PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Opportunistic in-vehicle noise measurements assess road surface quality to improve noise mapping: preliminary results from the MobiSense project.

Luc DEKONINCK[1]; Wout VAN HAUWERMEIREN[1]; Joachim DAVID[1]; Karlo FILIPAN[2]; Toon DE PESSEMIER[1]; Bert DE COENSEL[1,2]; Wout JOSEPH[1]; Luc MARTENS[1]; Dick BOTTELDOOREN[1]

[1] Ghent University, Belgium

[2] ASAsense cvba, Belgium

ABSTRACT

The quality of road pavements affects noise emission caused by tire-road interactions. This in turn affects the health and well-being of residents near these roads. Road pavement quality degrades over time due to wear, accidents, and infrastructure works. These local features are usually not included in noise mapping due to the lack of high-quality information on pavements with enough spatial resolution.

The aim of Mobisense is to assess the quality of the road surface by performing opportunistic noise and vibration measurements inside vehicles that are on the road for other purposes than road quality measurement. In the demonstrator phase of the project, 20 vehicles collect data while the drivers make their usual trips. Measurements from all vehicles are combined using machine learning techniques. This removes engine noise, corrects for vehicle specific speed dependence, and finally determines a rolling noise proxy in third-octave bands. This rolling noise correction includes the effect of pavement type as well as the effect of road surface degradation. This local variation in road surface quality is included as a correction in the rolling noise component of CNOSSOS and used to calculate a subset of the noise map for the Flemish region in Belgium. Including road surface quality in this way changes noise maps locally over a range of 6 dBA.

Keywords: Noise mapping, Road surface, Big Data

1. INTRODUCTION

Noise mapping is standardized in the Environmental Noise Directive for reporting noise exposure to the European community. The common calculation methodology is compiled in the CNOSSOS-EU The noise mapping relies on various sets of external data: traffic data, speed limits, fleet composition and road surfaces. With the increased introduction of electric and hybrid vehicles and due to increasingly stringent EU noise emission regulations, engine noise is dropping considerably. Rolling noise caused by tire-road interaction therefore will become the next focus in traffic noise mitigation [1]. The influence of the choice of pavement and the actual state of the road surface will become more important. This is particularly the case for urban areas. In addition to noise mapping, EU member countries are required to draft action plans to mitigate (road traffic) noise. Pavement choice and road maintenance are possible mitigation measures that should show up in the noise maps. Hence a continuous monitoring methodology could be very advantageous. Moreover continuous monitoring could be a tool for noise emission labeling of road surfaces [2, 3].

2. IN-VEHICLE NOISE MEASUREMENTS FOR ROAD QUALITY PREDICTION

2.1 Opportunistic sensing – the Mobisense project

In this paper an opportunistic approach is proposed: equipping cars that are on the road for other

[1] luc.dekoninck@ugent.be

purposes with noise and vibration sensors to assess road quality. For this, sensor boxes equipped with a microphone, a tri-axial accelerometer and a GPS sensor are put in the trunk of the fleet of cars. Using a 3G connection, the acquired data is transferred to the analysis server. As computation power, data storage, and wireless data transfer are decreasing in cost, opportunistic sensing and big data is on the advent. In addition, a landscape of open source software frameworks (Pandas, TensorFlow, NumPy, SciPy, scikit-learn, etc.) provide the scientific community with the necessary tools to utilize big data, machine learning and artificial intelligence algorithms.

Rolling noise not only depends on the type and maintenance state of the pavement, but also on the tire that is used to sample it. Each vehicle has its own set of tires and therefore their noise emission will vary. Moreover, the interaction between road and tires causes differences in the dependence on driving speed [4]. In addition to the source mechanisms, also the transfer function between the tire and the interior microphone may be quite different between vehicles, due to differences in microphone placement and differences in construction between vehicles.

To account for all the above, the measurement data collected by each vehicle is related to the average measurement over all travelled roads by removing the speed dependent mean value. Averaging over many vehicles with slightly different characteristics eventually results in a correction per third octave frequency bands in the range 350Hz till 2500Hz where pavement quality matters. This averaging converges quickly showing insensitivity to vehicle sampling. More details on the methpodology can be found in [2, 3]

2.2 Mobisense as an alternative for road pavement type and CPX

Noise mapping can be considerably improved by accounting for the type of pavement that is used on each road segment. However, pavement databases are hard to keep up to date and mostly not available for lower level roads. It will be shown how opportunistic sensing could be an alternative to including road surface type from existing databases.

