

## Pavement Assessment Using On-Board Sound Intensity System

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**Abstract.** The purpose of this paper is to present an innovative method of measuring sound intensity called On-Board Sound Intensity on electric (EV) or hybrid electric vehicle (OBSIe). Typical sources of noise emitted by modern vehicles in urban areas are propulsion noise and noise generated at the tyre/pavement interface. Thinking of a future we can imagine cities full of silent, zero-emission cars. Propulsion noise becomes insignificant while tyre/pavement contact noise can still dominate in the urban, low-speed areas. Current methods of pavement noise measurements are not suited for the application in such scenarios and only partially eliminate the propulsion noise. Thus there is a need for research methods that can assess tyre/pavement noise at speeds lower than 50 km/h which is a threshold between propulsion noise and tyre/pavement noise. Our method developed at Road and Bridge Research Institute (IBDiM) in Poland is especially well suited to measure noise intensity in densely populated urban areas where vehicle transport generated noise is problematic. High manoeuvrability of a testing vehicle, quick installation and low cost are only some of the benefits of the OBSIe. An application of the OBSIe method to support sustainable development in the urban areas will be investigated in this paper.

**Keywords:** reducing noise, noise measurement, environmental sustainability, electric vehicle, safety.

**Conference topic:** Roads and railways.

### Introduction

Noise is characterised as a mix of different sound types, which is perceived unpleasant for human or in some cases can be harmful to physical conditions and health. Traffic noise is understood as a sound generated by passing cars, trucks, vehicles, planes, vessels, etc. The vehicle noise can be generated by different sources including propulsion noise, transmission noise, aerodynamic resistance noise or tyre pavement interaction. In conventional, internal combustion engine cars (ICE) most of the movement noise to a certain speed known as crossover speed is generated by propulsion. Above this speed tyre/pavement contact noise plays significant role in the overall vehicle generated noise. The crossover speed for passenger cars varies from 16 to 40 km/h and for trucks varies from 56 to 80 km/h during cruise speed and increases from 32 to 48 km/h for passenger cars and over 80 km/h for truck during acceleration. In modern hybrid-electric vehicles (HEV), electric vehicles (EV) or latest fuel-cell electric vehicles (FCEV) the propulsion and transmission noise becomes insignificant, so tyre-pavement interaction noise becomes dominant regardless the vehicle speed. It can be assumed that crossover speed is close to 0 km/h in this type of vehicle.

Reduction of traffic noise especially in urban areas should be a top priority for all planners, engineers and decision makers. Creating sustainable cities free of vehicle emissions and noise is the responsibility of transport researchers for the society at large. Currently, there are many methods dedicated to measure noise in more or less standardised manner. In this paper we will further describe the OBSIe method in details and the innovations and potentials it bears. We will shortly go over the calculation issues and we will conclude with benefits and future developments of the method and its specific application in sustainable development.

### Noise generation factors

Noise as already mentioned is a batch of different sounds with regards to soundwave length or frequency and sound level. The propagation of noise and its perception by humans is affected by different environmental factors including temperature, air pressure and humidity. Other factors such as obstacles, barriers or their surface type also play significant role. Different noise sources are even likely to decrease the overall noise perception, by interfering with each other destructively, resulting in the noise cancellation effect.

Researchers found several mechanisms of noise generation and amplification for pavement noise originating from tyres (Jacobsen, de Bree 2005; Vaitkus *et al.* 2014, 2016). This particular type of noise may be generated by:

- radial vibrations of tyre tread,
- air compressing and decompressing during wheel pass,
- tread tangential motion (referred to as “stick-slip”),
- breaking of adhesion of tread rubber to the pavement (called “stick-snap”).

Amplification mechanisms are responsible for noise emphasis and cannot be omitted in overall tyre/pavement noise generation analysis (Rasmussen *et al.* 2007). The following amplification mechanisms can be mentioned:

- horn amplification effect,
- radiation of resonant air (Helmholtz resonance),
- pipe resonances in channels formed in the tire footprint,
- tyre sidewall vibrations,
- cavity resonance in tyre tube.

