Reduction of road traffic noise by source measures — present and future strategies

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(Received: 2 May 2017; Revised: 13 November 2017; Accepted: 13 November 2017)

The current trend worldwide is less focused on reducing road traffic noise. This is in strong contrast to the severe impact of traffic noise to the general health and quality of life. A more holistic and combined strategy is needed. Current international rules and regulations regarding vehicles and tyres are not sufficient to reduce traffic noise levels in an effective way. Calculations show that these regulations will only yield a reduction of approximately 1.5 dB in L_{den} levels for urban traffic. Additional measures need to be implemented. By combining optimized tyres and road surfaces, a noise reduction of 4–6 dB can be achieved. Such tyres are currently being developed for electric and hybrid-electric vehicles. In addition to noise reduction, these tyres have less rolling resistance that can reduce vehicle energy consumption up to 15% on normal road surfaces. However, there are several obstacles still to be removed, such as the effectiveness of the EU tyre labeling system, and the implementation and durability of low-noise road surfaces. These challenges are discussed in the article.

Primary subject classification: 52.3; Secondary subject classification: 08

1 INTRODUCTION

In addition to air pollution, road traffic noise is the most severe environmental impact in the urban areas worldwide[1]. Road traffic noise is an important source of increased health risk and reduced quality of life for millions of people, exposed even to moderate noise levels.

In Europe, The European Environmental Agency (EEA) has estimated that more than 125 million people are exposed to noise levels above accepted limits[2]. This is nearly one out of every four inhabitants.

The effects of noise are particularly widespread. For the one in four Europeans exposed to noise levels above the EU's threshold for assessment and action, there are both direct and indirect health effects. Traffic noise annoys almost 20 million Europeans and disturbs the sleep of an estimated 8 million. Environmental noise is also linked to approximately 43,000 hospital admissions, 900,000 cases of hypertension, and up to 10,000 premature deaths per year[2].

According to the World Health Organization (WHO) L_{den} levels above 65 dB and L_{night} levels above 55 dB will increase the risk of cardiovascular diseases with 20–40%[1].

WHO has estimated that between 1 and 1.6 million healthy life years (DALYs) are lost every year in EU, due to traffic noise exposure. One healthy life year has been estimated to cost 40,000 to 80,000 Euros (based on air pollution data). This means that the costs of noise exposure in EU can be valued to be in the region of 40 to 80 billion Euros per year, if the estimate of 1 million lost healthy years is used.

There is a significant health burden also among people exposed to noise levels below 55 dB L_{den}. The health risks for one person are lower for these lower noise levels, but the number of people exposed to these noise levels is much larger. The overall health burden for this group, therefore, is still quite large. In the EEA, data are extrapolated to lower noise levels than those that are mandatory in the Environmental Noise Directive (END) and included in the health impact assessment. The estimation is that the results increase further with about 25% for severe annoyance and 70% for severe sleep disturbance. For hypertension, hospital admissions and premature mortality, the increase is about 10%[3].

2 TRAFFIC NOISE WORLDWIDE

Even if the effects of noise are now well-known facts, there seems to be a lack of a common strategy in Europe

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and other regions to reduce the impact of road traffic noise. The priority seems to be limited to climate change and reduction of greenhouse gases.

For traffic noise, the situation for some regions/countries can be summarized as follows:

- European Union: Some important projects were finalized in the last couple of years, such as PERSUADE (2015), ROSANNE (2016) and the CEDR projects DISTANCE, ON-AIR, QUESTIM and FOREVER (2015). No new major projects seem to be ongoing, except LIFE Nereide project, which regards durable and sustainable low-noise road surfaces using recycled asphalt and crumb rubber from scrap tyres[4], and in the research program Horizon2020, there are presently no calls related to road traffic noise. However, the CEDR Road Noise group will continue to work for the next few years. Plans for a Project Call for Road Noise are currently being drafted and, if approved by the governing board, a call for projects will come in 2018. In addition, there seem to be some national projects on low-noise road surfaces running in Germany, Netherlands, Belgium and in Switzerland. In 2017, all EU and the Europe Economic Agreement member states shall make a new mapping of the noise situation for L_{den} levels above 55 dB and L_{night} levels above 50 dB, according to the Environmental Noise Directive 2002/49/EC. The action plans shall be finalized in 2018. There are no legal processes to ensure that these action plans will be followed up in practice, and thus there is no guarantee that the mapping process and action plans will ensure a reduction of noise levels in practice or even compensate for increased traffic volume and densification of cities (more people living close to major roads).
- Nordic countries: In Norway, the number of people exposed to noise levels above L_{den} 55 dB has increased by approximately 54% between the year 1999 and 2014. The goal is to reduce the number of people exposed to noise with 10% in 2020, based on a special national noise exposure index (SPI). Even if there are action plans available, there is presently no research activity going on, to meet the national goals. In Denmark, the activity of the Danish Road Directorate on road traffic noise has dramatically been reduced. Presently, there seems to be a much higher priority on reducing CO_2 emissions from the road traffic.
- Japan: Previous research activity on poroelastic road surfaces (PERS) has been terminated. The general trend is less focused on projects reducing road traffic noise.
- United States: On a federal level, reduction of traffic noise has never been an important issue. General noise limits have only been established for heavy trucks. In some states, like Arizona, tests of low-noise pavements have been going on for some time. With the election of Donald Trump as the president, there is less likely that the federal Environmental Protection Agency (EPA) will focus more on environmental issues like road traffic noise. President Trump has proposed severe cuts in the budget of EPA.

3 VEHICLE NOISE SOURCES AND TRAFFIC NOISE PREDICTION MODELS

Road traffic noise in urban areas is dominating by two independent sources on a vehicle:

- Powertrain related sources
- Tyre/road interaction—rolling noise sources

Both sources are vehicle speed dependent, and the contribution of each source is different for different vehicle categories. Based on a large number of measurements, a relationship between these two main sources and vehicle speed has been established for use in traffic noise prediction models. Figure 1 shows an example of this relationship, based on the Nord2000 prediction model[5].

