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Specific Air Pollution in Road Tunnels

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ABSTRACT: Negative effects of air pollution are, apart from the adverse effects on human health, also associated with damaging material goods which is manifested in e.g. the shorter service life of construction materials and faster material corrosion. Road tunnel environment is very specific since the emissions of passing vehicles are not dispersed into the surroundings and materials in the tunnel are thus immediately exposed to the pollutants produced by traffic. This paper presents the first results of measurements of specific air pollution in road tunnels of the project No TA01031043 "Quantification of specific pollution effect on materials and corrosion protection in tunnels". The total concentration of nitrogen oxides was higher in the first sampling campaign. Nitrogen dioxide concentration was higher in the second sampling campaign that corresponds to a higher traffic intensity. H_2S and SO_2 concentrations were almost similar in both campaigns. Higher $PM_{2.5}$ concentrations were measured in the second sampling campaign that corresponds to higher traffic intensity associated with higher fine particle emissions from combustion processes. Lower PM_{10} concentrations in the second sampling campaign were measured probably due to the conversion of some particles to a gaseous phase due to a higher temperature and humidity. The concentrations of all measured pollutants were typically changed in between local minimal values and local maximum values in relation to daytime, or traffic volume, respectively. The particle size distribution showed in both campaigns a dominant share of coarse PM fraction $PM_{2.5\text{-}10}$ but also its very high fluctuation in time. The highest share of coarse fraction was determined in the time of rush hours in the morning, as opposed to the lowest share during the night time.

KEYWORDS: Road tunnel, emission, nitrogen oxides, particulate matter.

1 INTRODUCTION

The negative effects of air pollution are, except for the adverse effects on human health, also associated with the damage of natural ecosystems, agricultural production and with the damage of material goods manifested in e.g. the shorter service life of construction materials and faster material corrosion. From this point of view, road tunnel environment is very specific since the emissions of passing vehicles are not dispersed to the surroundings and materials in the tunnel are thus immediately exposed to the pollutants produced by traffic which results in the fast degradation of materials, even those which should withstand these processes.

Only several measurements of air pollution in road tunnel have been performed in the Czech Republic. Measurements by Czech Hydrometeorological Institute using a measuring vehicle in the Letenský tunnel was performed in 1992 and by TESO Praha a.s. in the Strahovský tunnel in 2009 (Velíšek, 2010). More attention has been paid to road tunnel environment in other countries. Air pollution was monitored in different types of road tunnels generally in order to characterize the emission production by vehicles and for subsequent calculations of emission factors of different pollutants, for validation of different numerical models or for the assessment of exposure of persons in passing vehicles. Measurements were performed in road tunnels that are a component of the main road network in different cities such as Gothenburg (Barrefors, 1996), Stockholm (Kristensson et al., 2004), Vilnius (Valiulis et al., 2002), Vienna (Handler et al., 2008), Lisbon (Oliveira et al., 2011), Antwerp (Worobiec et al., 2011), Pittsburgh (Greishop et al., 2006), Houston (McGaughey et al., 2004), New York City (Lonneman et al., 1986), Sao Paolo (Sánchez-Ccoyllo et al., 2009), Hong Kong (Ho et al., 2009). Air pollution monitoring was also performed in several highway tunnels such as the Lundby tunnel in Sweden, the Plabutsch tunnel in Austria, the Gubrist tunnel in Switzerland (Hausberger et al., 2003; Colberg et al., 2005), the Grand Mare tunnel in France (Gouriou et al., 2004), the Wutong tunnel in China (He et al., 2006) or the Hsueh-shan tunnel in Taiwan (Ma et al., 2011).

Very few studies deal with other aspects of tunnel environment, including possible degradation and corrosion of materials. Song et al. (2005) characterized dust accumulated on tunnel walls and roof in tunnels in Hong Kong and Guangzhou in China. Similarly Lésniewska et al. (2004) analysed dust from city road tunnels in the Bialystok area in Poland, especially to determine the content of platinum group metals. Kurtenbach et al. (2001) demonstrated the heterogeneous formation of nitrous acid (HONO) on the walls of the Kiesberg highway tunnel in Wuppertal in Germany.

2 METHODS

The Mrázovka road tunnel is a component of the internal city ring in Prague and was chosen for the measurements of specific air pollution in this microenvironment. The Mrázovka tunnel is 1.260 m long with driving directions placed in separate tubes, each with two lanes. Traffic intensity in the tunnel part where the measurements were performed was in 2011 23.000 vehicles per 24 hours, of which 96 % were passenger cars. Sampling and measuring devices were placed in the breakdown lane where there was enough space for manipulating the devices during the full operation of the tunnel.

Pollutants concentrations measurements were performed during one week sampling campaigns to characterize week variability, both in emission composition and traffic flow. Separate campaigns were performed in different seasons to characterize also seasonal variations, especially in relation to winter road maintenance.

Several devices were used for measurements dependent on the character of the monitored pollutant. Particulate matter concentrations in fractions $PM_{2.5}$ and PM_{10} were determined discontinuously by gravimetric analysis on microbalances MX5 (Mettler–Toledo GmbH, Switzerland) after their capturing on nitrocellulose filters in 24 hour intervals by using middle volume samplers Leckel MVS6 (Sven Leckel Ingenierbüro GmbH, Germany). EnvironCheck 107 (Grimm Aerosol Technik GmbH & Co. KG, Germany) operating in continuous mode of measuring with 1 min. intervals of data logging was used for particle size distribution in fractions $PM_{1.0}$, $PM_{2.5}$ and PM_{10}. Concentrations of gaseous pollutants particularly O_3, NO_2, NO, NO_x, CO, CO_2, SO_2 and H_2S were measured continuously by the compact air quality monitoring system Airpointer (Recordum Messtechnik GmbH, Austria) with 1 min. intervals of data logging, except for SO_2 and H_2S which had 5 min. intervals of data logging.

Data evaluation and assessment was performed by using statistical software QC Expert (TriloByte, Czech Republic), NCSS (NCSS LLC USA) and R (The R Foundation for Statistical Computing, Austria).

3 RESULTS AND DISCUSSION

Mean week concentrations of measured pollutants summarized in Table 1 show differences between separate sampling campaigns. The small sample size of the dataset was the reason for the use of pivot half sum for mean of PM_{10} and $PM_{2.5}$ concentrations, means of the other parameter was calculated as pivot half sums (Horn, 1983).

Table 1: Means week concentrations of measured pollutants and other parameters.

Pollutant / Parameter	Measurement duration		Unit
	7. – 13. 12. 2011	6. – 12. 6. 2012	
O_3	5.98	2.92	$\mu g.m^{-3}$
NO_2	146.7	174.3	
NO	442.2	378.0	
NO_x	824.6	753.3	
CO	4.65	5.19	$mg.m^{-3}$
CO_2	764.3	777.4	
SO_2	6.79	3.09	$\mu g.m^{-3}$
H_2S	4.13	3.85	
$PM_{2.5}$	66.6	74.9	
PM_{10}	175.1	149.3	
Temperature	10.1	21.1	°C
Humidity	46.8	50.7	%
No. of cars	107 356	162 297	veh. / week

Ozone concentration was nearly two times higher in the first sampling campaign. The total concentration of nitrogen oxides was also higher in the first sampling campaign as the nitrogen monoxide concentration was higher although the traffic intensity was higher in the second sampling campaign. On the other hand, the nitrogen dioxide concentration was higher in the second sampling campaign which corresponds to higher traffic intensity. The lower concentration of nitrogen monoxide in the second sampling campaign could be caused by its faster conversion to nitrogen dioxide due to higher temperatures and humidity in the tunnel environment. A possible explanation is also the faster decay of nitrogen oxides due to heterogeneous formation of nitrous acid (HONO) and nitric acid (HNO_3) on the tunnel walls or with the reaction of nitrogen oxides with air humidity in the presence of heated soot particles, although this process was described rather for the reaction of NO_2 (Kurtenbach et al., 2001). In the second campaign, it also corresponds to a lower ozone content. Concentrations of carbon dioxide and carbon monoxide were somewhat higher in the second sampling campaign reflecting higher traffic intensity associated with higher carbon oxides emissions. H_2S and SO_2 concentrations were higher in first campaign, as in the case of NO_x. Both PM_{10} and PM_{10} concentrations differences between the 1st and 2nd campaigns respectively were not statistically significant.

All differences between the concentrations of pollutants and other parameters except for PM were statistically significant (see Table 2) on level alpha=0.05 (i.e. with 95% probability variances are different from zero), as no confidence interval (CI) except for PM contains zero. The small sample size of dataset was the reason for the use of a pivot half sum for the means of PM_{10} and $PM_{2.5}$ concentrations differences.

Table 2: 95% CI of medians and pivot half sums (*) of differences between concentrations of measured pollutants and other parameters in 2nd and 1st campaign (units are the same as in Table 1).

Difference: 2nd-1st campaign	Mean	CI Lower Bound	CI Upper Bound
D_O3	-2.94	-3.02	-2.85
D_NO2	24.4	23.2	25.6
D_NO	-62.3	-66.6	-58.0
D_NOx	-68.0	-75.0	-61.0
D_CO	0.682	0.664	0.701
D_CO_2	8.11	6.39	9.82
D_SO2	-3.54	-3.63	-3.44
D_H_2S	-0.154	-0.207	-0.100
D_PM_{10}*	-19.9	-62.1	22.3
D_$PM_{2.5}$*	8.23	-11-5	28.0
D_T	10.8	10.7	10.9
D_RH	6.30	6.00	6.60

The concentrations of all measured pollutants were typically changed in between local minimal values and local maximum values in relation to daytime, or traffic volume, respectively. These values correspond to night time resp. day time. No more than 10 cars in a five minute interval passed through the tunnel part at night while the highest traffic intensity (from 30 up to 120 cars in five minutes interval) was between 6:45 to 10:00 AM.

The following graphs present the trends of one hour mean concentrations of separate pollutants within both sampling periods. Figure 1 presents the trends of nitrogen oxides concentrations. The minimum values of these pollutants concentrations were identified in both campaigns between Saturday midnight and 5 AM on Sunday morning. These very low concentrations compared to others correspond to the lowest traffic intensity during the whole campaign. Only 8 vehicles passed through the tunnel section during the period from Saturday midnight (10.12.2011) to Sunday morning 5 AM (11.12.2012). In general, nitrogen oxides concentrations were lower during weekend days when compared to working days. The highest concentrations were measured in both campaigns on Monday and Tuesday when NO_x concentrations achieved a range between 1520 $\mu g.m^{-3}$ and 900 $\mu g.m^{-3}$.

Similar trends were also identified for sulfur compounds (SO_2 a H_2S) in the 1st campaign with the minimal concentrations between Saturday midnight and 5 AM on Sunday morning and maximum concentrations on Monday and Tuesday (Figure 2). More significant variations of concentrations were measured during the 2nd campaign but it was also possible to determine the minimum values in the same time period.