All those factors result in the overall final noise during vehicle pass-by. It is difficult to isolate these factors from each other, but there exist methods for objective noise measurement.

## Description of the OBSIe method

### *Methodology*

Nowadays, there are a number of standardised noise measurement methods used in various parts of the world. Below is a short summary of those methods and also classification of the OBSIe method respectively.

1. SPB – Statistical Pass-By (overall noise method) – this method utilizes set of microphones located in a certain distance to evaluated road and vehicles; microphones register the overall noise generated by randomly passing vehicle, while the observer measures its actual speed; in this method the registered noise consist of the summary of noise generated by all mentioned noise sources or amplification methods. Different vehicles and different pavement types can be observed in this method; special conditions (distance to obstacles) should be ensured to conduct proper measurements.
2. CPB – Controlled Pass-By (overall noise method) – similar to SPB method, with the difference that passing vehicles are instructed to pass with the setup measurement speed; also particular vehicle types or pavements can be chosen for evaluation.
3. CPX – Close Proximity method (by source method) – method of evaluation of the tyre /pavement noise; this is a trailer method, where the set of microphones are mounted on a single wheeled trailer, attached to a measurement car; the trailer is designed with a special sound insulated cover which decreases bounced sounds and is generally designed to measure pure noise emission generated by the tyre and pavement interaction; different tyres or pavement types can be used for evaluation; this method is more popular in Europe.
4. OBSI – On-Board Sound Intensity method (by source method) – this method is similar to CPX method but there is no need of using special trailer; the pair of synchronised sound intensity probes (Trinth, 1993) is attached directly to the car wheel; measurement takes place during the car movement; no special sound insulation is used, so measurement can be affected by other vehicles, obstacles in close proximity or by noise generated by the testing vehicle itself. To, The crossover speed should be carefully controlled during testing to measure the tyre/pavement interaction noise; this method is more popular in the USA.
5. OBSIe – On-Board Sound Intensity on electric (EV) or hybrid electric (HEV) car (by source method) – this method is an evolution of OBSI method, so it does not utilize special trailer; a pair of synchronised sound intensity probes is attached directly to the electric car's wheel. Measurement takes place during the car movement and no special sound insulation is used. Measurement can be affected by other vehicles or obstacles in close surrounding but noise generated by the testing vehicle itself can be omitted or treated as unimportant. The tyre/pavement interaction noise can be measured from as low speeds as 10 km/h due to the crossover speed in this case being quite low. This method was first time presented by IBDiM, Poland in September 2015.

### *Detailed description of the OBSIe method*

The OBSIe noise measurement method is an easy and robust method and could be treated as an alternative to CPX method. This method is meant for conducting measurement at any speed but it is especially recommended for use in urban or low-speed areas, where the trailer methods would be inconvenient or even impossible to use. The OBSIe method provides an opportunity to be used in such scenarios as on historic pavements made of stone paving brick, concrete paving brick and other types of wearing courses, for example to decrease its noisiness by a paving technique or maintenance technology. It could also help to evaluate methods or technology of increasing noisiness of EH's, HEV's or FCEV's i.e. with special tyre technology or additional equipment installed on-board. The OBSIe method comprises the following elements:

- Two pairs of sound intensity probes with wheel hub mounting assembly (Fig. 1),
- Digital/Analog Converter,
- PC computer with registration and interpretation software,
- Wiring.



Fig. 1. Sound intensity probes mounted on wheel hub, calibration process in progress

The measuring set is mounted onto an EV, HEV or FCEV of which the plug-in HEV (PHEV) type would be most convenient or practical. Since EVs have only limited range to approximately 120 km in order to perform continuous measurements it needs to be transported by a car carrier. HEV's or PHEV's are able to drive in pure electric mode and if it can be activated by the driver, it would be a very convenient solution for carrying the OBSIe set (see Fig. 2).