The cross-over speed, where both sources have equal contribution to the total noise, is approximately 35 km/h for passenger cars and 60 km/h for heavy vehicles. The vehicle noise emission data, which are the basis for the Nord2000 model (and models like CNOSSOS-EU[6]), are based on measurements performed 10–15 years ago[7]. Since then, there has been a continuous development of more silent engines and propulsion systems, mainly due to more stringent exhaust emission regulations. In order to meet Euro VI limits for exhaust emission, Volvo needed to increase the volume of the muffler on their trucks. By doing so, they could reduce the exhaust noise with approximately 10 dB in the low frequency range[8]. This reduction of noise of powertrain related sources will obviously shift the cross-over speed for the example given in Fig. 1 to a lower value. A lower cross-over speed means that the importance of the tyre/road noise component is increasing also in urban and residential areas, where the general speed is within the range of 20–40 km/h.

The data shown in Fig. 1 are based on steady speed conditions. If there are frequent stop-and-go traffic conditions, the importance of powertrain noise sources will increase, due to accelerating and decelerating vehicles.

In a recent Swiss research project,[9,10] the acoustical performance of low-noise road surfaces at speeds below

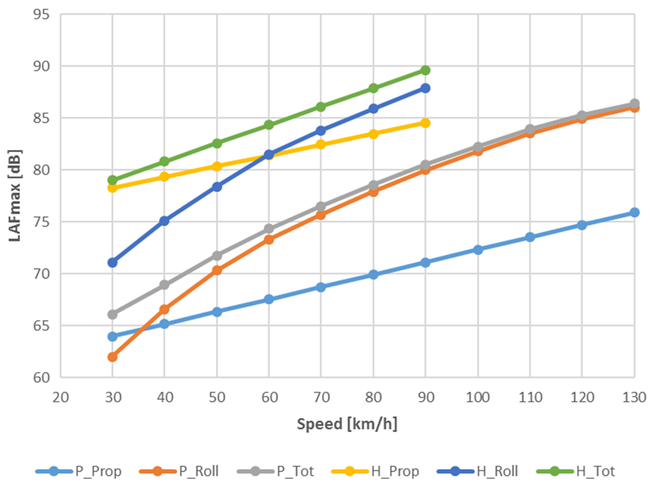

Fig. 1—Propulsion noise (Prop), tyre/road noise (Roll) and total noise (Tot) for passenger cars (P) and heavy vehicles (H). Data based on the Nord2000 prediction model; distance, 7.5 m.

50 km/h has been studied. The effect of such low-noise road surface depends very much on the cross-over vehicle speed, as shown in Fig. 1. To study this cross-over speed for light vehicles, a measurement program of 22 light vehicles was conducted. The vehicle fleet consisted of two electric and two hybrid vehicles, one light duty commercial vehicle with diesel engine and the rest with diesel or petrol engines. The majority of vehicles were 2012–2014 models and they were measured on a closed test track. To separate the rolling noise and the propulsion noise, both Coast-by (engine off) and Controlled Pass-by (engine on) measurements were made in the speed range between 0 to 60 km/h. To study the influence of traffic lights, speed bumps, etc. where uneven driving conditions can occur, two different acceleration modes were implemented: prudent or impetuous. Figure 2 shows the results for the vehicles with petrol and diesel engines. The rolling noise levels are referred to the road surface used in CNOSSOS-EU, which is DAC0/11 or SMA0/11, 2–7 years old[9].

The results show that the cross-over speed was found to be 15.2 km/h for petrol cars and 15.9 km/h for diesel cars. For the light duty commercial vehicle, the cross-over speed was 33.7 km/h. This is significantly lower than the present data used in models like Nord2000 or CNOSSOS-EU. This indicates that these models underestimate the effect of reducing the tyre/road noise contribution at lower speeds on the total noise level (combined power-unit noise and tyre/road noise).

Presently, there is a lack of similar data for heavy vehicles. In a recent Nordic project on tyres, NordTyre, a measurement campaign was conducted on a heavy truck, tested with 30 different tyres[11]. The tyres were tested on SMA0/11 surface, as well as on other road surfaces, including ISO 10844[12]. On average, the tyre/road noise level at 7.5 m distance (coast-by measurements) was 77.7 dB(A) at 70 km/h, with a standard deviation of 1.0 dB. Measurements were performed in the speed range from 35 to 75 km/h. A comparison of the measured values for a single tyre, compared to a standardized tyre noise level vs. speed relationship in Nord2000, is shown in Fig. 3. The difference is within the range of 5 dB. This indicates an overestimation of the tyre/road noise component in the prediction models, also for heavy vehicles. This again would underestimate the effect of a noise reducing pavements. However, this comparison should be verified through a similar test program for heavy vehicles as conducted for light vehicles in Switzerland.

4 CURRENT STRATEGIES TO REDUCE ROAD TRAFFIC NOISE

The most cost-efficient strategy to reduce road traffic noise is the source noise reduction[13]. Since the noise sources of a vehicle are primarily related to the power-train sources and to the rolling noise, the most effective source reduction strategy would be:

- to use low-noise vehicles
- to use low-noise tyres
- to use low-noise road surfaces

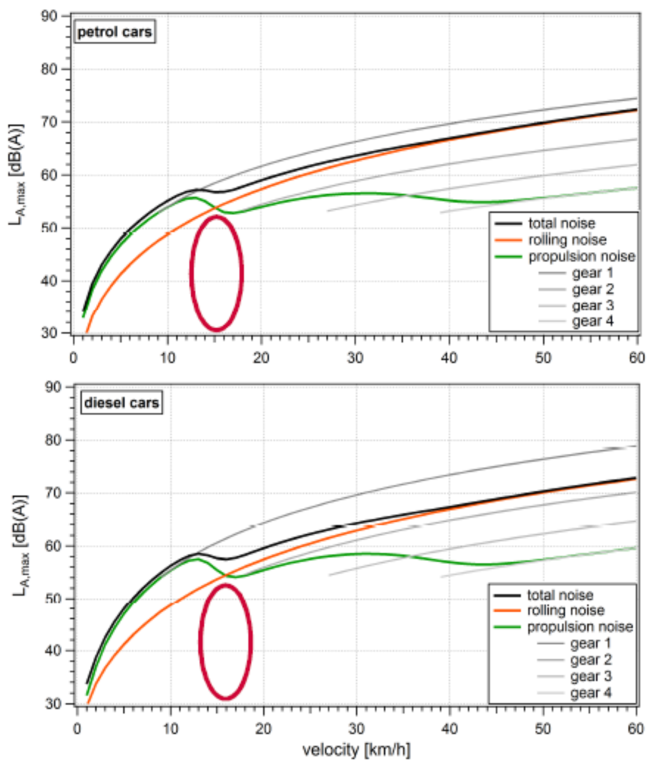

Fig. 2—Rolling noise (red) and propulsion noise in driving gears (grey) as weighted gears (green) as well as the total noise (black) from petrol and diesel cars.

