td>Noise annoyance index (Støyplageindeks) / SPI</td>
<td>SPI = ( N_{per} \cdot G_{pvei} ) [7] ( G_{pvei} = 1.58 \cdot (L_{den} - 39.4) )</td>
<td></td>
</tr>
<tr>
<td>EU</td>
<td>Percent Highly Annoyed / % HA = 9.868 ( \cdot 10^{-4} \cdot (L_{den} - 42)^3 ) - HA also called the Miedema curve</td>
<td>[8]</td>
<td></td>
</tr>
</tbody>
</table>
Figure 14: Dose response curves used for defining noise indicators in Denmark (DK) Norway (NO) and EU (Miedema) as a function of the day-evening-night noise level $L_{den}$.

6.2 Noise mappings

The results of the Danish noise mapping were reported in the National noise map in 2012, in which results of mappings made by the Danish Road Directorate and by a number of municipalities have been merged. The total number of mapped dwellings was 1.5 million, 723,000 of which were exposed to $L_{den} = 58$ dB or more. The data were specified with the number of dwellings per 1 dB exposure class, on different road types (urban, highway and motorway). The overall distribution of these 723,000 noise exposed dwellings according to noise level is illustrated in Figure 15.

The Norwegian data extracted from the “Støybygg” data base were sorted by DRD into 1 dB wide noise level classes. The received data cover five regions of Norway and they are complete for four of these five regions. The data contains information on 223,824 dwellings, out of which 146,728 was supplied with information on the traffic speed limit. After limiting data to noise exposures exceeding 55 dB, the total number of dwellings was approximately 126,000. The overall distribution of these 146,728 noise exposed dwellings according to noise level is illustrated in Figure 15.
6.3 Effect of regulation on annoyance

Based on the data on population exposure to different noise level classes, the contributions from each noise level class to the overall noise indicators for the population as a whole were calculated. The reduction from the individual road types are calculated from both the passenger cars and the trucks, and afterwards added to find the total effect.

The results for potential noise reductions are illustrated in Chapter 5. The effect on annoyance of regulating the tyres and the road surfaces is for the Danish case illustrated by the annoyance indicator SBT (Noise Annoyance Number) and for the Norwegian case illustrated by the annoyance indicator SPI (Noise Annoyance Index). The effect on annoyance in Denmark and Norway is presented in the following sections.

6.3.1 Denmark

The effect on regulating the tyres and road surfaces in Denmark is illustrated in Table 12 and in Figure 16. In the before situation the total SBT was 155,600 and after the reductions it is reduced to 117,700. The table clearly illustrates that most of the reduction comes from the passenger cars. The reduction of noise from the trucks is responsible for a 2 % reduction, the passenger cars 22 % and in total the reduction is 24 %. If the dwellings which after the reduction are exposed to less than 58 dB were not excluded, the total reduction would have been 20 %.
Table 12: Change $\Delta$SBT in SBT for Denmark for reducing the noise from the trucks, passenger cars and the total reduction.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Reduction [dB]</th>
<th>Total SBT [SBT]</th>
<th>$\Delta_{SBT}$</th>
<th>$\Delta_{SBT}$ [%]</th>
<th>Reduction caused by trucks $\Delta_{SBT}$</th>
<th>$\Delta_{SBT}$ [%]</th>
<th>Reduction caused by passenger cars $\Delta_{SBT}$</th>
<th>$\Delta_{SBT}$ [%]</th>
<th>Total reduction $\Delta_{SBT}$</th>
<th>$\Delta_{SBT}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>1.4</td>
<td>135,400</td>
<td>2,500</td>
<td>2 %</td>
<td>27,400</td>
<td>20 %</td>
<td>29,900</td>
<td>-22 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highway</td>
<td>1.7</td>
<td>5,800</td>
<td>200</td>
<td>4 %</td>
<td>1,400</td>
<td>23 %</td>
<td>1,600</td>
<td>-27 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorway</td>
<td>2.4</td>
<td>14,400</td>
<td>300</td>
<td>2 %</td>
<td>6,100</td>
<td>43 %</td>
<td>6,400</td>
<td>-45 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>155,600</td>
<td>3,000</td>
<td>2 %</td>
<td>34,900</td>
<td>22 %</td>
<td>37,900</td>
<td>-24 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 16: Illustration of the total reduction and change in distribution of SBT in Denmark.
6.3.2 Norway

The effect on regulating the tyres and road surfaces in Norway is illustrated in Table 13 and in Figure 17. In the before situation the total SPI was 7,768,000 and after the reductions it is 6,947,000. The table clearly illustrates that the most of the reduction comes from the passenger cars. The reduction of noise from the trucks is responsible for a 1 % reduction, the passenger cars 9 % and in total the reduction is 11 %. Despite the higher potential noise reduction in Norway than Denmark, the differences in annoyance indicator and distribution on noise classes causes annoyance reduction in Norway to be smaller.