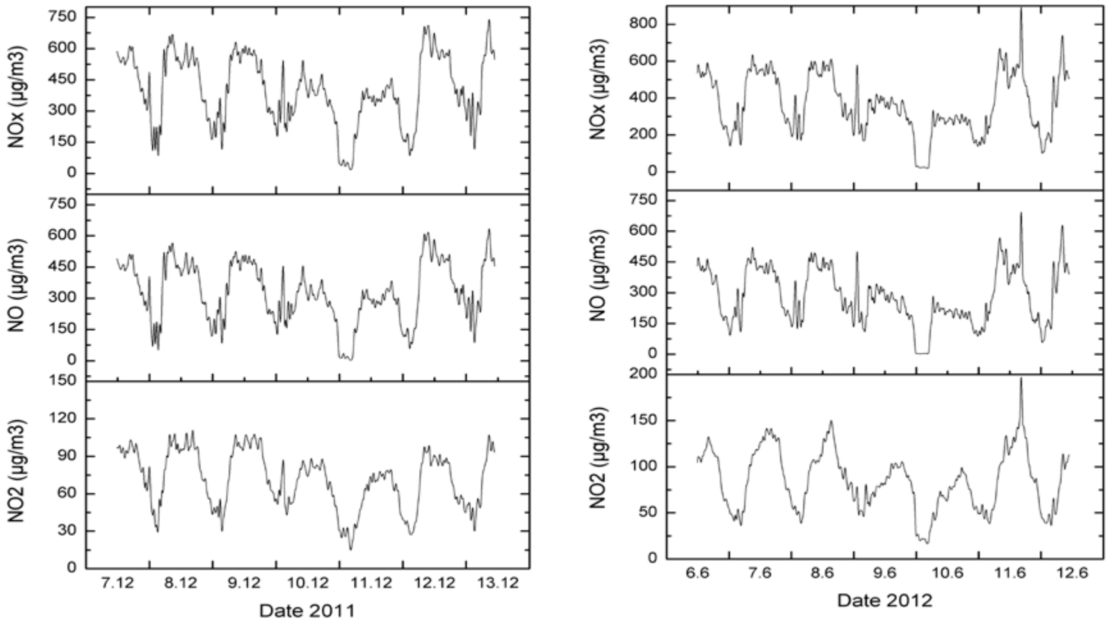

Figure 1: Nitrogen oxides concentrations progress (1st sampling campaign on the left, 2nd sampling campaign on the right graph).

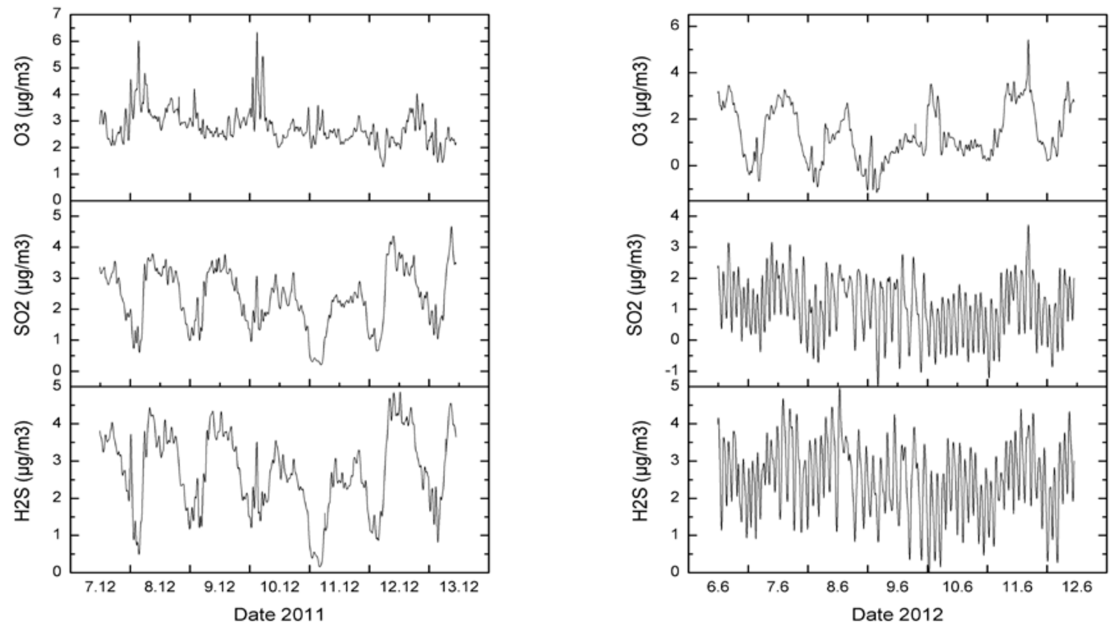

Figure 2: Sulphur dioxide, hydrogen sulphide and ozone concentrations progress (1st sampling campaign on the left, 2nd sampling campaign on the right graph).

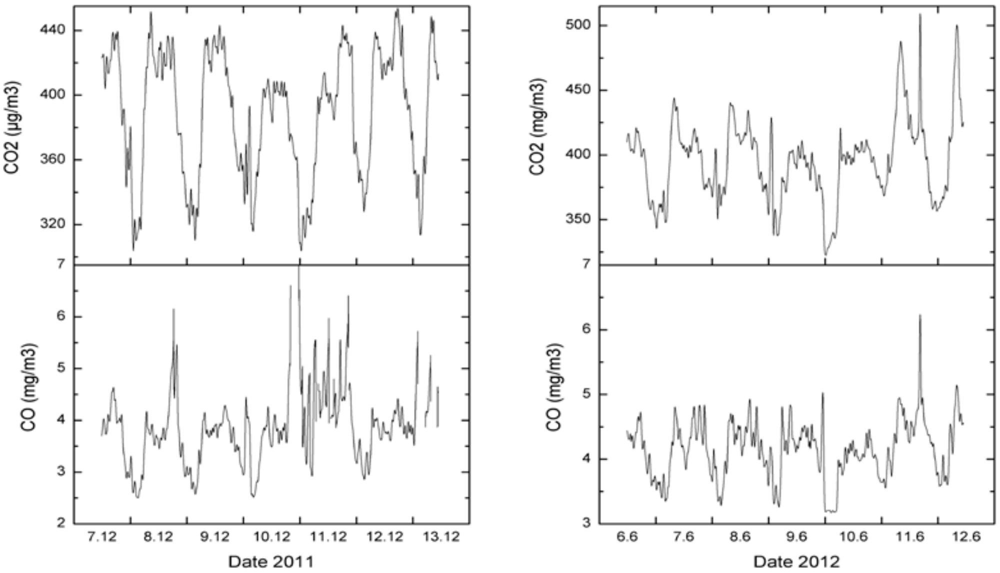

Figure 3: Carbon oxides concentrations progress (1st sampling campaign on the left, 2nd sampling campaign on the right graph).

Similar trends were also determined for carbon oxides with the minimal concentrations between Saturday midnight and 5 AM on Sunday morning and maximum concentrations on Monday and Tuesday (Figure 3). However, there was a significant difference between the separate campaigns since the concentrations in the 2nd campaign were somewhat higher.

The following graphs in (Figure 4) present the continual measurements of particles size distribution. In general, particle size distribution showed in both campaigns a dominant share of coarse PM fraction $PM_{2.5\text{-}10}$ but also a very high fluctuation over time. The highest share of coarse fraction was determined during the time of rush hour in the morning; on the other hand the lowest share was during the night time. These high shares of coarse PM fractions during rush hours could be caused by the resuspension of road dust from the road surface or its proximity due to the movement of a higher number of vehicles. Smaller differences were determined for fine particulate matter fraction ($PM_{2.5}$ and smaller) that are produced mostly by fuel combustion in vehicle engines. Nevertheless, the graphs showed higher concentrations of this particle fraction also during the rush hours.

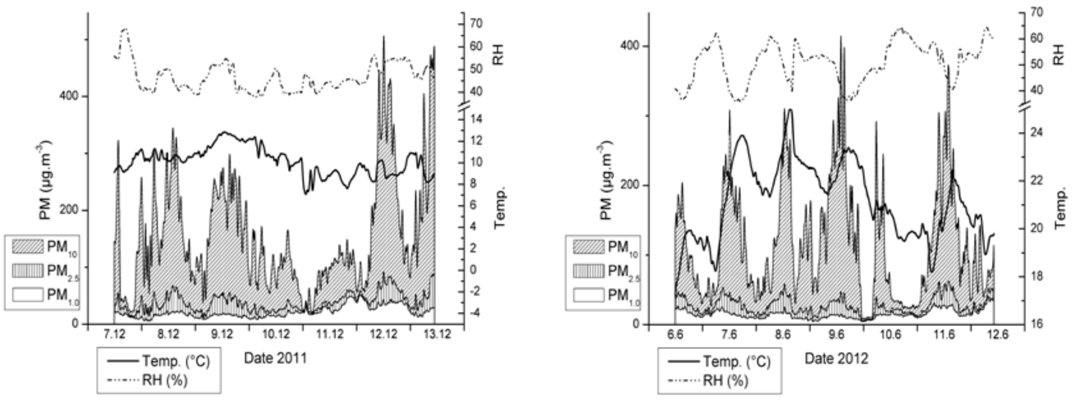

Figure 4: Particle size distribution (1st sampling campaign on the left, 2nd sampling campaign on the right graph).

Measured PM_{10} concentrations were in very good agreement with the measurements in the road tunnel with nearly the same traffic intensity in Taiwan (Ma et al., 2011) and were slightly higher than in the road tunnel in Vienna (Laschober et al., 2004). $PM_{2.5}$ concentrations were in accordance with those measured in the road tunnel in Antwerp (Worobiec et al., 2011). On the other hand, concentrations of CO and NO_x were in this presented study 15 times lower compared to concentrations in the road tunnel in New York City (Lonneman et al., 1986). Such a big difference is probably either due to nearly 5 times higher traffic intensity or due to the worse quality of fuel in the 80`s and different types of engines with higher emissions of pollutants. The same causes could be the reason for nearly four times lower fine particles concentrations than those measured in 1993 in a freeway tunnel near Zürich (Weingartner et al., 1997). Nevertheless, the measured CO, SO2 and NO_x concentrations in the road tunnel Mrázovka are also nearly an order of magnitude lower compared to concentrations of gasses in the road tunnel in Taiwan (Ma et al., 2011) with nearly the same traffic intensity. However, the dominant compound in NO_x is NO in both studies. Chow and Chen (2003) measured CO and NO_2 concentrations in 11 road tunnels in Hong Kong and adjacent areas. The measured concentrations (ranging between 7.5 $\mu g.m^{-3}$ and 50 $\mu g.m^{-3}$ for CO and between 657 $\mu g.m^{-3}$ and 1561 $\mu g.m^{-3}$ for NO_2) were higher, but this comparison could be questionable because of the different methodology used for concentrations measurements since concentrations were measured in passing vehicle with opened windows.