The state of the road surface related to rolling noise production is assessed regularly in many countries using close proximity (CPX) measurements [5]. The Mobisense approach can add value to this method by including a representative sample of tires used in the fleet and avoiding bias due to tire choice in the CPX method [8]. Moreover, it is not limited to the standardized speed of the CPX method and provides valid data for the entire road network sampled at a speed that is appropriate for this type of road. Furthermore, information is obtained at a reduced operational cost and with faster updates.

3. APPLICATION IN REGIONAL NOISE MAPPING

3.1 The reference: MIRA noise map of Flanders

The reference map is a region-wide noise map calculated for the Flemish Environment Agency environmental reporting (MIRA) [6]. The noise map provides L_{den}, L_{day}, $L_{evening}$ and L_{night} for all main and secondary roads in Flanders. The map does not include shielding by dwellings but includes detailed information on noise emission (CNOSSOS-EU) and noise barriers [7]. Its main asset is the spatial accuracy of the lower order roads. Traffic data is available on a generalized network but by routing the generalized links on a routable OSM streetmap layer (www.openstreetmap.org), the traffic is mapped to its exact physical location. The underlying grid of immission points lies on distances of 10, 20, 50 and 100 m from the roads and on a 100 by 100 grid outside the first 100 m buffer of the road network. The maximum exposure near a road is by design the immission at 10 m distance from the center of the closest road.

A pavement dependent rolling correction is classically implemented based on a pavement database from the Flemish road Agency (AWV, https://wegenenverkeer.be/). This dataset is incomplete and for the secondary roads the pavement types are not available. Missing data is extrapolated stochastically. The overall statistics on used pavements is valid, but locally there is no guarantee that the actual road surface is used.

The next three figures show (1) the original map ($L_{den,ref}$), including the road surface corrections based on the pavement database, (2) the map without the road surface correction (L_{den,no_road}), (3) the difference between both maps. For the purpose of this paper, only the main roads are included.

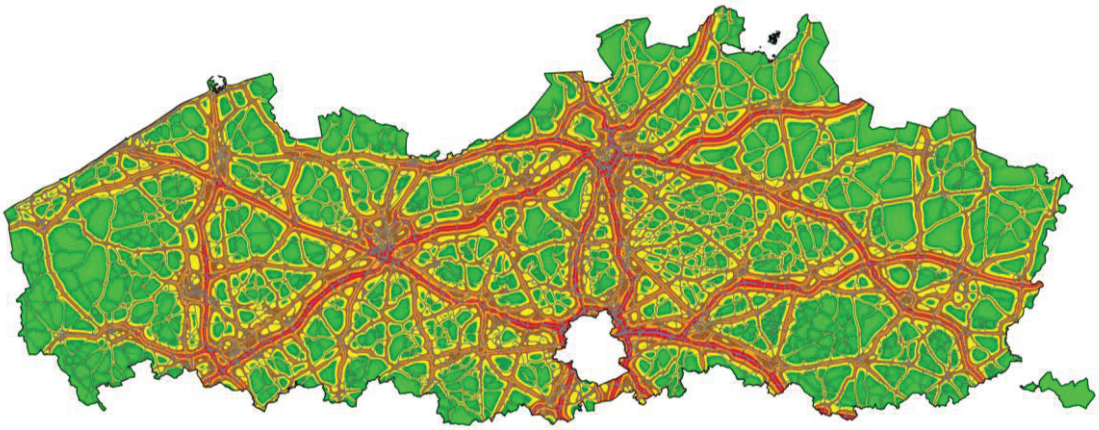

Figure 1 – L_{den} noise map based on pavement database ($L_{den,ref}$)