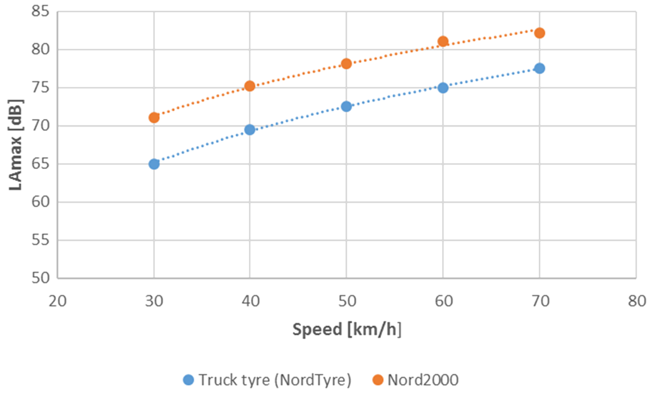

Fig. 3—The rolling noise level as a function of vehicle speed of a truck tyre measured in the NordTyre project (blue) compared to the normalized curve for rolling noise for heavy vehicles in the Nord2000 model (red).

The maximum is a combination of all three, for example, an electric powered vehicle, using tyres with the present lowest tyre/road noise level on a porous road surface.

This seems reasonable simple, but there are major questions and challenges to this:

1) Low-noise vehicles:

What is a low-noise vehicle? A vehicle that fulfils already Phase 3 (from 2024/26) of the present international vehicle regulations EU 540/2014 or ECE Reg.51-03?

Phase 3 vehicles will have a type approval level 3–4 dB below the present limit. However, the limits of Phase 3 are still subjected to a cost/benefit evaluation before approval. The EU/ECE regulations are based on a revised ISO type approval test procedure[14], which simulates real world urban driving conditions better than the old system. In a Polish-Norwegian research project, LEO (www.leo.mech.pg.gda.pl), the effect on L_{den} levels of the approved noise limits of EU/ECE (including Phase 3 for vehicles and adopted limits for tyres), has been calculated up to the year 2030[15]. The calculations have been made for different road categories and for the present vehicle fleet in Norway and in the EU, using the German traffic noise calculation model TraNeCam.

The reduction of A-weighed levels of L_{den} (dB) relative to 2016 is shown in Fig. 4, with separate results for Norway and EU. The reason for separate calculations is that in Norway, already 2% of the fleet is electric vehicles and the average age of cars is somewhat higher than the average of EU. The reference surface is SMA0/11, and due to the road conditions in Norway, the rolling noise part in the model is somewhat higher. In Fig. 4, the calculations are shown for two urban road categories (city trunk road and residential road). No general increase in the total number of vehicles (traffic volume) is included in these calculations.

Even with a reduction of the limits of 3–4 dB, the effect on the L_{den} levels is rather small, in the range of 1.5 dB. It should be noted that these calculations do not consider any increased number of EVs/PEHVs in the traffic fleet. However, both in the project LEO and in the CEDR project FOREVER[16], the increased number of EVs has shown a marginal effect on L_{den}. With up to 25% share of EVs in the fleet, the expected reduction is less than 0.5 dB. This is due to the domination of tyre/road noise. However, if the EVs are combined with low-noise tyres, the reduction will be larger, as shown in Sec. 5.1. For the calculation of L_{den} for all vehicle categories as shown in Fig. 4, there is no difference in levels between Norway and EU. However, if only passenger cars are compared, the effect of low-noise tyres for EVs and a porous road surface will give approximately 1 dB higher reduction of L_{den} levels in Norway compared to EU. This is mainly due to a higher volume of electric cars in the vehicle fleet in Norway.

However, there are still challenges related to reduction of vehicle noise:

Annoyance from road traffic, especially during evenings/nights, can often be related to single events. This could

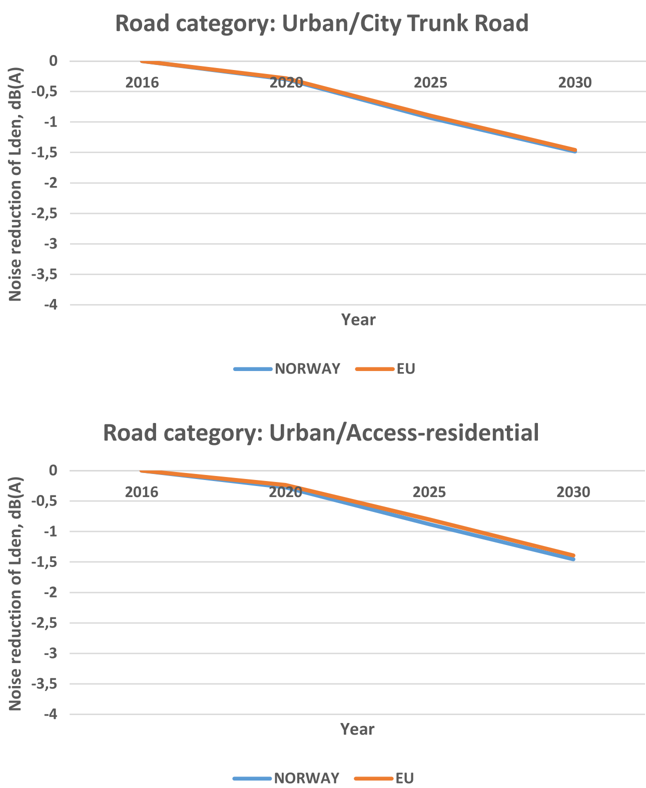

Fig. 4—Calculations of the expected noise reduction of L_{den}, due to the accepted and proposed noise vehicle limits in EU/ECE regulations for two different road categories.