4 CONCLUSIONS

All differences between mean concentrations in both the 1st and 2nd campaigns except for PM were statistically significant. The total concentration of nitrogen oxides was higher in the first sampling campaign although the traffic intensity was higher in the second sampling campaign. On the other hand, nitrogen dioxide concentration was higher in the second sampling campaign which corresponds to the higher traffic intensity. The lower concentration of nitrogen oxide in the second sampling campaign could have been caused by its faster conversion to nitrogen dioxide due to higher temperatures and humidity in the tunnel environment. Another possible explanation is also the faster decay of nitrogen oxides due to heterogeneous formation of nitrous acid (HONO) and nitric acid (HNO_3) on the tunnel walls or by the reaction of nitrogen oxides with air humidity in the presence of heated soot particles.

H_2S and SO_2 concentrations were somewhat lower in the 2nd campaign, probably due to faster oxidation due to the higher temperature, similarly to the case of nitrogen oxides.

The concentrations of all measured pollutants were typically changed in between local minimal values and local maximum values in relation to daytime, or traffic volume, respectively. These values correspond to night time resp. day time.

Particle size distribution in both campaigns showed a dominant share of coarse PM fraction $PM_{2.5\text{-}10}$ but also a very high fluctuation over time. The highest share of coarse fraction was determined in the time of rush hour in the morning, on the other hand the lowest share was during the night. These high shares of coarse PM fractions during rush hours could be caused by resuspension of road dust from the road surface or its proximity due to the movement of a higher number of vehicles.

Data with pollutants concentrations and the ratios between them are being used to define conditions in accelerated degradation tests of several materials under laboratory conditions.

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Measurement of Noise from Road Surface Using Dynamic Method

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ABSTRACT: Road transport has been the dominant source of noise in the environment for many years and most of the noise is nowadays generated by the interaction of the tyre with the road, beginning with relatively low speeds. The condition of the road wearing course is the factor that particularly influences the noise pollution generated by the movement of vehicles on roads. The CPX method (CloseProXimity) used for measuring the amount of noise from the rolling of tyres consists of drawing a special trailer fitted with reference test tyres that are surrounded by microphones recording the noise generated by the rolling tyres along a test section. This dynamic method allows the evaluation the noise from the road surface in the field for the full length of the examined road section. It can be performed during the normal operation of the road with no need for traffic restrictions. Monitoring and early exchange of road surface can significantly contribute to the sustainable development of transport and a reduction of its negative impacts on the environment and human health thanks to the effective reduction of the excessive noise from road traffic. This paper presents the process of field measuring tests with a subsequent evaluation of results.

KEY WORDS: CPX method, road-noise measurement, tyre/pavement, road-noise reduction.

1 CPX METHOD

The CPX method is described in detail in the draft standard ISO/CD 11819-2 - Acoustics – Method for measuring the influence of road surfaces on traffic noise – Part 2: The Close Proximity method, 2000. Measurements are performed with the intention to determine the noise produced at the tyre/road interface at one or more reference speeds – 40, 50, 80, and 100 km/h. The method gives a good estimate of the acoustic characteristics of road surfaces. It can be used to study the homogeneity of road surfaces over long distances and under different conditions, or monitor the road maintenance so as to assure its efficiency (Ongel et al., 2008; Paje et al., 2010). The advantage of assessing the tyre performance using this method is that the influence of other sources of noise, such as the engine noise and the noise from exhausts, is reduced to a minimum (Wong et al., 2009).

1.1 Equipment for measurement using CPX

For the actual measurement, the Tigerpaw Uniroyal 225/60 R16 SRTT tyre is used all over the world as the reference tyre. Five measuring microphones connected to a suitable noise analyzer are placed at a height of 0.1 m and 0.2 m above the road surface at a distance of 0.2 m and 0.65 m from the tyre/road surface interface, exactly according to the relevant standard (ISO/CD 11819-2), see Figure 1. For the measurement, a specially designed trailer pulled behind a car is used (Křivánek & Cholava, 2010; Křivánek et al., 2012) see Figure 2. This equipment needs to meet strict requirements, which are described in detail in the draft standard ISO/CD 11819-2 (e.g. the measurement must not be influenced by other vehicle parts, permanent position of microphones, absence of reflecting surfaces, dimensions, load, etc.).

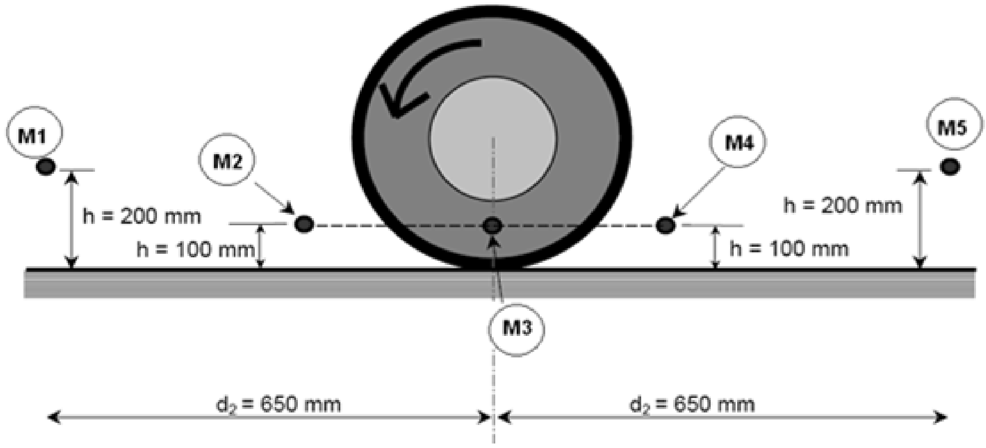


Figure 1: Location of individual measurement microphones on CPX trailer.

The measurement using the CPX method does not depend on the density of the surrounding traffic flow. However, it is very helpful if the traffic flow density at the time of measurement is as low as possible, allowing a constant speed to be easily maintained on the measured road section. Measurements can be performed only on completely dry roads, due both to the requirements of the relevant standard and economic reasons, as in the case of a wet road surface the very sensitive measuring microphones fitted only at the minimum height from the road surface (0.1 and 0.2 m) could be damaged or destroyed. There is therefore a limited number of suitable terms when this measurement can be performed – it must not rain at least two days prior to the measurement at the locality in question (the road is dry), wind speed does not exceed 5 m/s and the air temperature is higher than 5° C.

Figure 2: Placement of individual measurement microphones on CPX trailer.

As according to the last CPX draft standards it is very important to monitor the speed and the ambient temperature (Anfonsoo & Pichaud, 2007; Křivánek et al., 2012) to implement the speed and temperature corrections to the relevant reference values. We use devices shown in Figure 3 that are connected to the measuring laptop. The measured data (noise at the tyre/road surface interface, air temperature, speed of the measurement system, and its position) are fully synchronized, allowing the measured places to be accurately located together with the specific velocity of the measuring system at a particular place, and the surface temperature, which is important for possible correction of the measured values to a constant reference velocity (40, 50, 80, or 100 km/h) and the reference temperature (20° C). During the actual measurement it is suitable to use the cruise control in the vehicle, so as to keep the speed during the measurement as constant as possible and as close to one of the reference velocities as possible.

Figure 3: Non-contact infra-red temperature sensor CALEX and GPS module.

2 PROCESS OF MEASUREMENT WITH CPX METHOD

At an appropriate place – most often a parking place – before the measured section a final preparation phase for the actual measurement is accomplished, when individual microphones are set up in their particular positions desired for the measurement. Particular fastening clamps and the tightening nut for the fastening of microphones are then tightened so as to prevent the change of their position during the measurement. Cables are connected to individual microphones and at several places attached with the use of mounting strips. Microphones are fitted with protective caps that are also firmly attached by pieces of elastic bandages, which hold the protective caps of microphones in place during the measurement without compromising the recorded acoustic situation.

After making the final adjustments the vehicle can move towards the section to be measured. The measurement recording devices are switched on prior to reaching the measured section as the measuring van reaches the desired measuring speed and cruise control is put in action. The measured road is driven in regular traffic conditions. Microphones are unidirectional and are placed at a very small distance from the measured tyre that emits a loud noise which is recorded. For this reason the influence of the surrounding traffic on the acoustic situation recorded by microphones (the sources of which are at least at ten times a greater distance) are negligible – the distance from individual other sources of noise is large enough (Cho & Mun, 2008).

As the vehicle attains the desired speed and enters the measured section, the operator starts the measurement by switching on all five microphones. If the beginning of the analyzed road section or reaching the desired speed is different from the start of the measurement, the operator makes a verbal mark with an additional microphone or inserts a "mark" into the measurement record. This allows measuring also on consecutive sections of roads.

There are two basic options for the recording of the measurements: storing a raw signal or storing analyzed variables (one-third-octave characteristics, course of the level, etc.). Since these measurements have an influence on the human organism, all measurements are adjusted with an A-weighting filter. In accordance with standards IEC 61260 and ISO/CD 11819-2, the measurement or analysis is performed in the one-third octave frequency range from 315 Hz to 5 kHz (Cho & Mun, 2008). By averaging all measured values from all measuring microphones we get the corresponding value of the equivalent level of acoustic pressure, and one-third-octave characteristics of the acoustic pressure when using an A-filter for the given segment of the measured road surface.

2.1 Example of evaluation of the measurement record

Storing the raw signal from the measurement has the advantage of having the possibility to process the results at ease at any time after the measurement and, moreover, it is possible to change the parameters of the raw signal that we want to analyze. A partial selection of one segment of the raw signal from the stored record is shown in Figure 4, where the bottom part of the figure shows a closer detail of the analyzed section that was selected for analysis.