Table 13: Change \( \Delta \text{SPI} \) in SPI for Norway for reducing the noise from the trucks, passenger cars, and the total reduction. The number of persons per dwelling is set to 1.8.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Reduction [dB]</th>
<th>Total SPI before reduction [SPI]</th>
<th>Reduction caused by trucks ( \Delta \text{SPI}/1000 ) [%]</th>
<th>Reduction caused by passenger cars ( \Delta \text{SPI} ) [%]</th>
<th>Total reduction ( \Delta \text{SPI} ) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>1.9</td>
<td>4,749,000</td>
<td>32,000</td>
<td>1 %</td>
<td>390,000</td>
</tr>
<tr>
<td>Highway</td>
<td>2.8</td>
<td>2,570,000</td>
<td>50,000</td>
<td>2 %</td>
<td>279,000</td>
</tr>
<tr>
<td>Motorway</td>
<td>3.3</td>
<td>449,000</td>
<td>7,000</td>
<td>2 %</td>
<td>63,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7,768,000</td>
<td>89,000</td>
<td>1 %</td>
<td>732,000</td>
</tr>
</tbody>
</table>

Figure 17: Illustration of the total reduction and change in distribution of SPI in Norway.
### 6.3.3 All three indicators Denmark and Norway

For both Denmark and Norway the effect on regulating the tyres and road surfaces have been calculated for the three noise indicators SBT used in Denmark and SPI used in Norway as well as for the percentage of highly annoyed persons according to an EU position paper (see table 11 and Figure 14). These three noise indicators are defined differently and this is reflected in the predicted results that can be seen for Denmark in Table 14 and for Norway in Table 15.

#### Table 14: Overview of the total noise exposure in Denmark expressed as the three indicators SBT, SPI and % HA. The total reduction of these three indicators obtained by regulating both the road surface and the tyre use is also shown.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Total before reduction</th>
<th>Total reduction</th>
<th>Total reduction in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise annoyance number / SBT</td>
<td>155,600</td>
<td>37,900</td>
<td>24 %</td>
</tr>
<tr>
<td>Noise annoyance index / SPI</td>
<td>50,342,000</td>
<td>3,255,000</td>
<td>6 %</td>
</tr>
<tr>
<td>Percent Highly Annoyed / % HA</td>
<td>203,299</td>
<td>25,937</td>
<td>13 %</td>
</tr>
</tbody>
</table>

#### Table 15: Overview of the total noise exposure in Norway expressed as the three indicators SBT, SPI and % HA. The total reduction of these three indicators obtained by regulating both the road surface and the tyre use is also shown.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Total before reduction</th>
<th>Total reduction</th>
<th>Total reduction in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise annoyance number / SBT</td>
<td>19,220</td>
<td>6,603</td>
<td>34 %</td>
</tr>
<tr>
<td>Noise annoyance index / SPI</td>
<td>7,768,000</td>
<td>821,000</td>
<td>11 %</td>
</tr>
<tr>
<td>Percent Highly Annoyed / % HA</td>
<td>28,055</td>
<td>5,220</td>
<td>19 %</td>
</tr>
</tbody>
</table>

From the above tables it can be seen that the predicted noise reduction potential of regulating both the road surface and the tyre use varies a lot depending on which indicator that is used to describe the total noise reduction achieved in percent. The highest potential are seen when using the Noise annoyance number (SBT) and the lowest when using the Noise annoyance index (SPI). This can be explained by the way the different indexes are defined (see Figure 14) with the SBT following an exponentially function and SPI following a linearly function. The use of noise indicator SPI for Denmark and SBT for Norway is only included for comparison on the results, but will not be applied in the respective countries.

The noise reduction potential of regulation road surfaces and tyres is around 50 % higher in Norway than in Denmark expressed with all three indicators. The main reason for this is the fact that the starting point in Norway is SMA 16 road surfaces which are noisier than the SMA 11 road surfaces being the starting point for the Danish case.
7 Discussion and conclusion

The NordTyre projects have been carried out in order to clarify the possibilities of reducing traffic noise in the Nordic countries by regulating the use of vehicle tyres and road surfaces. As clearly illustrated this has not been a simple task. One of the big challenges in basing such evaluations on the tyre noise labelling system is that the label values are measured on a relatively smooth ISO surface, which does not represent typical Nordic road surface types having a rougher surface texture.