be vehicles with non-legal replaced silencers, high acceleration driving styles, etc. Neither of these types of events is connected to type-approval legislation of new vehicles. Except for mopeds and motorcycles, all vehicles in the EU region more than 3 years old are called in for a periodic technical inspection. External noise is one of the parameters to be evaluated. It is doubtful if this inspection is effective to reduce abnormal noise behavior of vehicles in traffic. It is well-known that many of the motorcycles in-use have modified (and very noisy) exhaust systems. Only random road-side inspection of such vehicles can reveal non-legal and noisy vehicles. An improved simplified noise test should also be developed, as the present noise inspection is based on a stationary tests of vehicle exhaust system noise (measured close to the exhaust pipe) and is not very well correlated with pass-by tests (manly due to a test with little or no-load on the engine).

2) Low-noise tyres:

The noise from tyres is regulated by UN ECE Reg.117[17]. New noise limits were adopted in 2014 (C1/C2 tyres) and 2016 (C3 tyres). Stage 2, with a reduction in the range of 2–4 dB, will be introduced in 2018/2020.

In the EU, a regulation on the labeling of tyres was introduced in 2012[18]. This regulation specifies a labeling system and limits for rolling resistance, wet grip and noise. The rolling resistance is based on laboratory measurements (drum) and the noise is measured on an ISO 10844 surface (smooth). The values for rolling resistance is labeled with A to G, where A is the best (since January 11, 2012 the G label is not used any more). Similar labels A to G are specified for wet grip where the F and G labels had been withdrawn in January 11, 2014. For noise, the symbol for the different noise classes is marked as shown in Fig. 5.

One bar means a label value of 3 dB or more below the limit, two bars mean 1–2 dB below or at the limit and three bars mean a noise level exceeding the limits.

For a new vehicle, the manufacturer fits the tyres as OE-tyres (Original Equipment). They shall meet a wide set of requirements from the vehicle manufacturer, and the three items in the labeling regulation are just a few of those. In addition to the tyre noise limit (set at 80 km/h for passenger car tyres), the combined tyre and vehicle must meet the noise regulation for vehicles (EU/ECE), which

Fig. 5—EU tyre labeling of noise levels.

normally is type approved at a speed around 50–60 km/h (category M). To have a certain margin for the contribution from the powertrain (internal combustion engines), the demands from the vehicle manufacturer on the tyre supplier may then be more stringent than the actual tyre noise regulations.

To choose replacement tyres is not straightforward for the normal car owner. For many, the price is a prime parameter. If comfort is a main issue, the customer may look at the label value. However, this label value is related to the external noise level, and it does not necessarily correlate with the internal noise level. But even if the customer chooses a tyre with the best noise label value (one bar and for example a label value of 66 dB, which presently is the lowest value on the market[19]), it is no guarantee that this tyre will contribute to a general reduction of traffic noise. Several investigations[20–22] have demonstrated the lack of correlation and ranking of tyres on the ISO surface and on real road surfaces (see Fig. 6). In some of these projects, the noise has been measured using a CPX trailer and not fitted at a vehicle, as specified in the UN ECE. Reg.117. The load and tyre pressure could deviate from this regulation, and then the tyre contact area could be different. This has been a major criticism from the industry and the main explanation for the lack of correlation. However, additional measurements where the load and tyre pressure was adjusted did not improve this correlation[23].

In the LEO project, passenger car tyres were measured on drums at the facilities of Technical University of Gdansk (TUG) in Poland on replicas of different road surfaces. In Fig. 7, a regression analysis has been presented between measured sound pressure levels on a replica of an SMA0/8 surface (with similar maximum aggregate size as the ISO surface) and the EU label values[24]. This analysis confirms the lack of correlation, also when drum measurements are being made.

In the NordTyre part 2 project, 31 passenger car tyres were measured on different normally used road surfaces in the Nordic countries (dense asphalt concrete surfaces and stone mastic surfaces with maximum chipping sizes from 6 to 16 mm). In addition, measurements were also made on two different ISO tracks[21]. In all these measurements, two CPX trailers were used: the trailer of the Danish Road Directorate (trailer without an enclosure) and the trailer of the Norwegian Public Roads Administration (trailer with a protective chamber). Since the load and the tyre pressure are somewhat different from the specifications in the ECE tyre regulation, the results were theoretically adjusted to compensate for this deviation, using correction factor of 1.4 dB per 100 kg load for each individual tyre. The analysis showed that the variation in label values could only explain less than 10% of the variation in measured CPX levels, no matter if the results had been corrected or not for deviations from the specified load in the