Fig. 2. OBSIe measurement set installed on EV, BMW i3

The following activities should be performed before each measurement takes place:

- Sound probe calibration,
- Record of tyre rubber hardness, temperature and tyre pressure,
- Record of pavement temperature,
- Record of ambient temperature, humidity and pressure.

#### *Benefits of using the OBSIe method in urban areas*

The OBSIe method is cheaper and more energy efficient than any other available noise measuring methods. It does not require any trailer or special vehicle to have the set of microphones mounted on, it can be installed and operated virtually on any vehicle. Sustainable urban development requires green and eco-friendly design and planning solutions, thus this noise measuring method comes in handy. We are using an electric vehicle that is not producing any carbon footprint and yet does not cause any propulsion noise. While designing sustainable cities quiet pavements need to be

considered and this method helps measuring their noisiness and also can contribute to decision making process in terms of where the noise walls should be located and whether they are needed at all. Our method can also be used to determine transport noise in cities and urban areas especially in hard to access areas where an electric vehicle with noise measuring probes mounted can be deployed to collect measurements.

*Preliminary Results*

First tests of the OBSIe system were performed in real traffic conditions on several road test sections. These were asphalt and cement concrete wearing courses paved on roads located in Poland (motorway, rural and urban scenarios were tested). One of the test sites chosen was a stone paving brick on Krakowskie Przedmieście in old town Warsaw (see Fig. 3).



Fig. 3. Downtown Warsaw Noise Measurements with OBSIe

The preliminary test results showed that measurements can be conducted at speeds as low as 10 km/h. Unsurprisingly, stone paving brick was the loudest pavement type and generated equivalent noise levels as loud as at 10 or 20 km/h higher speeds for other pavements. The preliminary test results in discussion are presented in Figure 4.