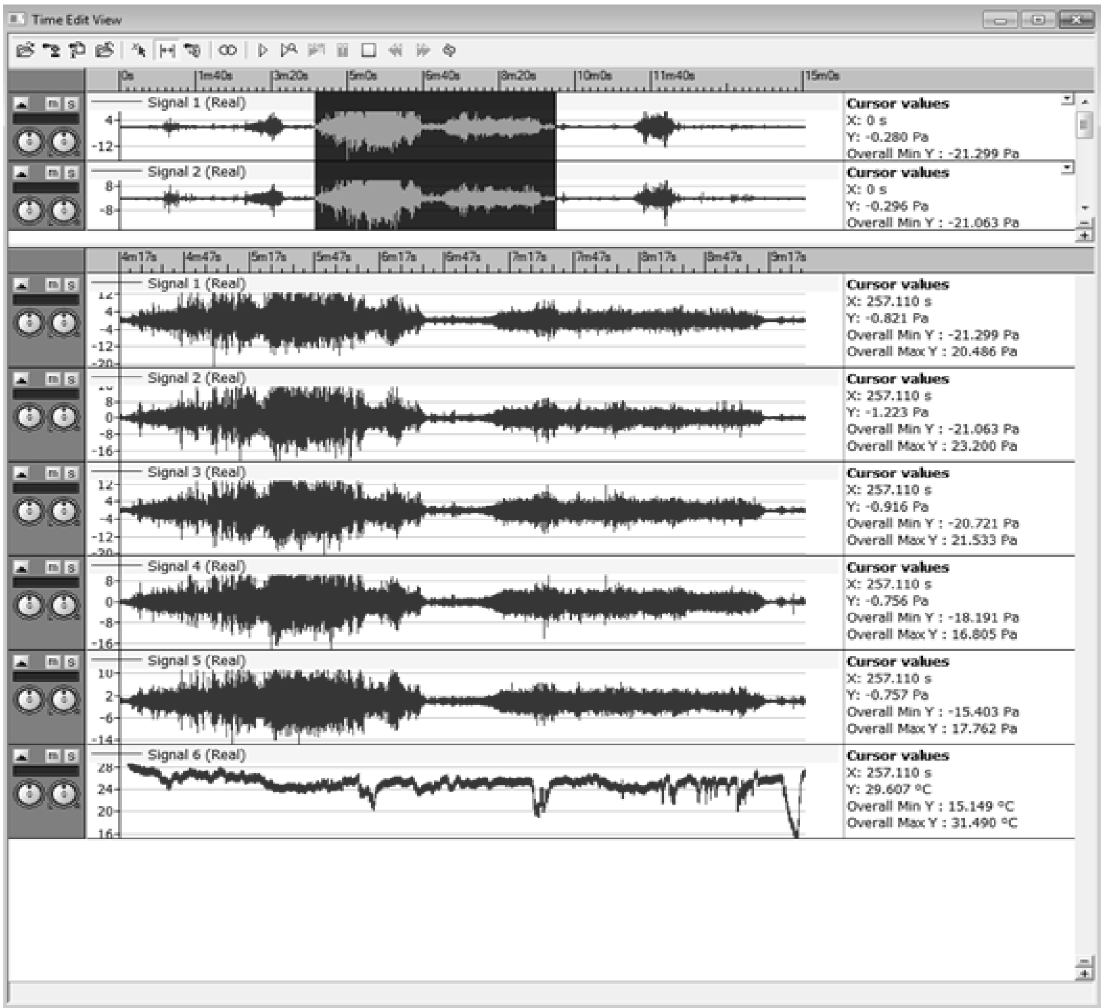
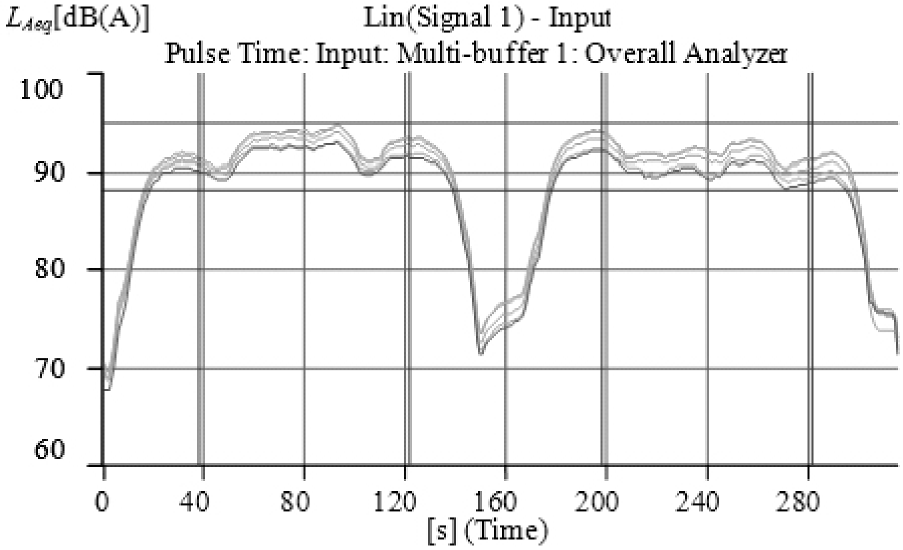
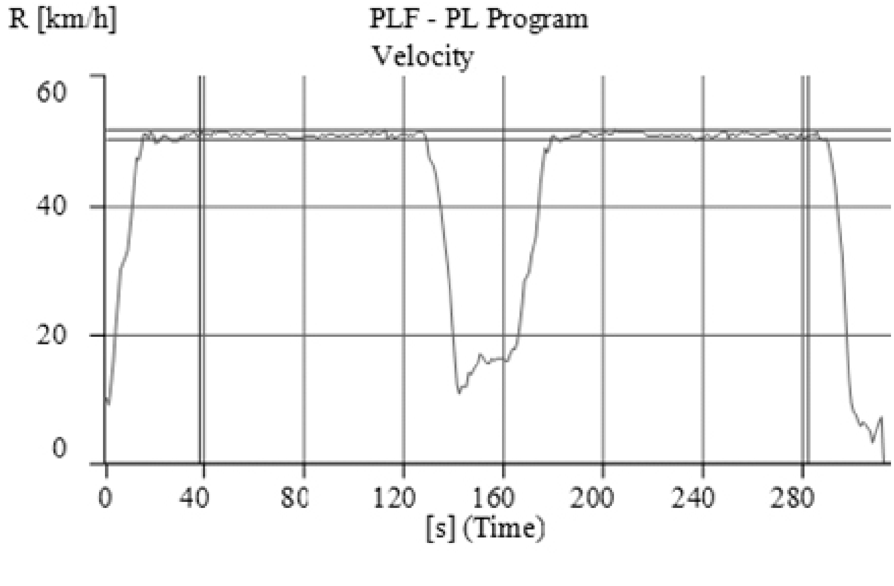


Figure 4: Saved record of the raw signal for 5 measurement channels and a temperature sensor, with a cut selected for analysis.

In the relevant software environment for the analysis of the measurements (in our case, the software Pulse 16.1) it is necessary to define what kind of parameters should be evaluated. Concerning the noise at the tyre/road surface interface we are particularly interested in the dependence of noise on time (first part of Figure 5), which allows the noise generated from road surfaces in the field to be evaluated in their full length. Figure 5 illustrates the measurement on two consecutive road sections of approximately equal length (on the relative time axis it corresponds to about 40 – 120 s and 200 – 280 s of the record of the selected partial segment of raw signal) at a speed of 50 km/h (middle of the figure) and a temperature of about 23 to 26° C (the third, lowest part in Figure 5). For an ordinary comparison, to find places in which the road surface is noisier, it is not necessary to make temperature corrections since the reference velocity of 50 km/h was maintained for the whole length of the measured sections, and there is a low variability of the surface temperature at the given places, but if the results will be used for comparing the noise emitted from different types of surfaces with different characteristics and from different places, it may be necessary to make corrections of the upper part of Figure 5 for temperature variations from the bottom part of the same figure so that the equivalent level of noise corresponds to the reference temperature of 20° C.





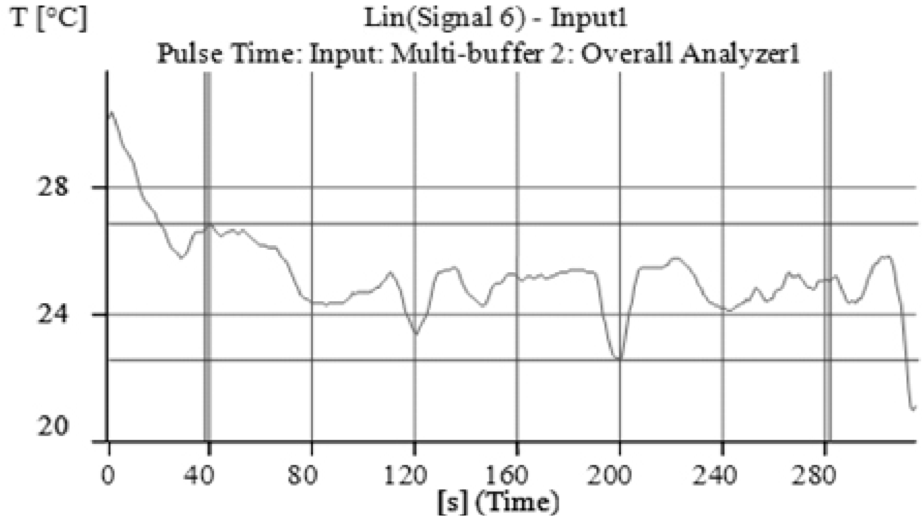


Figure 5: Equivalent noise levels, speed and temperature on a selected section on synchronized timeline.

3 CONCLUSION

This paper discusses the dynamic method where the measurement consists of the assessment of noise emitted from the whole length of road on the basis of special reference tyres by CPX method. CDV within the projects “Change of noise from road surfaces over several years of use” (Křivánek et al., 2012) and “Transportation R&D Centre” further innovated, improved and optimized the trailer they designed for measurement with the CPX method – the only device in the CZ for noise measurement using the CPX method. The paper describes the basic measuring equipment used that also allows the fitting of additional devices for the synchronous measuring of other important parameters.

The CPX method gives a good estimation of the acoustic properties of road surfaces. Traffic noise is currently one of the most discussed topics; it affects a large number of people, and thus there are efforts to reduce noise in the vicinity of roads. The construction of road wearing courses and road surfaces with reduced noise emissions allow for noise reductions right at the interface of a tyre with the road surface (Dürr et al., 2011; Plitz & Švadlák, 2011; Sýkora et al., 2010; Valentin & Mondschein, 2010) which can be clearly assessed through the use of the CPX method. Furthermore, it can be used to study the homogeneity of road surfaces over long distances and under different conditions, or to monitor maintenance and assess its effectiveness (Kašpar & Bureš, 2011; Kudrna et al., 2011; Stoklásek, 2010) - noise testing and confrontation with the requirements specified in tender documents, monitoring of the acoustic behaviour of the road over several years of use.

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Noise Impact on Inhabitants in Residential Areas under Various Anti-Noise Measures

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ABSTRACT: The sound environment is an inseparable part of the living environment. Noise is generally considered to be any sound or sounds which are undesirable, disturbing or harmful to people. Road transport has been the dominant source of noise in the environment for a number of years. Traffic noise modelling is used particularly for assessing the acoustic situation in the vicinity of roads, the identification of noise impact on population, designing anti-noise measures, strategic noise mapping, and action plans.

Regarding noise impact within the assessment of sustainable transport development, the programme SoundPLAN assessed different types of noise impact on inhabitants in residential areas through the use of alternatives such as the reduction of vehicle speed, construction of anti-noise barriers, installation of low-noise road surface, and various combinations of these. For the production of noise maps, input data was combined with geographic data or map materials respectively, data on buildings, roads, inhabitants, and traffic data.