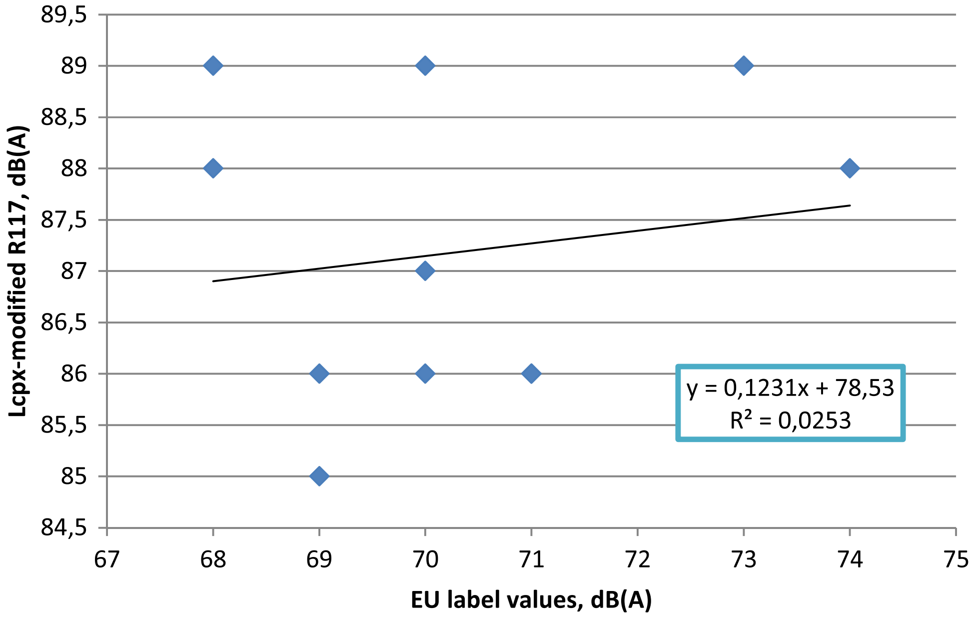

Fig. 6—Correlation between measured CPX levels and EU label values. The road surface is a smooth SMA0/8 surface.

ECE tyre regulation. Figure 8 shows the correlation between measured (and corrected for load deviations) CPX levels on the two ISO surfaces and the label values. There is an obvious lack of correlation. Doing such a regression analysis with normally used SMA0/11 surfaces shows an even worse correlation and difference in ranking order.

Some investigations[11,25] show that the correlation is improved if a comparison is made between measured values on an ISO 10844 surface and values from similar measurements are made on a smooth DAC0/8 or SMA0/8 surface. In these investigations, the equipment, tyre pressure and loading have been identical.

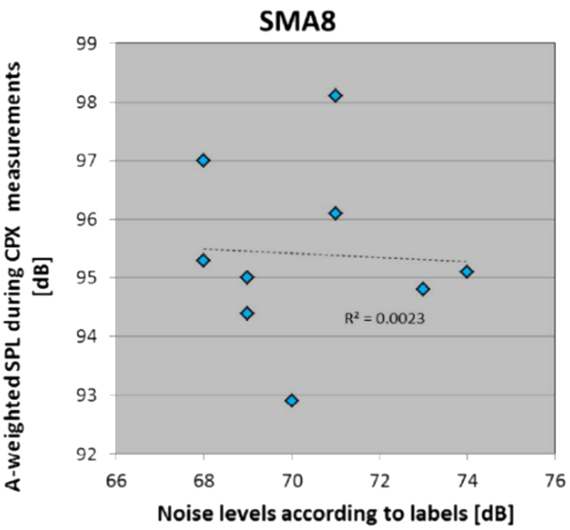

Fig. 7—Correlation between tyre label values and CPX values on a replica of SMA0/8 surface.

In a Swedish investigation[22], not only the correlation of measured noise (CPX levels) with the labeled values, but also the correlation of measured and labeled values for rolling resistance was investigated. For the labeled values, the rolling resistance was measured on laboratory drum facilities. These values were compared to rolling resistance values obtained on real roads (trailer measurements; see Fig. 9). Same as for noise, there is a lack of correlation between measured and labeled values.

3) Low-noise road surfaces:

To reduce road traffic noise and in particular the tyre/road component, the use of low-noise road surfaces is a well-established technology. Such surfaces can be a thin layer with optimized texture, single or two-layer porous surfaces or dense asphalt road surfaces with maximum chipping size in a range of 4–8 mm. Such surfaces will normally reduce the tyre/road noise in the range of 1–5 dB. Another type of surface is the poroelastic surface (PERS), which can give substantial reduction of noise levels from 8 up to 12 dB[26,27]. However, this type of surface is still at an experimental stage and has not yet been used as a conventional low-noise road surface. The biggest challenges are lack of durability and high costs. In the Nordic countries (except for Denmark), with winter conditions and studded tyres, there are still big challenges to implement traditional low-noise road surfaces. Tests with porous surfaces have shown that the surfaces are clogged after only one or two winter seasons, and then the noise reduction is severely reduced[28]. Mainly because of these experiences, there is no demand to invest in low-noise

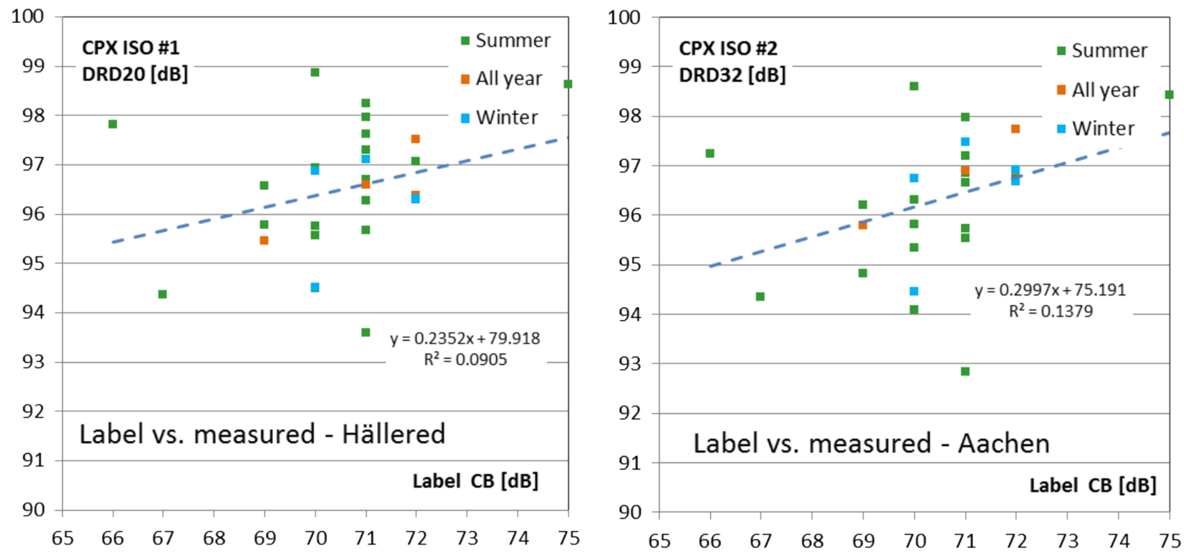

Fig. 8—Correlation between measured CPX levels on two ISO tracks and label values. All measured levels have been theoretically adjusted to correct for deviation of load according to the UN ECE Reg.117.

surfaces now neither from the road owners nor from the road building companies.