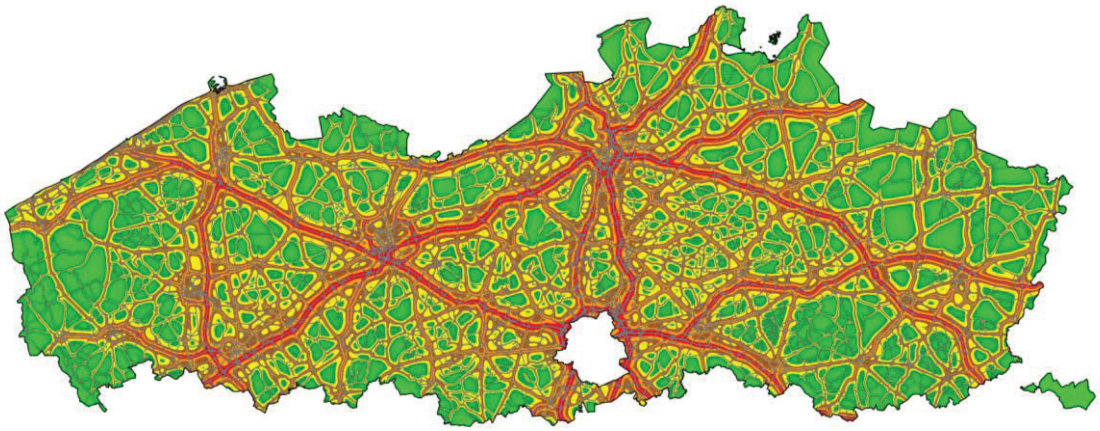

Figure 2 – L_{den} noise map without pavement corrections (L_{den,no_road}).

TO REPLACE

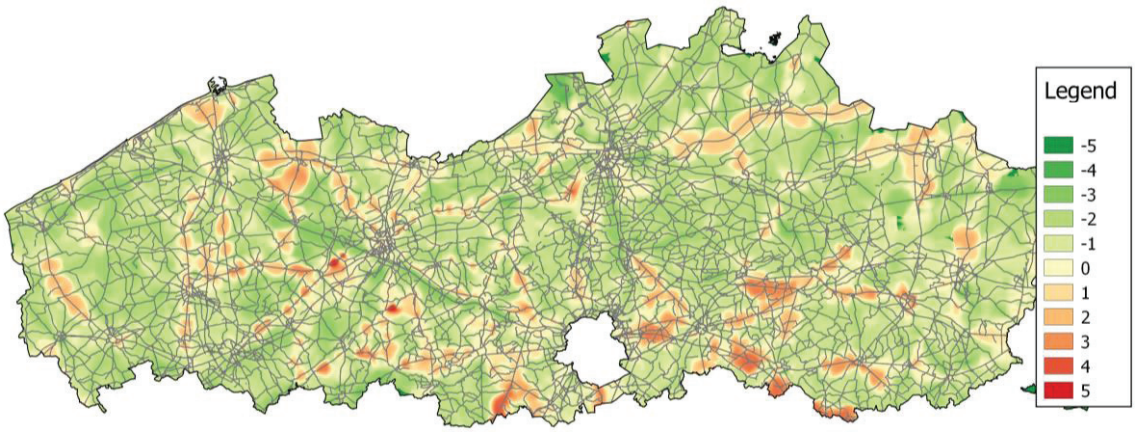

Figure 3 – Effect of pavement correction on L_{den} ($L_{den,ref}$ - L_{den,no_road})

3.2 Applying the Mobisense road surface correction

The noise emission model is based on CNOSSOS-EU. The noise emission is calculated as the sum of the engine noise and the rolling noise. The measured corrections are limited to the octave bands: 250, 500, 1000 Hz and 2000 Hz. At lower frequencies engine noise tends to dominate or the emission contributes marginally to the overall A-weighted level. Rolling noise at higher frequencies may be influenced too much by air pumping for the mobisense results to be valid, yet their contribution to A-weighted overall levels is also limited. A visual representation of the local road surface corrections (in 25 m segments) is shown in Figure 4. Most highways and a high percentage of main roads has already been sampled and the opportunistic sampling is ongoing. The correction is shown for all sampled roads but only the main roads are included in the mapping (see previous section).