The article presents the results of calculations of equivalent levels of acoustic pressure together with the division of impact on population into individual zones. Calculations are simulated on a terrain model of a part of the residential area surrounded by a busy trunk road and for the daytime. The residential area consists of detached houses and blocks of flats with a maximum height of 5 floors with the usual community amenities – garages, small shops, etc. Therefore, the application of simulated anti-noise measures may lead to a reduction of the negative impacts on the environment as well as on human health.

KEY WORDS: Anti-noise measures, road noise impact on inhabitants, SoundPLAN.

1 INTRODUCTION

On the topic of the noise impact within the assessment of sustainable transport development, the programme SoundPLAN assessed different types of noise impact on inhabitants in urban areas under such alternatives as the reduction of vehicle speed (Striegler et al., 2009), construction of anti-noise barriers, installation of low-noise road surface (Křivánek et al., 2012), and various combinations of these. For the production of noise maps, the input data was combined with geographic data or map materials respectively, data on buildings, roads, inhabitants, and traffic data.

2 CALCULATION SOFTWARE SOUNDPLAN

Traffic noise modelling is particularly used for: assessing the acoustic situation in the vicinity of roads, identification of noise impact on inhabitants, designing anti-noise measures, strategic noise mapping, and action plans.

The software is produced by Braunstein+Berndt GmbH; its use for acoustic calculation was approved by the National Reference Laboratory for communal noise at the Hygienic Station in Ústí nad Orlicí in July 1997. This software allows the modelling of the assessed area according to the current situation and the calculation of an isophone field in accordance with the given traffic technology (Braunstein+Berndt GmbH, 2008). After running the software, several modules of options are offered, see Figure 1.

Figure 1: SoundPLAN manager after opening.

2.1 Input data

- Geographic data or mapping materials:
  - topography and altimetry;
  - orthophotomap.

- Information about buildings:
  - position of buildings;
  - ground plan, height of buildings and number of floors.

- Data on roads:
  - routes of roads and railways;
  - road, railway profile;
  - type of road surface, rail track structure;
  - bridges, tunnels, etc.

- Data on inhabitants:
  - number of inhabitants in the monitored area is mentioned;
  - number of inhabitants per one address point, average number of inhabitants per one address point, etc.

- Data on industrial noise sources:
  - location and parameters of noise sources.

- Traffic data:
  - 24-hour traffic volume, train lengths, number of take-offs and landings of airplanes;
  - time division of traffic volumes into daytime (6 - 22 h) and night time (22 - 6 h);
  - composition of traffic flow – types of vehicles, trains, airplanes;
  - travel speeds in different road segments.

2.2 Output data

The output consists of data assessment providing summarizing overviews of the outdoor noise from road traffic and industry in a monitored area which can be used as material for the preparation of land-use planning documentation, or for informing the public on the condition of the environment. In compliance with the current legislation, the only binding descriptor to describe the condition of the acoustic situation in a certain area is the equivalent level of acoustic pressure *A* (L_{Aeq}) (Act no. 272/2011 Sb.; Act no. 258/2000 Sb.).

2.3 Noise modeling

The accuracy of the calculation results is particularly based on the accuracy and quality of the input data. It needs to be taken into account that any calculation software is just a powerful tool for the modelling of an acoustic situation. The accuracy of the calculation of noise maps is limited by the geographic accuracy of commonly available mapping materials and other input data (FEHRL, 2008). Regarding the digital mapping model ZABAGED 1 : 10 000, the root mean square error (root mean square error not the maximum deviation) for points clearly identifiable in terrain (railways, roads, buildings, etc.) is estimated at approx. 5 m. The impact of other changes of basic input parameters of calculations on emission values L_{Aeq} is shown in Table 1 (Ládyš et al., 2006).

In order for the calculation method or the software product used for the calculation of noise in an area to be acceptable, the calculations need to show the results in the same accuracy level as can be attained through field measurements (Methodological guidance of the measurement and evaluation of noise in an out-working environment, 2001). The difference of value L_{Aeq} from the conventionally correct value L_{Aeq} should not exceed 2 dB, i.e. the total uncertainty of the calculation model +/- 2 dB. With the approved methodologies for calculations for individual types of noise it is possible to reach this value on the basis of a sufficient precision of the input data.

Table 1: Value of the next error of noise map calculation on the basis of inaccurate input data (Ládyš et al., 2006).

Calculation input	**Input change**	**Value change L_{Aeq}**
Traffic volume	+/- 10%	+/- 0.4 dB
Traffic flow composition	+/- 5% NA	+/- 0.5 dB
Traffic flow speed	+/- 10%	+/- 0.8 dB
Road alignment	+/- 1 % (both ways)	+/- 0.3 dB
Surface type	Ac (F3 = 1.1)	+/- 0.4 dB

2.4 Alternatives of calculation of equivalent noise levels and impact on population

Calculations of equivalent noise levels, whose source is only road traffic in urban areas, and the impact on the population at a certain level of exposition, were performed for the following situations during the daytime:

Speed reduction alternative:

- 1A) Calculation of the "current situation" – all roads speed 50 km/h;
- 1B) Calculation of the "current situation" – trunk roads 50 km/h, urban roads speed 30 km/h;
- 1C) Calculation of the "current situation" without traffic on trunk road – speed 50 km/h;
- 1D) Calculation of the "current situation" without traffic on trunk road – speed 30 km/h.

Alternative with low-noise surface:

- 2A) Calculation of the "current situation" with installed low-noise surface on trunk road – all roads speed 50 km/h;
- 2B) Calculation of the "current situation" with installed low-noise surface on trunk road – trunk road 50 km/h, urban road 30 km/h;
- 2C) Calculation of the "current situation" with installed low-noise surface on all roads – all roads speed 50 km/h;
- 2D) Calculation of the "current situation" with installed low-noise surface on all roads without traffic on trunk road – speed 50 km/h.

Alternative with an anti-noise barrier (3 m height):

- 3A) Calculation of the "current situation" with an anti-noise barrier along trunk road – all roads speed 50 km/h;
- 3B) Calculation of the "current situation" with an anti-noise barrier along trunk road – trunk road 50 km/h, urban road speed 30 km/h.

To calculate noise maps and the overall noise impact on the population for the "current situation" in the model area in SoundPLAN software, the hourly traffic volumes during the day in accordance with Figure 2 were used. The calculation is simulated on a model area surrounded by a busy trunk road. The urban area consists of detached houses and blocks of flats with a maximum height of 5 floors with the usual community amenities – garages, small shops, etc. The assessment concerns just the noise from car traffic, no other impacts are considered (railway noise, industrial noise, household noise, etc.).

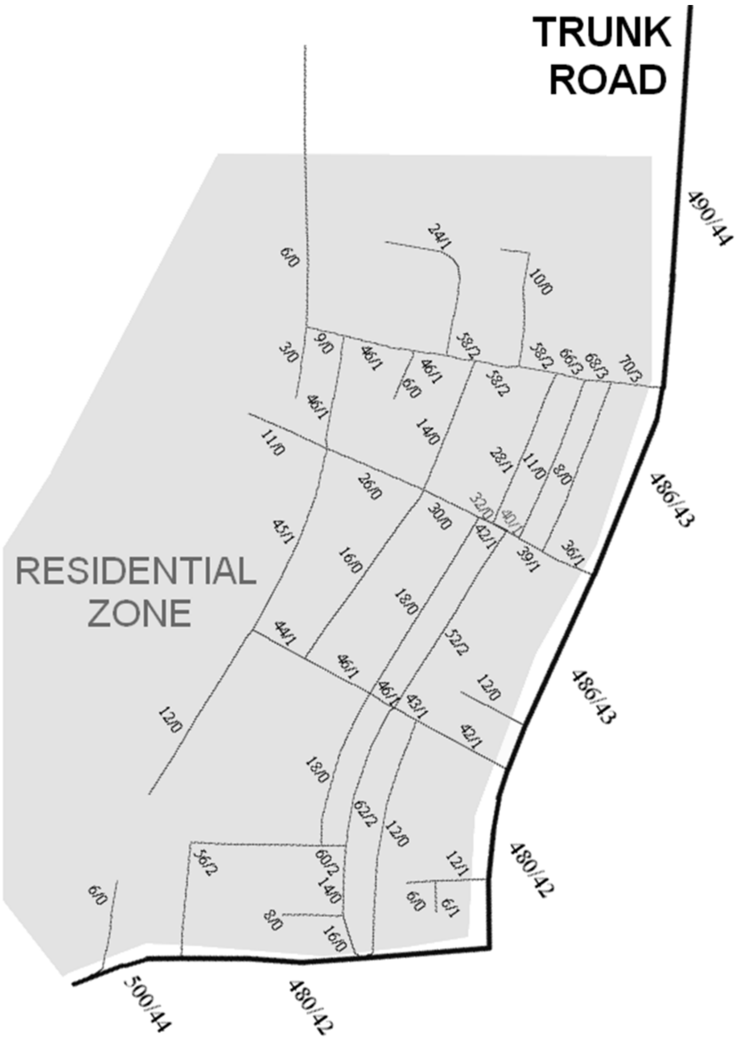

Figure 2: Hourly daily traffic volumes for the model area for the "current situation".

3 CONCLUSION

Table 2 shows the number of inhabitants affected by noise in a given zone for individual model situations. The determination of the number of inhabitants affected by traffic noise in an individual two-decibel zone is then given by the cumulative data loading on the number of inhabitants affected by noise in all monitored entities (flats or houses). Subsequently, it is possible to assess the traffic noise impact and assess the designed anti-noise measures and their contribution to the reduction of impact of noise on the population.

The speed reduction from 50 km/h to 30 km/h in a residential area with a neighbouring busy road is unable to reduce noise levels in the most affected zone. Furthermore, the noise reduction through this measure in a residential area is not very effective due to synergic effects of the trunk road. With the low-noise road surface on the trunk road, it is possible to reduce the number of affected inhabitants in the most affected zone with a partial impact over the first line of the residential area. The low-noise road surface and the speed reduction from 50 km/h to 30 km/h on the trunk road in a residential area brings about a significant shift of the number of noise affected inhabitants to lower zone along its range, see Figure 3.

Table 2: Table of inhabitants affected by traffic noise in the model area for individual alternatives.