In the ROSANNE project[29,30], a proposal for the methods to be used for a future noise classification system for road surfaces has been launched[29]. The Netherlands has also proposed a labeling system for roads in the same manner as for tyres[31] (see Fig. 10). In addition to noise, a label for rolling resistance, wet skid resistance and life span are parts of the proposed system. A road characterization and classification system is currently developed by CEN TC227/WG27. This work is fundamental for a labeling system, as proposed by the Netherlands, and if such a classification system is combined with economic incentives, e.g., financial support from road owners to the road contractors, this could perhaps motivate the use of such low-noise surfaces and to find good solutions for a Nordic winter climate and for all other European countries as well.

5 POSSIBILITIES FOR THE FUTURE

5.1 Noise Reduction

The previous section has shown challenges regarding source related measures to reduce road traffic noise. The most efficient measure is to adopt a holistic approach for noise reduction and avoid sub-optimization. Since there are separate regulations for vehicles and tyres (and no regulations for road surfaces), there is certainly a risk

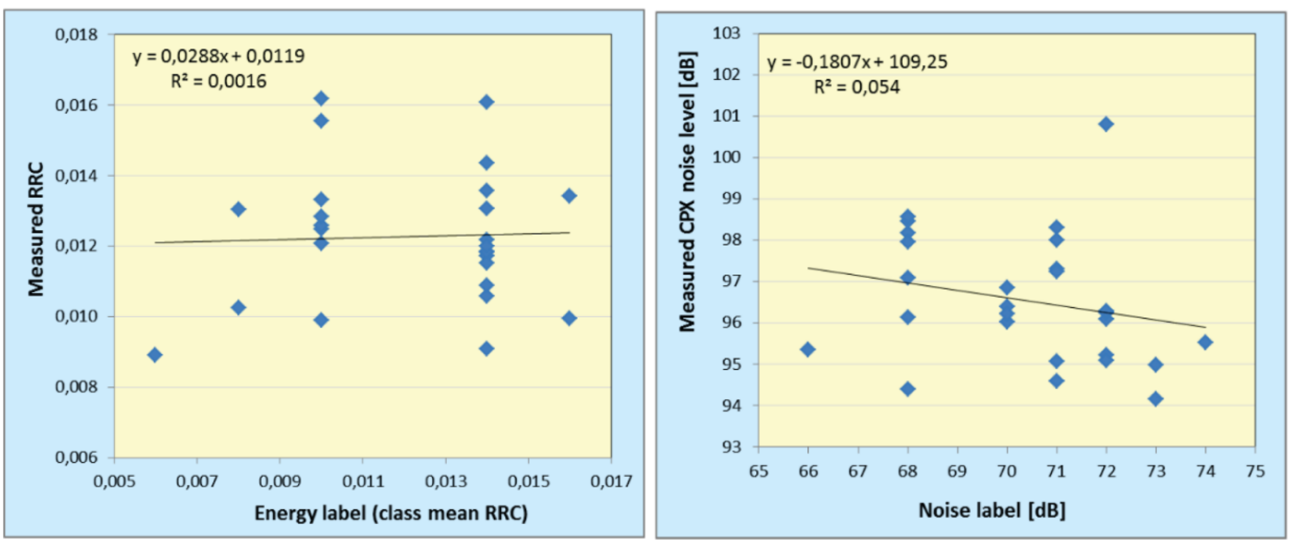

Fig. 9—Correlation of labeled values of rolling resistance (left) and labeled rolling noise levels (right) with measurements on real roads.

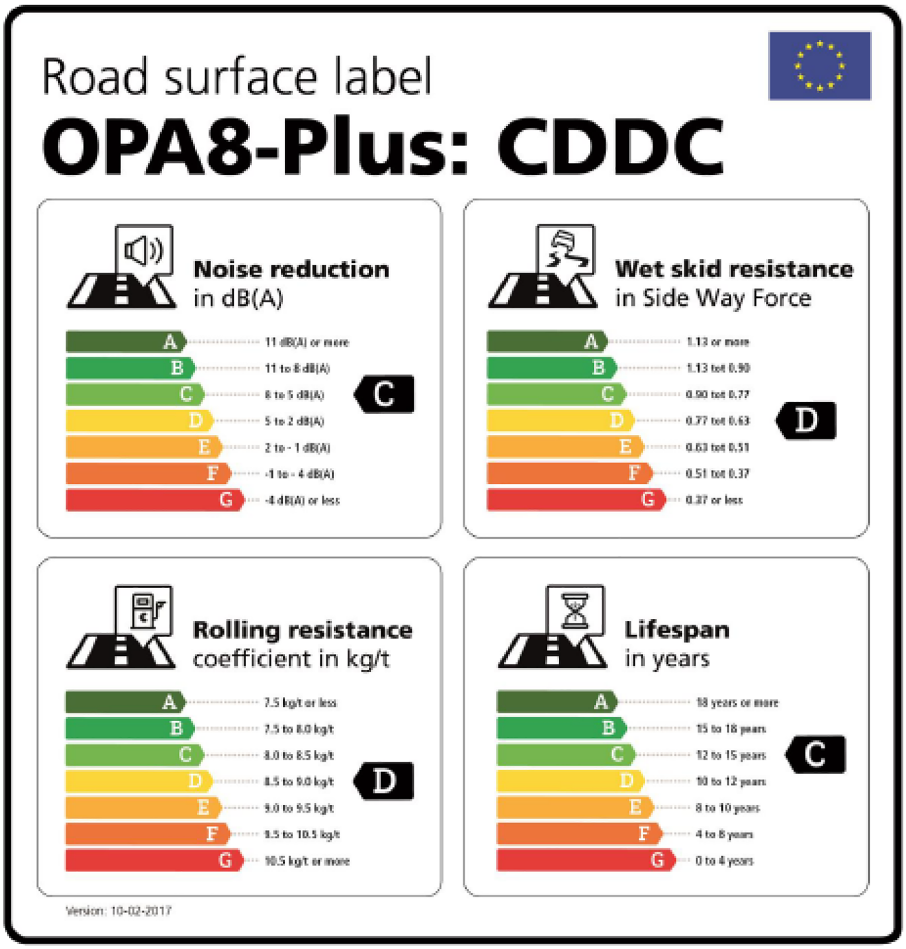

Fig. 10—Proposal from the Netherlands for a labeling system for road surfaces.

for sub-optimization, since these regulations are based on an "artificial" ISO surface.