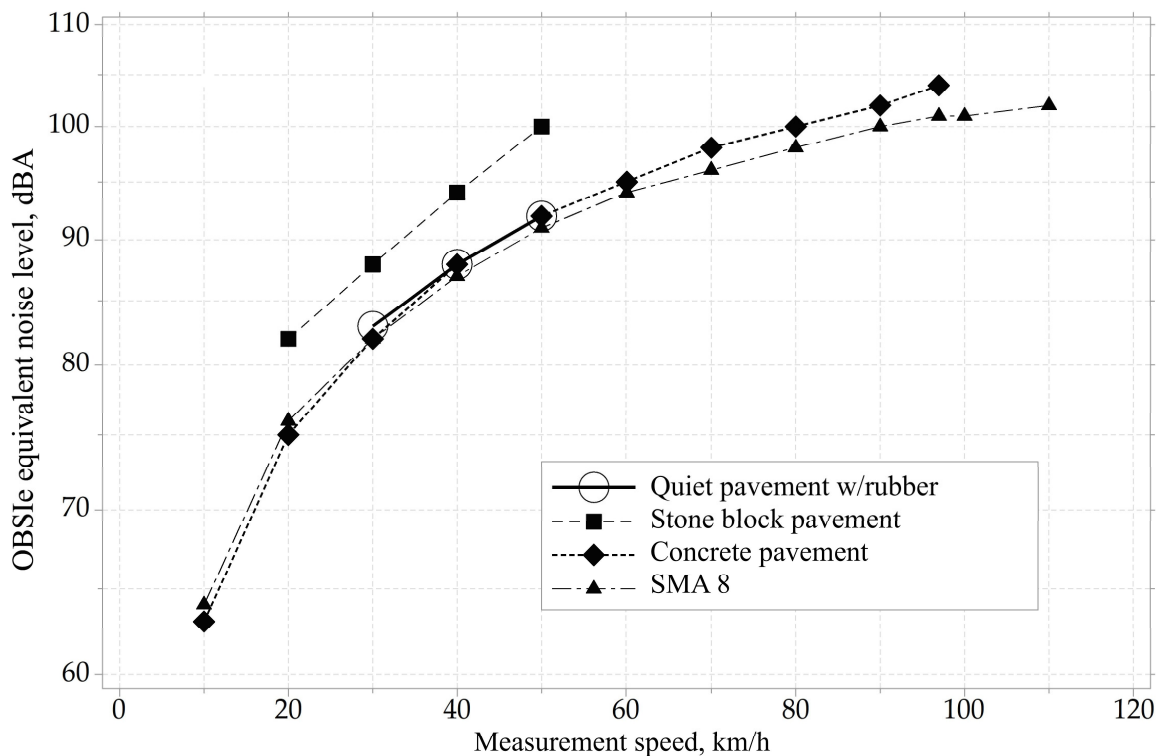


Fig. 4. Test results from OBSIe method

The preliminary results demonstrated our proof of concept where propulsion noise is eliminated due to usage of electric vehicles and that the porous and large graded pavements are much quieter than conventional asphalt and concrete pavements. Our results are as precise as results received from alternative methods such as CPX and thus can be used and further analysed towards acoustic properties of pavements including wave propagation phenomena. This study is being continued in the scope of The “RID – Noise”, new research project which has just started in January 2016 and will be continued for the duration of two years. IBDiM is involved as one of the partners in the project and will continue collecting data and then analysing the results which shall be available at the end of the project.

### Application of OBSIe in noise reduction

Noise pollution has long been recognised as affecting quality of life and well-being. Over past decades it has, in addition, increasingly been recognised as an important public health issue. According to a recent WHO report on the burden of disease from environmental noise (WHO 2014), at least 1 million healthy life years are lost every year in western Europe due to health effects arising from noise exposure to road traffic alone. WHO reports an onset of adverse health effects in humans exposed to noise levels at night above 50 dB and during a day above 55 dB (WHO 2009). Traffic generated noise in urban areas needs to be reduced to achieve balance and continuous sustainable development. Not only hot spots need to be identified but proper and economically proven solutions to noise measurement are needed. Fast and accurate measurements and targeting critical areas can contribute to policy and infrastructure changes towards noise reductions.

As mentioned above the OBSIe method gives an opportunity to evaluate some aspects related with the use of EV, HEV or FCEVs. These are amongst others:

- Tyre/pavement noise generation,
- Tyre construction and thread type,
- Intentionally generated sound signals outside the vehicle,
- Additional equipment helping or preventing noise generation.

### Conclusions

Traffic and in general transport generated noise in urban areas is a dilemma in many cities around the world because it affects human life and health. European Environment Agency (EEA 2014a, 2014b) reports that more than 100 mln people were exposed to road traffic noise (living inside and outside urban areas) above 55 dB. The same report states that almost 43 mln people living in urban areas were exposed to noise higher than 75dB. The vehicles that contribute more to road traffic noise are passenger cars and lorries, and less so buses and motorcycles. Based on the statistics presented above it is clear that increasing trend needs to stop. Thus roadway engineers have a difficult task to try and reduce at least the propulsion noise in the urban areas. We strongly believe that our innovative and cost effective method contributes to this incredibly difficult effort. Proper noise levels assessment and finding the correct noise generating media can contribute to creating the right solutions such as more aerodynamic vehicles, low noise pavements or sustainable noise blocking screens where applicable.

In the future research regarding OBSIe method we have extensive plans on performing analysis of not only noise generated outside the vehicle, but also to analyse noise inside the car, as regards different pavement types, different tyres or different measuring conditions. The detailed analysis will also include noise spectrum (Vorlander 2007), which means that different frequencies will be evaluated, not only the equivalent noise level.

### Funding

This paper was created as a part of the research project co-funded by the National Centre for Research and Development (NCBiR) and General Directorate for National Roads and Motorways (GDDKiA) [grant number: RIDI/76].



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