Alternative	L_d [dB(A)]	below 42	42-43.9	44-45.9	46-47.9	48-49.9	50-51.9	52-53.9	54-55.9	56-57.9	58-59.9	60-61.9	62-63.9	64-65.9	66-67.9	68-79.9	above 70	Total
V01A	No. of inhabitants	29	12	469	188	521	581	621	538	423	510	353	399	933	345	3	2	5927
V01B	No. of inhabitants	36	223	351	368	505	530	470	500	473	439	350	399	933	345	3	2	5927
V01C	No. of inhabitants	1358	397	635	365	706	796	711	498	289	167	5	0	0	0	0	0	5927
V01D	No. of inhabitants	1392	615	502	512	605	674	759	477	254	135	2	0	0	0	0	0	5927
V02A	No. of inhabitants	29	31	450	191	530	710	588	623	798	554	681	563	174	5	0	0	5927
V02B	No. of inhabitants	36	253	321	371	528	621	473	586	846	472	678	563	174	5	0	0	5927
V02C	No. of inhabitants	122	488	331	554	838	545	186	585	489	373	674	563	174	5	0	0	5927
V02D	No. of inhabitants	2035	586	480	667	1101	516	199	305	38	0	0	0	0	0	0	0	5927
V03A	No. of inhabitants	29	12	474	188	528	864	839	731	690	718	21	271	332	230	0	0	5927
V03B	No. of inhabitants	36	236	343	368	509	816	700	694	738	636	18	271	332	230	0	0	5927

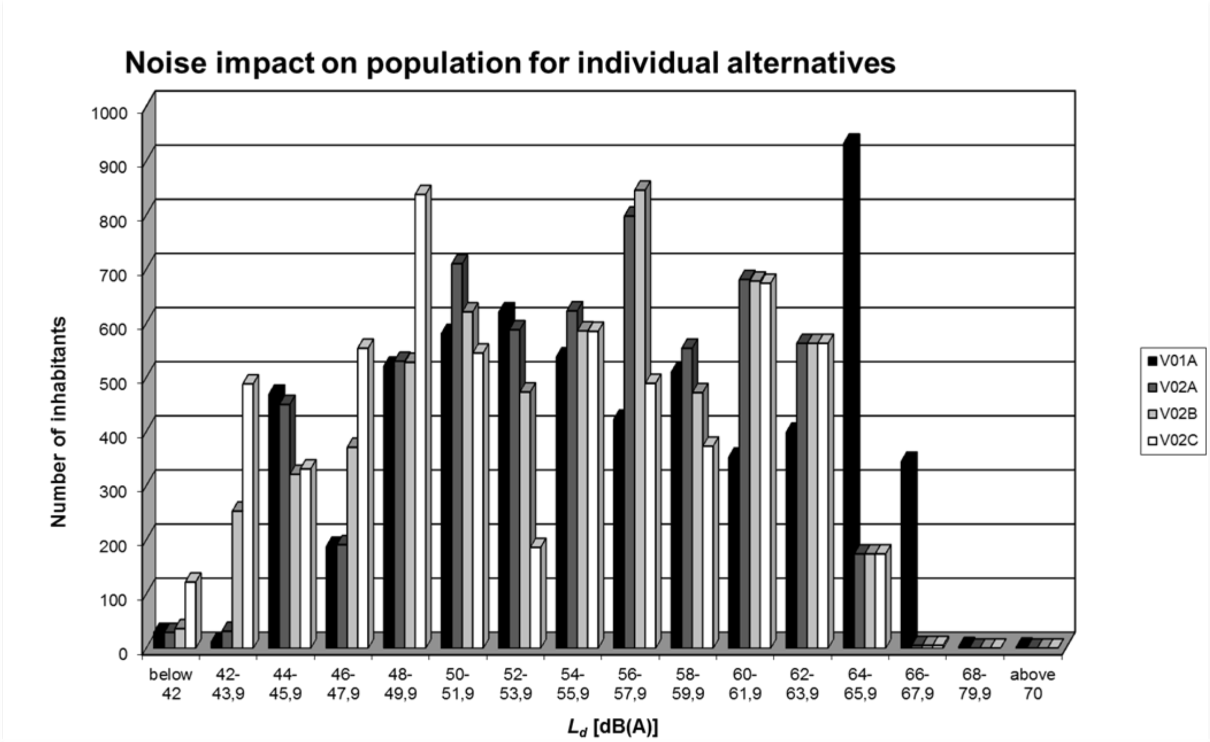

Figure 3: Noise impact on population for low-noise road surface in combination with speed reduction.

The installation of a 3 m high anti-noise barrier in the vicinity of the trunk road has a partial effect on the number of noise affected inhabitants in the most affected zone. In comparison with the low-noise road surface, this measure is not as effective in the most affected zone due to several reasons. There are a number of turn-off roads to the residential area and the anti-noise barrier is not consistent – noise may spread to the residential area through the gaps. Furthermore, a 3 m high anti-noise barrier is unable to protect multi-storey buildings – this measure is totally ineffective for higher floors. Regarding the aggregation of data over more zones, see Figure 4, this measure shows a higher effectiveness, which stems from noise damping behind the obstacle of an anti-noise barrier. In this case the impact of noise is reduced over several zones.

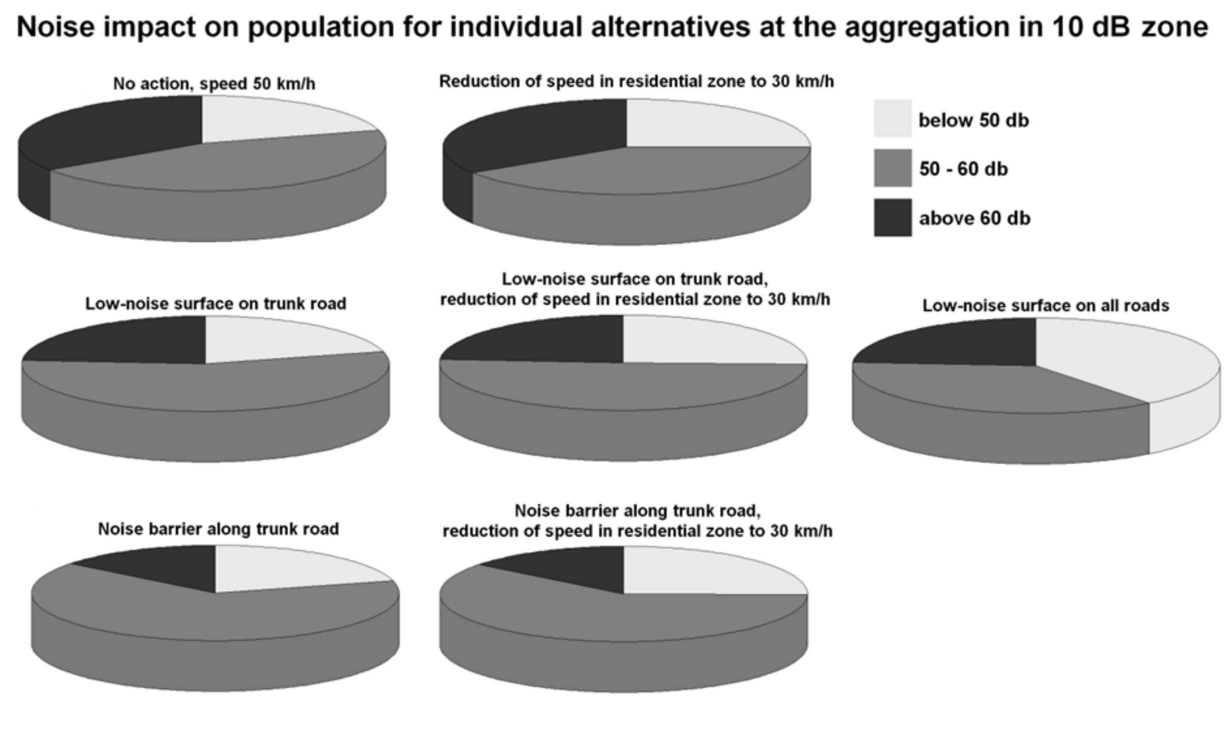

Figure 4: Noise impact on population for individual alternatives at the aggregation in 10 dB zone.

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Light Barrier for Level Crossings in the CZ – Experience after One Year of Operation

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ABSTRACT: In European countries, measures to increase warnings at level crossings are currently getting support. One of them is the so-called light barrier. Most of its applications are in the process of testing, in practice it is only used in Austria to some extent. In the Czech Republic, a light barrier was installed at a level crossing in Nová Včelnice under the R&D project SVEZA - TA01031404 "Research on the applicability and effectiveness of the so-called light barrier at level crossings in the CZ" (the project is being carried out with the financial support of the Technology Agency of the CZ). After one year of operation we can say that the device is effective. At the previously problematic level crossing (one accident every year on average and recurring risk situations) there has been no accident since the installation. In addition, a questionnaire survey among users showed mostly positive attitudes; respondents pointed to the enhanced comprehensiveness of the crossing, good light intensity, and the eligibility of the light barrier at this type of crossing. The testing of its operation and maintenance are still in progress, and camera monitoring of the behaviour of users is being prepared.

KEY WORDS: Level crossings, light barrier, safety.

1 INTRODUCTION, DEFINITION OF A LIGHT BARRIER

At present, the testing of a pilot installation of the so-called light barrier is taking place in Nová Včelnice at a level crossing on a narrow-gauge railway operated by JHMD (Figure 1). This is the first installation of a device of this kind in the Czech Republic and we do not find many examples of its implementation even in Europe, although in recent years reports suggest upcoming pilot projects. More widely, a light barrier is only used in Austria (Figure 2), where dozens of applications have been implemented, and more are being prepared. The device is also defined in Austrian legislation in the level crossing ordinance EKVO (Eisenbahnkreuzungsverordnung).

A light barrier is a device consisting of a set of red traffic light studs placed on the lane before a level crossing, perpendicular to the axis of the road. These studs will light up with flashing red lights simultaneously with the basic warning lights, creating an optical barrier in front of an approaching vehicle, which reminds the vehicle of the obligation to stop. In principle, it is another form of the so-called additional warning, similar to an audible alarm or mechanical barrier in addition to a crossing signalling device.

The colour of the light barrier is strictly red. Any colour variations are excluded. Only the colour red evokes unambiguous behaviour in road users (the signal for “Stop”). According to psychologists, interpretation of different colours could be perceived ambiguously and lead to serious problems in practice. All signalling devices used on roads always use red signalling colour to give the signal “Stop!” (whether it is an ordinary signalling device or warning lights).

A light barrier is activated by a non-potential or, in other words, free contact of the crossing signalling device relay, which passes information to the electronic control unit of the light barrier that warning lights at the level crossing were initiated. The circuit of the light barrier is safely separated from the crossing signalling device so that in the case of any failure (e.g. short circuit) of the light barrier, the basic warning light signal of the crossing signalling device would not be affected.

The basic idea of a light barrier is based on the assumption that the probability of the perception of the basic light warning can be effectively increased by in-road signalling devices. The purpose of a light barrier is to produce a strong light, enhancing the status of warning on a level crossing, thus “doubling” vital information. This reduces the risk of overlooking a warning, e.g. in bright sun (which can cause a sun-phantom effect) and it is in these situations where a light barrier can save lives. “A light barrier significantly increases attention or, more precisely, the potency of road users' perception” (Müller, 2010).