The vehicle fleet will change dramatically over the next couple of decades, with an increased fleet of pure electric, plug-in hybrid-electric and fuel cell (hydrogen) vehicles. Due to strong user and financial incentives, more than 50% of the new vehicles sold in Norway are presently of the abovementioned types, the majority being plug-in hybrids. To reduce the energy consumption, the tyre industry has developed special tyres to be used on these vehicles. Examples of such tyres are Conti.e-Contact (OE-tyres for VW e-Golf), Bridgestone Ecopia EP500 (OE-tyres for BMW i3) and Michelin Energy E-V (OE-tyres for Renault Zoe). Another example of expected future changes in the vehicle fleet is the France ban of petrol/diesel engines sales from 2040. Similar proposals have also been made in other European countries (France, Germany). In Norway, the aim is that already from 2025, all new vehicles shall be the zero-emission vehicles. Volvo has stated that they will produce only electric and plug-in hybrid vehicles from 2019[32].

One of the aims of the LEO project was to provide decision makers, road builders, local authorities and vehicle users with information related to optimal road surface and tyre selection for urban and suburban areas with strong emphasis on electric and hybrid vehicle use. The main intention was to present available technology of combined tyres and road surfaces, which could show a potential noise reduction and reduced energy consumption (low rolling resistance) beyond the average situation today.

Measurements of noise levels (CPX and coast-by) were made on regular existing roads in Norway and Poland and on the drum facilities of TUG[33]. Both the special EV tyres and selected normal passenger car tyres were tested. On most of the regular road surfaces, the EV tyres are the quietest or among the quietest tyres. In the laboratory drum measurements, there is almost no difference. In Fig. 11, the noise levels of the quietest (EV) tyres are compared with the results for the average tyres and with the noisiest tyres on four different road surfaces; PERS (poroelastic surface), DPA (double layer porous asphalt), SMA0/8 and SMA0/16. The figure shows that on the poroelastic surface (PERS), the EV tyres are 14 dB quieter than the noisiest tyres on the SMA0/16 surface.

By using the German traffic noise calculation program, TraNeCam, it is possible to estimate the effect of different measures to reduce the noise for future situations. In the LEO project, four different scenarios have been set up for prediction of changes in the L_{den} levels from 2016 to 2030:

1. Basic scenario: no additional measures, only the effect of approved changes in the vehicle and tyre regulations (EU/ECE); reference surface: SMA0/11
2. SMA0/11 + tyres for EVs; estimated source reduction (rolling noise): 2 dB
3. SMA0/8 surface + tyres for EVs; estimated source reduction: 4 dB
4. Double layer porous surface (DPAC) + tyres for EVs; estimated source reduction: 8 dB

The results of performed calculations are shown in Fig. 12. The effect of vehicle and tyre regulation is expected to a noise reduction of L_{den} around 1.5 dB in 2030. By changing the reference surface to an SMA0/8, combined with low-noise tyres for EVs, this will give a possible reduction of L_{den} of approximately 3 dB. This reduction includes the effect of EU/ECE regulations. With the best combination of tyres and a double layer porous surface, a reduction of more than 6 dB can be achieved. The calculation has been done for urban/city traffic in the speed range of 30–50 km/h[15]. It should be stated, however, that this is clearly a theoretical value, and should be considered as such. In reality, the reduction will depend on variables connected to noise performance of both, vehicle tyres and road surfaces, over their lifetime.

5.2 Rolling Resistance Reduction

Both in the LEO project and in the ROSANNE project, the coefficient of rolling resistance (CRR) of selected tyres has been measured on a wide range of surfaces[34]. Measurements have been done both using the TUG trailer and by measurements on their laboratory drum facilities.

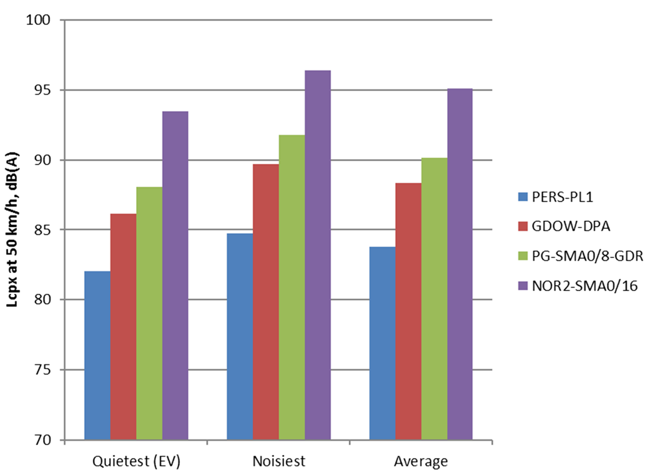

Fig. 11—CPX levels for three groups of tyres on four different road surfaces.

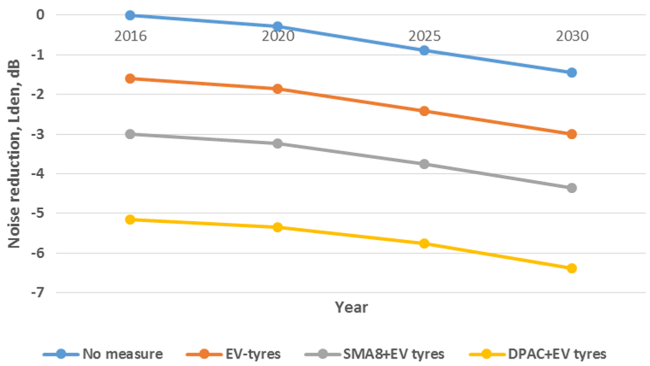

Fig. 12—Calculation of reduction of L_{den} levels for four different scenarios.