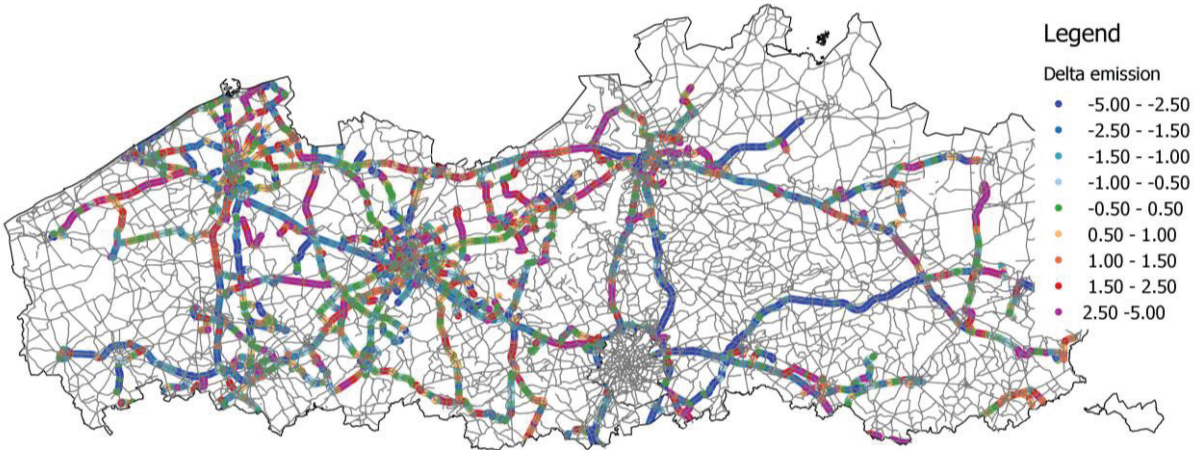

Figure 4 – Mobisense corrections by road segment of 25 m

3.3 Calibration of the two procedures

The CNOSSOS emission functions are based on large samples of vehicle CPB's. CNOSSOS noise maps include the hypothesis that the local fleet matches the sample of vehicle used to determine the emission functions. In the rolling noise component, a reference road surface and corrections are available. The Mobisense procedure assumes a zero correction on rolling noise emission at each octave band for the average road surface travelled by each car. Thus, a calibration should be included to relate the average Flemish road to the standard CNOSSOS road. This calibration step has thus far not been performed. With this calibration and a large sample of measurement cars, Mobisense should reflect the average fleet, including tire types and tire wear better than the CNOSSOS-EU rolling noise functions. On the other hand, the Flemish road Agency has supporting data that the standard road surface in Belgium results in lower rolling noise compared to the reference road surface in the CNOSSOS-EU method. Thus an offset between including the expected road performance and the actual road performance (from Mobisense) is expected.

4. Results: noise mapping with Mobisense road surface corrections

4.1 Mobisense road surface corrections.

Figure 5 presents the difference in L_{den} due to the Mobisense road surface correction. In the yellow-colored areas the difference might also be zero as these roads may not have been sampled during the pilot phase. Red areas correspond to higher immission than expected by the calculation with the reference road surface, green areas represent lower immission than expected with the reference surface. Figure 6 gives the same results zoomed to the Ghent area. Most of the main highways are sampled and show distinct patterns matching the local variations between quiet and noisy road surfaces.