The efficiency of light barriers as perceived by drivers can be scientifically documented e.g. on the basis of the research project “Analyses of drivers' views at level crossings”, implemented by the Institute for Holistic Accident and Safety Research under E. Pfleger (2009). Analysis of driver's views using a unique technology Viewpointsystem, conducted at 31 level crossings, found deficits in driver's visual perception and helped formulate recommendations to optimize the arrangement of level crossings. As stated by Pfleger (2009): “drivers usually concentrate visually on vertical markings on the right side of the road and the area before the crossing”. Another finding is that a driver who is under psychological pressure and does not concentrate fully on driving (e.g. quarrel with driver's wife, naughty children, ringing phone, etc.) tends to look down”, that is rather on the road than up to the warning lights. Pfleger (2009) also states: “In a stress situation, the probability of perception of a warning produced by a light barrier is very high”. These are convincing arguments for the implementation of light barriers.

In Austria, a light barrier is a part of the strategy “let's help drivers” adopted by ÖBB. The strategy is based on the assumption that accidents on level crossings are caused by a failure of drivers who must therefore be assisted with complying with the principles of safe conduct, and that therefore the crossings must be improved and made more driver-friendly. This principle is based on a partnership approach rather than repressions. In this connection, reference can be made to a study of 87 fatal accidents from years 1988 – 1998 (Sochon & Davies, 1998). Over 80% of them occurred during daylight and in nice weather, and the main cause of 42% of them was found to be an “accidental mistake of road user”. According to the study it is likely that “it is difficult for the driver to understand in time the road signs and signals at the crossing, estimate the speed of a train and the position of the intersection”.

New safety features are also supported from a state level. The manufacturer of light barriers (EBE-Solutions, GmbH, ensuring delivery of light barriers for ÖBB) was rewarded a state prize for their project in a technological competition Staatspreis Verkehr 2009.

Installations from other countries are not known, with the exception of Slovakia, where there is only one experimental level crossing in Bratislava-Jarovce. Slovakia however does not count with further applications, mainly due to administrative reasons.

Figure 1: Light barrier in Nová Včelnice.

Figure 2: Light barriers in Austria.

2 ARRANGEMENT OF A LIGHT BARRIER WITH REGARD TO ROAD AND CONNECTION TO CROSSING SIGNALLING DEVICE, ECONOMIC ASPECTS

A light barrier usually consists of five traffic light studs; on narrow roads with no dividing line we can also find light barriers consisting of four studs. Studs are usually mounted 20 cm before a single solid transverse line (traffic sign No. V 5).

In principle, a light barrier is mounted on the approach lane before a crossing. It is not mounted over the whole width of the road. In addition to higher prices and more complicated maintenance, such an arrangement would also imply a more complicated installation – the need of complete road closure, and there would be no safety benefits (e.g. no case of driving around a light barrier has yet been recorded).

Connecting to the crossing signalling device is very simple in principle. The only element to be provided by the level crossing administrator is the non-potential, or free contact, of the activation relay of the crossing signalling device. This contact gives information to the control unit of the light barrier that the warning state of the level crossing has been initiated (in principle, similar to the consecutive light signalling device of the neighbouring intersection).

The electronic control unit of the light barrier is normally located in a crossing house (Austrian practice). In the pilot light barrier project in the CZ (site Nová Včelnice, see below) the control unit is placed in a separate distribution board next to the crossing house (for administrative reasons – the light barrier can also have a different administrator).

Light barriers are powered from the network (an electric connection is always available at crossings with a crossing signalling device). Actual power consumption of traffic light studs with LEDs, however, is very low (supply current for two light barriers at a level crossing is only about 20 mA).

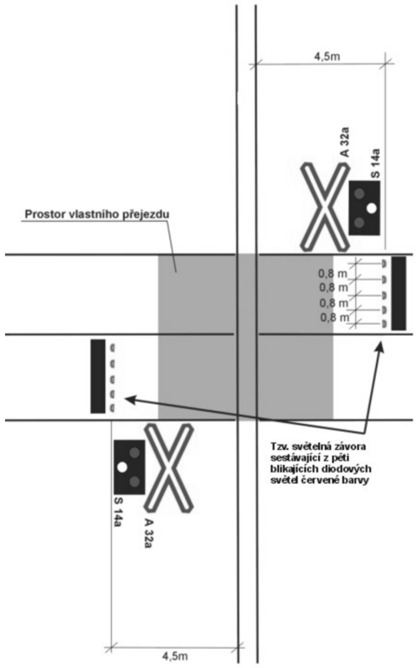

Figure 3: Scheme of light barrier.

A light barrier is very reliable in practice, mainly due to the absence of mechanical elements. Since 2008, when the first light barrier was installed in Wieselburg an der Erlauf, only sporadic problems have been reported. There were several cases when the current protection of the light barrier circuit was activated during a storm. In one case one traffic light stud was torn away by a snow plough (due to an installation fault). LEDs are extremely reliable, only in a few places has their glass cover been damaged, especially where fine gravel is used for winter gritting (the LED lights up but the light loses its intensity, it is therefore advisable to check the condition of glass covers once a year). The light barrier at the pilot Czech level crossing has been in operation for over a year without a single failure. Compared, e.g. with mechanical barriers, this device is less vulnerable and damageable, and the probability of failure is smaller (this does not suggest that light barriers should completely replace mechanical ones, as it is a device for a different purpose and criteria of usage).

The installation costs of a light barrier (meant in both travel directions) for a standard level crossing in Austria are approximately EUR 15 000 (i.e. the equivalent of about

CZK 380 000). In the Czech Republic, the cost of a light barrier can even be more favourable due to the generally lower price levels (about CZK 250 000 and less).

3 USE OF A LIGHT BARRIER

A light barrier can be very effective at level crossings having the following features:

- The crossing is less conspicuous in the terrain (e.g. a track in a slope, complex urban environment with many stimuli, etc.) and there is the risk of overlooking the basic warning lights;
- Direct road line, high speeds, wide open view through a level crossing;
- Risk of overlooking the basic warning lights due to low sun (risk of being dazzled at sunrise or sunset, or possibly mistaking the warning state for a sun-phantom effect), especially when the road intersects the track in an east-west direction;
- Great importance of road transport and low importance of railway transport evoke in drivers the psychological feeling of having the right of way, which may decrease the vigilance of drivers towards rail traffic (which in fact has the right of way).

Although light barriers were originally used as a cheaper option to additional mechanical barriers at level crossings secured by a crossing signalling device without barriers, in the Czech Republic a research team under the SVEZA research project has formulated the hypothesis that light barriers could also be effectively used on level crossings protected by a crossing signalling device with mechanical barriers. The main advantage could be in particular their immediate commencement to work, decreasing the probability of a driver entering the crossing when the warning bell is ringing beforehand and the mechanical barriers have not yet been lowered (which is interpreted by many drivers as “I still have time” or “the train is coming, but in a long time”). According to CDV surveys, 1-2% of drivers and more than 15% of pedestrians behave in this way, and these could possibly be stopped by an additional light barrier (Skládaná & Skládaný, 2012). Ellinghaus and Steinbrecher (2006) also point at the risk associated with ringing the bell beforehand: “Switching on the red lights beforehand leads to the confusion of road users and undermines the authority of the light warning”.

However the idea of having a combination of a light barrier with mechanical additional barriers slightly controverts the original philosophy of a light barrier as a low cost alternative to conventional barriers. Such a solution will therefore be tenable in practice only in exceptional, substantiated cases.

4 LEGISLATIVE SITUATION ON LIGHT BARRIER

Legislation of the Czech Republic does not regulate light barriers as a whole, and laws and regulations relating to the railway and road traffic do not recognise the term light barrier. However, the light barrier as an element (traffic stud and traffic light stud) is defined as a traffic device by Decree No. 30/2001 of the Ministry of Transport and Communications, which implements road traffic rules and the arrangement and management of traffic on roads. The optical part of the light barrier is mentioned only in technical regulation TP 217 Highlighting optical elements on roads – Highlight posts, curb reflectors, guiding permanent light studs and highlight studs – principles of use, mentioning basic conditions related to their arrangement and parameters. From the perception of a road user, a light barrier is an unambiguously and intuitively understandable – in their subconscious, a red light is strongly associated with the signal “Stop” (i.e. a light barrier is in compliance with the principle of a so-called self-explanatory road).

In Austria, the light barrier was incorporated in 2011 into the amendment to implementing Decree to the Law on Railways EKVO – Eisenbahnkreuzungsverordnung, which factually means its formal legislative recognition. It is regulated in § 13 of EKVO, where it is given the status of a device for additional warning (literally “other additional equipment”), i.e. in principle, it is regarded similarly to e.g. an additional mechanical barrier or an acoustic warning device.

5 PILOT SOLUTION OF A LIGHT BARRIER IN THE CZECH REPUBLIC

In accordance with the plan of activities of the research project SVEZA, a pilot installation of a light barrier on a level crossing in the Czech Republic was implemented. It was carried out on a level crossing in Nová Včelnice (a district of Jindřichův Hradec) on the track Jindřichův Hradec-Obrataň, at point km 12.189 (owner Jindřichohradecké místní dráhy, a.s.). It is intersected by a regional through road III/12826.

The manner of selecting the crossing in Nová Včelnice was complicated and lasted several months. The solution team considered and discussed a number of potential sites, and also consulted this matter with the Railway Infrastructure Administration, on whose network the first installation was initially expected. The main aim was to choose a crossing in which a light barrier would operate efficiently (have a favourable effect on drivers) and clearly demonstrate its features and benefits (referred to in the chapter Usage of a Light Barrier).

The level crossing in Nová Včelnice was finally found to be the optimal solution for the following reasons:

- The crossing used to be a black spot;
- It is inconspicuous in the terrain and visually disappears in the field, which is a very important typological aspect helping to emphasize the light barrier;
- Concerns about the so-called psychological right of way, because the road is straight, very comfortable (about 10 m wide) and inspires drivers to high speeds;
- The track gives the impression of being very subtle (760 mm narrow gauge track, apparently insignificant) and the danger of a collision with train may be underestimated by drivers (objectively the railway traffic is quite intense – more than 20 trains per day);
- Technical feasibility, mainly the good condition of the road before the crossing, allowing the traffic light studs to be embedded in it (any road defect would affect installation quality or lifetime);
- A smaller railway company with a clear structure, responsiveness of JHMD management to technical innovations and experimental solutions, simpler process of negotiating;
- It was financially and time efficient to combine the implementation of the light barrier with the construction of a crossing signalling device, initiated at the beginning of June 2011 (the crossing was originally secured only by a level crossing sign and sign “Stop, give right of way”).

After the pilot level crossing had been selected the phase of obtaining opinions and statements of the authorities concerned followed, which included the Ministry of Transport. It can be appreciated that the concerned parties showed a very positive attitude towards the test installation of a light barrier, including the railway company (Jindřichohradecké místní dráhy, a.s.) that, without any difficulties, agreed to connect the light barrier with the crossing signalling device and provide the power. It is also necessary to appreciate the understanding and professionalism of the road administration, who officially specified the light barrier in terms of roads. Accordingly the project researchers obtained positive opinions in a relatively short time, and the light barrier installation was performed as early as June 8th, 2011 (installation of traffic light studs in the road) during the planned closure of both the railway and the road. The light barrier was factually put into operation in mid-July, 2012 together with the regeneration of the crossing signalling device.