Proper selection of tyres for electric vehicles combined with optimized road surfaces may lead to very substantial energy savings but on the other hand, improper selection may result in great losses. On the best pavements, the tyres designed for electric vehicles may reach CRR = 0.004 which corresponds to energy savings (in relation to typical road/tyres combinations) of about 15%. This corresponds to a reduction of fuel consumption by 2–3%. At the same time, improper selection of tyres and road surfaces may lead to increase of CRR by 12% (see Fig. 13)[15]. This shows how important it is to use low rolling resistance road surfaces on urban and suburban roads and energy saving "Electric Vehicle Tyres" on electric, hybrid and conventional cars used primarily for urban and suburban driving.

6 CONCLUSIONS

In the next few decades, we predict a huge change in the transportation systems. The growing fleet of low- and zero-emission vehicles, autonomous vehicles, on-demand public transit, integrated bicycle networks, etc. will certainly lead to a revolution in the transportation situation in the future. It is obvious that these changes can have a major influence on the traffic noise development. Is a car-free city the goal to improve the quality of life of citizens in a sustainable way? At the same time as this may change in the way we organize the transport, the population increases and people are moving towards the cities. These developments will not necessary lead to less road traffic, or a "car-free" city. Thus, the way we organize the transportation system needs to counteract a further increase in traffic volume.

The currently available traffic noise prediction models do not reflect these changes. In some of the models, only a certain increase in traffic volume per year is used as a parameter for future situations.

Today's situation for source related measures to reduce traffic noise could be summarized as follows:

- Vehicles and tyres — international regulations: The approved noise regulations and limits for the future will give only a minor reduction of

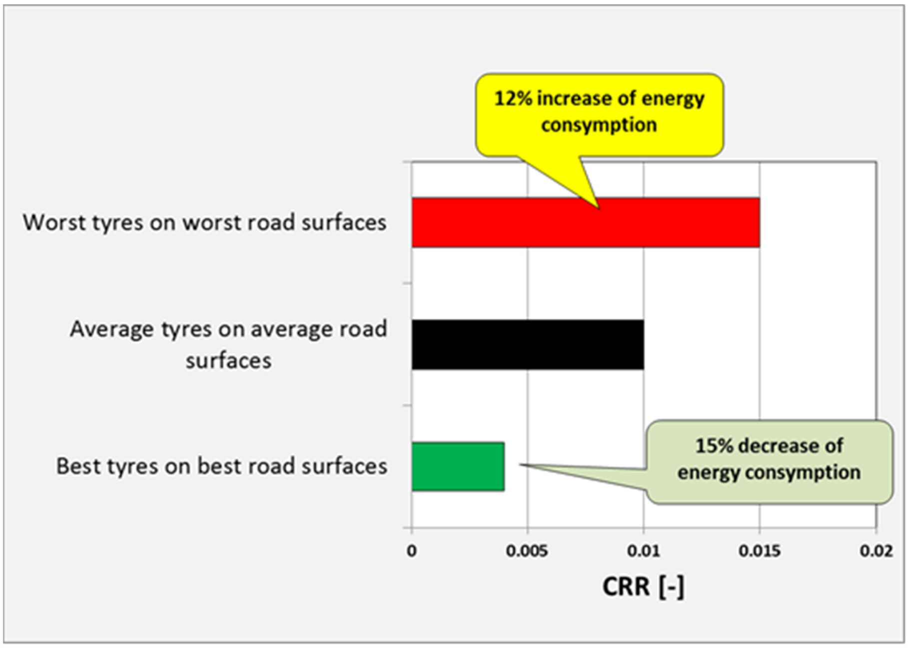

Fig. 13—Possible energy losses and savings due to selection of tyres and road surfaces.

L_{den} levels. Additional measures need to be adopted. If zero-emission vehicles are combined with low-noise tyres and optimized road surfaces, there is a great potential to reduce road traffic noise. Many of such vehicles do not need tyres certified for a maximum speed of more than 200 km/h, as most of European countries have now a maximum speed limit of 110–140 km/h. Lower speed index gives the tyre manufacturers a wider set of tools to reduce the noise, without losing other important features of the tyres.

- Vehicles-in-use: Improvements in periodical checks and in road-side measurement procedure are necessary to ensure that the noise of vehicles does not increase during the lifetime. A special focus should be on mopeds and motorcycles, as they are not part of the periodical technical inspection in EU.
- Road surfaces: Except for a few countries, like the Netherlands, low-noise surfaces are still not in widespread use. The most obvious reasons are increased costs and reduced lifetime compared to the most commonly used dense pavement types. Increased costs need to be compensated, for example, by economic incentives. Durability of open porous surfaces is still a problem in the Nordic countries (with exception for Denmark), due to the use of studded tyres. More research is needed to find good solutions for these winter conditions. In the PERSUADE project, some laboratory results using a studded tyre and PERS showed very promising results indicating a substantial increase in wear resistance compared to normal dense surfaces, mainly due to the elasticity of this surface[27].
- Avoid sub-optimization: Even if the traffic noise is very much interconnected between the vehicle, the tyre and the road, the legal system as it is today favours a sub-optimization of noise reducing measures. Example of this is designing the noise performance of vehicles and tyres during type approval conditions only. As shown in this paper, there is a poor correlation between tyre/road noise measured on an ISO surface and on normally used surfaces, like an SMA type. In a holistic approach for noise reduction, the overall performance must be balanced between noise, safety and overall environmental impact. The noise reduction with the lowest trade-off on overall environmental and safety performance should be encouraged. The LEO project shows the potential for such a combined approach. The current target to reduce energy consumption and CO_2 emission from the road traffic can be a powerful tool to change the current trend of increased number of people exposed to unhealthy road traffic noise.

7 ACKNOWLEDGMENTS

The LEO project has been funded by the Polish National Center for Research and Development (NCBiR) within the Polish-Norwegian Research Program CORE, project LEO (Grant Agreement 196195/2013).

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