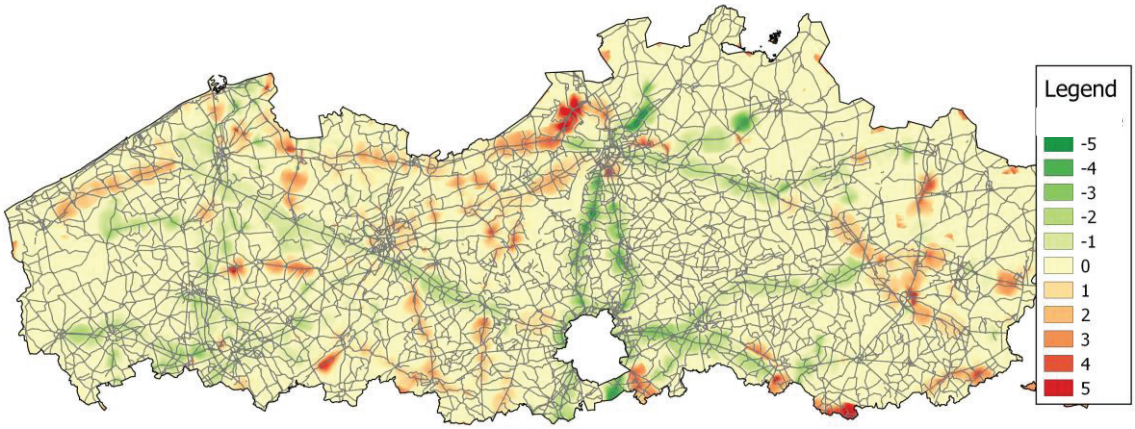

Figure 5 – Effect of Mobisense road surface corrections on L_{den} ($L_{den,mobi}$ - L_{den,no_road}) ;red = noisier surface than reference.

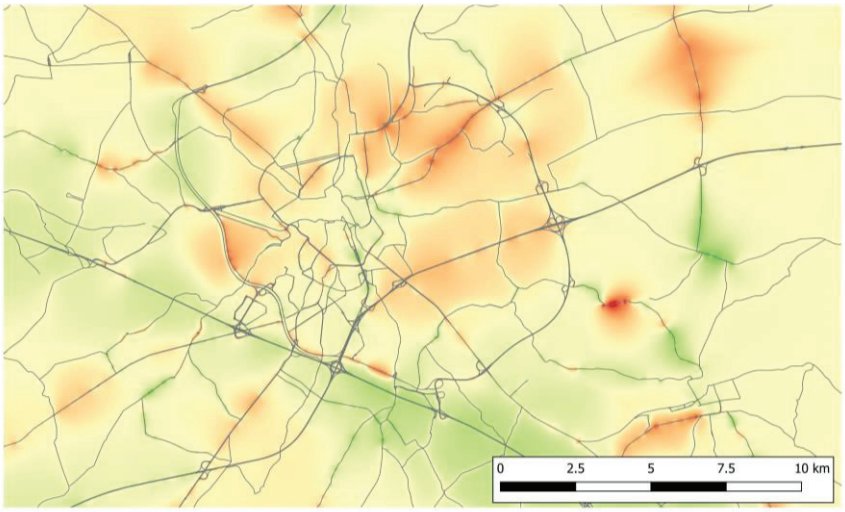

Figure 6 – Effect of Mobisense road surface corrections on L_{den} ($L_{den,mobi}$ - L_{den,no_road}) – detail for Ghent

4.2 Mobisense road corrections compared to pavement type corrections.

The magnitude and alignment of the respective corrections is visualized in Figure 7 as a 2D histogram of cell-by-cell comparison. Only cells with L_{den} larger than 60 dBA are selected to limit the amount of data points and to remove the cells affected by the local roads only. The cells with a Mobisense correction less than 0.2 dB are removed to limit the dataset to cells that are affected by the Mobisense sensing campaign.

The 2D histogram peaks at slightly negative values for both the calculation based on assumed reduction in rolling noise due to pavement choice and the calculation based on measured reduction of rolling noise. However, it can also be seen that for a large number of locations $L_{den,mobi}$ - L_{den,no_road} is larger than $L_{den,ref}$ - L_{den,no_road} which indicates that rolling noise is higher than theoretically expected on the basis of the pavement choice. On the other hand, there are surfaces where noise levels based on measured characteristics are lower than those based on average expectations for the selected pavements. Part of this discrepancy may be due to the timeliness of information in the pavement database.

In Figure 8 the distributions of the cell-based comparison of the three noise maps are visualized. The road surface corrections retrieved from the CNOSSOS-EU emission functions and the pavement database, $L_{den,ref}$ - L_{den,no_road} shows a narrower distribution compared to the measured Mobisense road surface corrections (IQR 1.65 vs IQR 2.13). The distribution of the differences between both corrections is even larger (IQR 2.5 dB). The offset in the distribution of 0.96 dB (median) illustrates the unknown calibration factor between the two methods. The restriction to cells with L_{den} > 60 dBA induces a spatial bias towards roads with higher traffic intensity and the resulting offset in the

distribution of $L_{den,mobi}$ - L_{den,no_road} illustrates that low noise road pavements are more common on these high intensity roads.