The light barrier in Nová Včelnice has now been successfully in operation for over a year and the experience and reactions to its operation are practically only positive. The device works excellently, is one hundred percent reliable; no single failure of an electrical or mechanical character has occurred. The overall visual impression of the light warning emitted from the road is very positive, effective and comprehensible (Figure 4). As indicated by the survey results presented below, the distinctive impression of the transverse red line motivates drivers to stop. The positive acceptance by users is reflected in the local press: "Though a light barrier is a device having a psychological effect, in contrast to traditional mechanical barriers that form a physical obstacle, it is far more reliable, and of course cheaper. The psychological effect of the red line lit before a driver across the road is really strong. First experiences are excellent and the device seems to fully meet expectations: On the mentioned site, drivers pay much more attention than before" (Šatava, 2011).

Figure 4: Light barrier in Nová Včelnice, day and night.

During the pilot testing the following quality criteria and parameters are expected to be verified:

- The state of public opinion (using a questionnaire survey of users),
- The impact on the behaviour of road users (by analysing camera recordings),
- Evaluation of visibility under different lighting conditions and when snowing,
- Measurement of luminance and other light-technical parameters, temporal stability,
- Reliability in terms of electricity (possible existence of error messages and their form),
- Mechanical reliability – resistance to heavy traffic and winter maintenance,
- Traffic accident rate (evaluation is expected after 3 years of operation).

Out of these activities, the survey on the opinions of users on the installed light barrier at the crossing has been currently completed, which is mentioned below.

6 USERS' SATISFACTION WITH LIGHT BARRIER AT THE LEVEL CROSSING IN NOVÁ VČELNICE – QUESTIONNAIRE SURVEY AFTER ONE YEAR OF OPERATION

6.1 Objective of survey and the method

In June 2012, a questionnaire survey on users' satisfaction with the light barrier was carried out around the level crossing in Nová Včelnice. After one year of operation, users could express their views on the application of this device in a given location both in terms of their own comfort and the effect on the behaviour of other drivers, cyclists and pedestrians, and assess the advantages and disadvantages of the device compared to conventional level crossing protection. The objective of this survey was only a description of the users' opinions, not a description of the real impact of the light barrier on their behaviour; the real impact has been the subject of a long term observation.

Interviewers addressed passing motorists, cyclists and pedestrians (Figure 5). Drivers were stopped by a Czech Police patrol during their normal activities. Due to the nature of the questions, only those respondents who had had a personal experience with the device were interviewed. Interviews were therefore conducted only with respondents who live nearby or pass through the place on a regular basis, and are already familiar with the device. Drivers passing over this level crossing for the first time were not interviewed. With regard to traffic and the form of questioning, interviews were mostly brief; the questionnaire form contained three elaborated questions as follows:

- Are you satisfied with the present design of the railway crossing? Please choose the answer that suits you most. (Possible answers: Yes, a crossing signalling device with a light barrier in the road is a good solution; Yes, but I think that a crossing signalling device with no supplements would be sufficient, a light barrier is unnecessary; Yes, but extra mechanical barriers would be better; No, a mechanical barrier instead of the light barrier would be better; It is quite unnecessary, the previous solution, a level crossing sign and "Stop sign" was sufficient; Other);
- What do you think are the advantages and disadvantages of a level crossing equipped with a light barrier compared to a level crossing equipped with other forms of protection? (A light barrier is clearly visible, even if sun lights – agree/disagree/no opinion; Even to a distracted person, a light barrier gives a clear signal to stop – agree/disagree/no opinion; Unlike with mechanical barriers, no risk of getting trapped on a crossing - agree/disagree/no opinion; A light barrier does not prevent crossing on a red light as reliably as mechanical barrier - agree/disagree/no opinion; A light barrier saves time, it turns off faster than a mechanical one rises - agree/disagree/no opinion; A light barrier attracts too much attention, one may overlook something important - agree/disagree/no opinion; Other);
- Do you think that the light barrier at this level crossing helps– at least to a certain extent – to prevent users from crossing on a red light? Please choose the answer that suits you most (Possible answers: Yes, definitely; Yes, partially; Yes, but rather only on drivers; Yes, but rather only on pedestrians; No).

Figure 5: Inquiry in Nová Včelnice.

6.2 Survey results

The sample set

In total, 125 valid interviews were gathered (91 drivers, 29 pedestrians, and 5 cyclists). In the sample group, as well as between the users of the crossing, motorists prevail. They are also usually more receptive to new level crossing arrangements than most pedestrians.

Satisfaction with the device

Generally, it can be said that users are satisfied with the light barrier (see Table 1). The vast majority of respondents are satisfied with supplementing the crossing signalling device at this level crossing with a light barrier, especially in comparison with the previous situation (a stop sign and a level crossing sign) and they do not wish any changes. Some respondents generally consider a crossing signalling device with a mechanical barrier more reliable, but they regard such a solution at this crossing unnecessarily expensive. Among the respondents, only four of them would prefer a crossing signalling device with mechanical barriers, and five of them a crossing signalling device with both the mechanical and light barrier. Two respondents would welcome supplementing the warning lights with white positive signal. Two female respondents (one pedestrian and one driver) did not realize that, for already one year, there had neither been the level crossing sign nor the traffic sign No. P6 “Stop and give way” but instead the new device, even though they often travel there.

Table 1: Satisfaction of respondents with the light barrier.

Yes, a crossing signalling device with a light barrier in the road is a good solution	111	90.2%
Yes, but I think that a crossing signalling device with no supplements would be sufficient, a light barrier is unnecessary	0	0.0%
Yes, but extra mechanical barriers would be better	5	4.1%
No, a mechanical barrier instead of the light barrier would be better	4	3.3%
It is quite unnecessary, the previous solution, a level crossing sign and “Stop sign”, was sufficient	0	0.0%
Other	3	2.4%
Total	123	100%

(Two respondents did not answer.)

Regarding satisfaction with the light barrier, there were no fundamental differences between the categories of users.

6.3 Advantages and disadvantages of the device

In comparison with other types of protection (crossing signalling device without supplements, or those with mechanical barriers) users especially appreciated the good visibility of a crossing signalling device with a light barrier in any weather, at dusk and in full sun, its conspicuousness and efficiency in warning even a distracted person to stop. They often also mentioned time savings, as compared both to a crossing signalling device with mechanical barriers (light barrier turns off immediately after a train passes, no lost time) and the previous situation (a crossed level crossing sign and "Stop sign") – no need now to stop and take a long look. If the device is not in operation, they can slowly continue the journey. In this connection, some respondents expressed their desire to have a positive white light here, enabling them to pass through more quickly. Other advantages or drawbacks were mentioned only marginally. The results are summarized in Table 2.

Table 2: Perception of advantages and disadvantages of light barriers by respondents.

	Agree	Disagree	No opinion	Total
A light barrier is clearly visible, even when the sun shines	86 (68.8%)	2 (1.6%)	37 (29.6%)	125
Even to a distracted person, a light barrier gives a clear signal to stop	89 (71.2%)	1 (0.8%)	35 (28.0%)	125
Unlike with mechanical barriers, no risk of getting trapped on a crossing	49 (39.2%)	0 (0.0%)	76 (60.8%)	125
A light barrier does not prevent crossing on a red light as reliably as mechanical barrier	34 (27.2%)	15 (12.0%)	76 (60.8%)	125
A light barrier saves time, it turns off faster than a mechanical one rises	63 (50.4%)	2 (1.6%)	60 (48.0%)	125
A light barrier attracts too much attention, one may overlook something important	3 (2.4%)	25 (20.0%)	97 (77.6%)	125

In assessing the advantages and disadvantages, respondents from the group of drivers were more active. Though pedestrians commented on individual items to a lesser extent, their opinions were not different.

6.4 Effects on user behaviour

The majority of respondents positively assessed the effectiveness of the light barrier on user behaviour. Among the respondents, 63% of pedestrians and 56% of drivers reported that the device definitely helped deter users from crossing on a red light, while 11% of pedestrians and 18% of drivers viewed that this was only true to some extent. Among the respondents, 22% of pedestrians and 21% of drivers felt that a light barrier affects drivers rather than pedestrians. The results are summarized in Table 3.

Table 3: Respondents' estimation of the effect of the light barrier on user behaviour.

Yes, definitely	69	57.5%
Yes, partially	20	16.7%
Yes, but especially only on drivers	24	20.0%
Yes, but especially only on pedestrians	1	0.8%
No	6	5.0%
Total	120	100%

(Five respondents did not answer.)

6.5 Other remarks and experiences

Respondents also noticed some other details. Several mentioned that the light emitted by the barrier is stronger than that of the warning lights. Others pointed to the uniqueness of that device – many users stop just because they are curious, and moreover, the light barrier is a local attraction. The combination with a psychological brake is something which they also liked.

On the other hand, respondents pointed to the fact that the force of habit of local people often makes them behave the same as when the crossing had been fitted only with a crossing sign and a “Stop and give way” sign – in all cases, they stop and look around. Two female respondents did not even realize that the crossing had changed a year ago, although they travelled there regularly. Not all are certain to understand how to behave on such a protected level crossing when the device is not warning. For any further installations, relevant information e.g. in the local press would therefore be useful.

7 CONCLUSION AND PERSPECTIVES

Although not all activities that are part of the testing of the device within the framework of the research project have been finalised, we can now say that the installation of the light barrier on the level crossing in Nová Včelnice was the right step towards increasing the safety of level crossings. At this crossing, which had previously been problematic, no accident or failure was recorded during the testing, and the assessment of users, though non-professional, confirms the hypothesis that the device makes the level crossing distinctive, strongly reminds users of an alert state of the crossing and improves its visibility. Satisfaction of road users and thus their demand is a strong argument for the broader use of light barriers in practice.

Within the research project SVEZA it is assumed that a light barrier will be installed at three level crossings (technical installation may vary slightly in the interests of comparison) and evaluated.

After completing and evaluating the research project SVEZA (in 2014), light barriers should be technically and legislatively prepared (let us say “handled” in terms of technology and especially legislation) for its possible “serial implementation”. One can imagine a situation where a light barrier would be part of a new construction or reconstruction of a crossing signalling device without mechanical barriers, where a level crossing is typologically suitable for the light barrier, e.g. the horizontal curve of the intersecting road has sufficient radius to enable a good view of the light barrier, etc.).

If developments in the Czech Republic proceeded similarly as in Austria, we can expect several dozens of installations in the near future (even hundreds if infrastructure managers take a positive attitude). Taken purely typologically, a light barrier can be justified at many level crossings secured with a crossing signalling device without mechanical barriers (and exceptionally even with mechanical barriers). The decisive factor is the need to highlight an inconspicuous crossing in the field or the risk of overlooking a light warning, e.g. due to low level sun. An additional light warning emitted from a light barrier installed on the road is virtually impossible to fail to notice.

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