For both truck and passenger car tyres there was a difference between the measured noise levels on an ISO surfaces and the labelled values. For passenger car tyres there was no correlation at all between measured and labelled noise levels. The reasons for this lack of correlation are discussed in the NordTyre part 2 report [2], and the authors believe that the main reason is variation in test track surface properties although it cannot be ruled out that differences in test conditions during labelling measurement and the measurements carried out in the NordTyre project also contribute to this unfortunate fact. It is also a fact that tyre manufacturers do not test all tyres, but tyres representative for a tyre family. It is not known to the NordTyre project group how large variations one can expect within a tyre family.

For truck tyres the analysis of the noise levels show big differences between labelled noise levels and noise levels measured in the NordTyre project. However, the test method described in R117 [9] allows truncation and deduction, and applying this method would explain most of the difference. After applying the method with up to 0.9 dB truncation of the measurement results and 1 dB deduction combined with a large allowed temperature span without any corrections for the temperatures, it is not possible to conclude that there is a difference between the measured and the labelled noise levels for truck tyres.

The total range of noise levels encountered between the least noisy passenger car tyre on the least noisy road surface (excluding the ISO tracks) and the noisiest tyre on the noisiest road surface was almost 11 dB. After removing extreme values for two tyres not reckoned to be representative (one high and one low), the range of labelled noise levels for the studied tyres was 5 dB. Leaving only the quietest tyre (except the one that were removed) the change in energy average noise level on road surfaces was 3.9 dB. The average noise level from tyre/road noise can be reduced by 1.7 dB if only the six quietest types of tyres are in use. For the calculation of national scenarios of potential noise reduction it was assumed that only tyres labelled 69 dB remain in the tyre population. This implies a passenger car tyre/road noise reduction of 1.4 dB.

The measurements of truck tyre noise showed a difference between the noise levels from steer axle and drive axle tyres, whereas all the trailer axle tyres yielded almost the same noise levels. Both the steer and drive axle tyres displayed a range of 6 dB and a potential of 0.4-0.5 dB tyre/road noise reduction using only the 25-33 % tyres with the lowest noise levels, whereas the trailer tyres have a range of only 1 dB and a potential of just 0.1 dB tyre/road noise reduction using only the 25-33 % least noisy tyres. Therefore, there is a potential for reducing the noise, by regulating the use of steer and drive axle tyres to only the least noisy tyres.

The NordTyre project only focussed on tyre/road noise. If it would also be possible to reduce the propulsion noise from trucks, the potential for noise reduction would be higher. If electrical trucks were introduced, it would most likely increase the noise reduction potential obtainable by using less noisy tyres.

The NordTyre projects have been carried out in order to clarify the possibilities of reducing traffic noise in the Nordic countries by regulating the use of vehicle tyres and road surfaces. As clearly illustrated this has not been a simple task. One of the big challenges in basing such evaluations on the tyre noise labelling system is that the label values are measured on a relatively smooth ISO surface, which does not represent typical Nordic road surface types having a rougher surface texture.
Measurements performed with retreaded tyres showed that the retreaded tyres were noisier than the original tyres. On the SMA surface (Stone Mastic Asphalt) the drive axle tyres were on average 0.5 dB noisier than the originals, whereas the retreaded trailer axle tyres were only 0.1 dB noisier than the originals. If the retreaded tyres were subject to regulation as the new tyres are, the potential for noise reduction would be greater. Even if the retreaded tyres were subject to only using the 33 % least noisy tyres there would be a potential. The retreaded tyres constitute a significant part of the truck tyre population (40-65 %), and the potential for reducing truck tyre noise therefore is considerably limited by the fact that retreaded tyres are noisier than the originals and by the same time not being part of the labelling system.

For truck tyres, the tyre/road noise levels at the SMA surfaces were higher than on the other surfaces, and the range between the lowest and the highest level was smaller. The potential reduction of truck tyre/road noise obtained by replacing SMA 16 by SMA 11 is 1.3 dB and when replacing SMA 11 by SMA 8 it is 0.7 dB. For passenger cars, the potential when replacing SMA 16 by SMA 11 is 1.5 dB and replacing SMA 11 by SMA 8 it is 1.9 dB.

Nordic countries are mainly using SMA surfaces. For both passenger car and truck tyres, replacing noisy road surfaces with less noisy road surfaces was found to potentially yield more reduction in traffic noise levels than the noise reduction obtained by regulating the tyre use, but the additional noise reduction which could be obtained by using the least noisy tyres is significant.