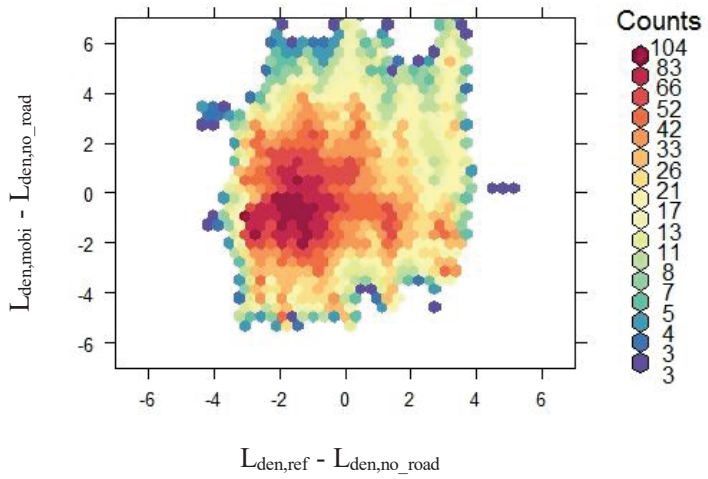

Figure 7 – Cell-wise comparison between $L_{den,mobi}$ - L_{den,no_road} and $L_{den,ref}$ - L_{den,no_road} (2D histogram)

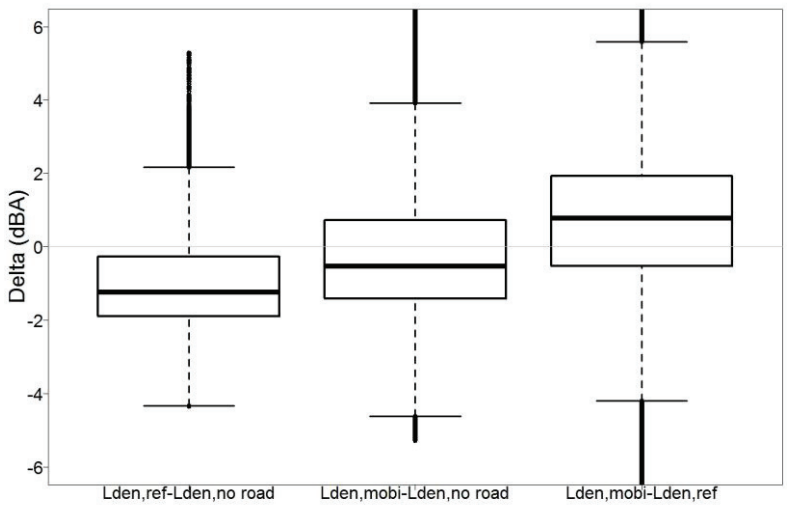

Figure 8 – Distributions of cell- based comparison between the noise maps.

Figure 9 presents the comparison between the $L_{den,ref}$ and $L_{den,mobi}$ maps. The offset is not adjusted. Areas in red represent higher immission level than expected from the pavement type databases.

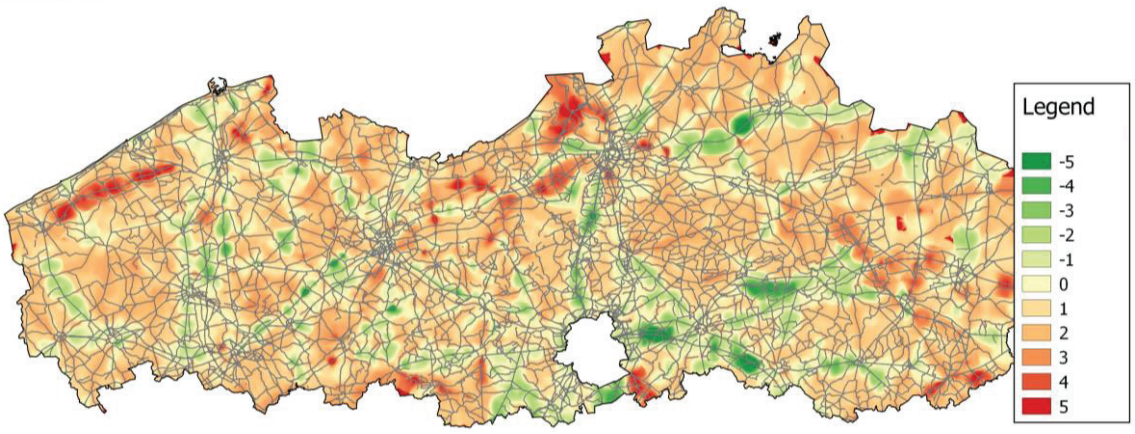

Figure 9 – Difference in effect on L_{den} between Mobisense and pavement database ($L_{den,mobi}$ - $L_{den,ref}$)

5. Discussion

The Mobisense opportunistic measurement method reveals the spatial variability of the road surface quality and its effect on rolling noise. It gives highly complementary information on the class of the road pavement with respect to rolling noise generation. Correlation with noise maps obtained by tuning the CNOSSOS model to road surfaces as retrieved from a road pavement inventory are rather low although the distribution of corrections peaks near slightly reduced immission for both approaches. Part of the discrepancy may be due to the lack of timely information on road pavements. But aging and damage due to intensive use, accidents, and local features such as bridges may contribute. The latter is even more pronounced for lower level roads owned by local authorities.

A calibration between Mobisense and the CNOSSOS-EU emission functions for reference road pavement will be necessary. Several options are under investigation. The strongest approach is to perform road-side measurements to align both methods. Third-party data (CPX and laser measurements of local road quality) have been linked to these outcomes to perform additional external validations.

6. Conclusions

The opportunistic sensing approach based on sensing noise and vibrations inside vehicles that or on the road for other purposes is very promising. The road surface corrections based on these measurements are complementary to data that can be retrieved from road pavement databases and standard corrections. Some road surfaces are under-performing compared to standard corrections, but others result in lower rolling noise than expected. These results support the overall goal of the mobisense methodology. The measurements can detect the deterioration of the road surfaces in a high spatial resolution. Overall, the Mobisense approach will add more value on the secondary road network where the quality of the pavement databases is expected to be low. Intervention on road quality can be guided by the opportunistic measurements and can become part of action plans. The local impact of road deterioration on the annoyance assessments and its potential relevance in health impact studies requires further investigations.

ACKNOWLEDGEMENTS

This work was performed within the framework of the ICON project MobiSense (grant No. HBC.2017.0155), supported by IMEC and Flanders Innovation & Entrepreneurship (Vlaio).

REFERENCES

1. K. Heutschi, E. Bühlmann and J. Oertli, “Options for reducing noise from roads and railway lines,” Transportation Research Part A: Policy and Practice, vol. 94, pp. 308-322, 2016.
2. David, J., Van Hauwermeiren, W., Dekoninck, L., De Pessemier, T., Joseph, W., Filipan, K., De Coensel, B., Botteldooren, D. and Martens, L. Rolling-noise-relevant classification of pavement based on opportunistic sound and vibration monitoring in cars, 48th International Congress and Exhibition on Noise Control Engineering (Inter.noise 48), Madrid, Spain, 16-19 June, (2019).
3. Wout Van Hauwermeiren, Joachim David, Luc Dekoninck, Toon De Pessemier, Wout Joseph, Dick Botteldooren, Luc Martens, Karlo Filipan, Bert De Coensel, "Assessing road pavement quality based on opportunistic in-car sound and vibration monitoring ", ICSV26 (2019).
4. J. Winroth, W. Kropp, C. Hoever, T. Beckenbauer and M. Männel, “Investigating generation mechanisms of tyre/road noise by speed exponent analysis,” *Applied Acoustics, 115, 101-108.,* vol. 115, pp. 101-108, 2017.
5. ISO 11819-2:2017, Acoustics -- Measurement of the influence of road surfaces on traffic noise -- Part 2: The close-proximity method
6. https://en.milieurapport.be/about-mira
7. Kephalopoulos, Stylianos, Marco Paviotti, and Fabienne Anfosso-Lédée. "Common noise assessment methods in Europe (CNOSSOS-EU)." Common noise assessment methods in Europe (CNOSSOS-EU) (2012): 180-p.
8. G. Licitra, L. Teti, M. Cerchiai and F. Bianco, “The influence of tyres on the use of the CPX method for evaluating the effectiveness of a noise mitigation action based on low-noise road surfaces.,” Transportation Research Part D: Transport and Environment, vol. 55, pp. 217-226, 2017.