If successful regulation of the noisiest tyres can be implemented in combination with replacing the road surface type by a less noisy surface, both the noise from passenger cars and trucks can be reduced. If all road surfaces in Denmark and Norway could be changed from the standard surface to Stone Mastic Asphalt with 8 mm maximum aggregate size and all but the least noisy 25-33 % of the tyres could be removed from the vehicle fleet, then annoyance from traffic noise could be reduced by estimated 24 % in Denmark (Danish SBT) and by estimated 11 % in Norway (Norwegian SPI). This is a significant potential for noise and annoyance reduction in the Nordic countries. The difference between Denmark and Norway is mainly because of different indicators for noise annoyance.

Measured rolling resistance coefficients were found to be uncorrelated with measured tyre/road noise levels. The same applies to most measured data on road grip. A trend was found for less good braking performance on ice and snow the better the labelled wet grip for all-season and winter tyres, which is as expected. For truck tyres the correlations between the labelled rolling resistance and the measured noise level was modest ($R^2 = 0.5$) for the ISO surface and low ($R^2 = 0.2$) for the SMA surface. The drive axle tyres had the highest rolling resistance and also yielded the highest noise levels.
8 Perspective

The conclusions in Chapter 7 imply the following perspectives.

The labelled values do not represent tyres operating on typical Nordic road surfaces. Since surfaces in Denmark are comparable to many other countries in Europe, the labelling values are probably not very representative for most surfaces in use. Both the results of measuring noise from passenger car tyre and truck tyre clearly illustrate a need for a supplementary test surface representing Nordic road surface types. The reference surface described in the CNOSSOS EU noise prediction method [15] is not a smooth textured ISO reference surface but a rougher textured virtual road surface consisting of an average of a dense asphalt concrete (DAC 11) and an SMA 11 surface.

Further the results indicate that the test method has other issues in representing the situation at real roads, so there is a need to work on:

- A test surface that represents the Nordic road surface
- A test surface that represents road surfaces used in other European countries
- A special noise label for Nordic conditions, reflecting the tyre/road noise on typical rougher surfaces used in Nordic and other countries
- Performing temperature correction of noise measurement results for all tyre types including truck tyres
- Reducing the allowed range of temperatures for performing noise testing of tyres in order to reduce the uncertainty caused by temperature
- Inclusion of the retreaded truck tyres in the labelling system, as well as introduction of noise limits for retreaded tyres
- Consideration of the need for a higher noise limit for winter tyres. Winter tyres may, according to the limit values, be 1 dB noisier than summer tyres but the measurements show that summer tyres usually are noisier than winter tyres
- For winter tyres there is a need for labelling of snow grip and ice grip since ice grip and wet grip contradict. Many other European countries should have an interest in this (such as Poland, the Baltic states, and the Alpine regions).

If the labelling system would be improved there is a significant potential for making use of the system in many ways:

- Campaigns and maybe tax incentives encouraging car owners to buy the least noisy tyres possible
- Encouraging public organizations and private companies with a green profile to require the use of the least noisy while at the same time safe tyres; e.g. publicly procured bus transportation, taxi approvals, and cooperating with large transportation companies to have them favour the use of least noisy and safest tyres. Rolling resistance might also be included
- In time: Further limit the allowed tyres on the market, as proposed in the scenario calculations by decreasing the limit noise levels in the tyre type approval system
- Expand the labelling value to represent the tyres during their lifetime, and not only in new condition.

The following important research needs have been identified throughout the project:

- Further investigation of the reasons for poor correlation between labelled values and measured values on actual road surfaces, applicable to both noise and rolling resistance
• Following the previous bullet suggestions how to improve the labelling system to obtain an acceptable correlation between labelled values and measured values on actual road surfaces, applicable to both noise and rolling resistance
• Develop a second and more rough-textured reference surface, for use in tyre noise regulations as well as for tyre labelling. Such a surface would be more representative of Nordic roads than the present ISO 10844 reference surface, but would also be of interest for many other European countries
• Establish stricter specifications of test track properties
• Development of a procedure for inter-calibration of test tracks
• Investigate the variation of noise levels within tyre families
• Investigate how tyre/road noise develops over time as tyres get older and worn
• Investigate tonality of truck tyre noise emission and tonality perceived by road neighbors.
References


[9] UNECE Regulation R117, Uniform provisions concerning the approval of tyres with regard to tyre/road noise emissions and/or to adhesion on wet surfaces and/or to rolling resistance, revision 3; February 2014


