Traffic Related Pollutants and Noise Emissions in the Vicinity of Different Types of Urban Crossroads

Dusan Jandacka¹, Martin Decky¹, Daniela Durcanska¹

¹Faculty of Civil Engineering, University of Zilina, Univerzitná 8215/1, 010 26 Zilina, Slovakia
dusan.jandacka@fstav.uniza.sk

Abstract. Particulate matter air pollution and noise pollution is a problem of everyday life. Particulate matter (PM) is one of the hazardous pollutants causing deterioration of the environment and thus quality of life of the population. Particulate matter and noise pollution by the road transport is a burning issue, particularly for larger urban areas. Air pollution and noise monitoring was focused on a possible change in the concentrations of pollutants and noise level after the change of the crossroad - three-arm crossroad to the roundabout. The subject of this paper is monitoring particulate matter (PM₁, PM₂.₅, PM₁₀) and noise pollution in the vicinity of crossroads in the urban area and an evaluation of fraction ratios PM₁₀, PM₂.₅ and PM₁ with regard to construction of crossroad, meteorological conditions and traffic volume. Paper deals with the comparison of the noise emissions objectified by direct measurements of noise levels before and after the reconstruction of the three-arm crossroad to the roundabout and comparison of changes in noise ratios detected by direct measurements and predictive calculations. The roundabout has specific construction and routing traffic, what can influence on production and dispersion of traffic related emissions and noise pollution. The obtained results indicate a decrease in particulate matter concentrations at the roundabout compared to the three-arm crossroad. According to the data obtained and analyzed, the PM₁₀ particulate matter concentrations at the roundabout could be reduced by up to 50 % over the three-arm crossroad.

1. Introduction

The dispersion of pollutants in the atmosphere is a difficult process that is not subordinated only to spreading rates of different sources producing this pollution. Of course, the source of various pollutants is decisive for a number of substances that get into the ambient air. There are also other physical factors during the spreading of produced emissions, which determine the dispersion of pollutants into the surrounding environment (meteorological parameters, the stability of the atmosphere and segmentation of the surrounding terrain [1-2]). The road traffic is one of the main sources of particulate matter, which produces particles not only in urban but in the rural environment, as well [3-4]. The concentrations of pollutants in the air may also be affected by the shape and construction of the road or crossroad (pavement, slope of the road, geometric shape of crossroad, traffic-light controlled crossroads ...) [5-7]. Crossroads are critical elements of road networks in terms of air quality impact, and their control type and geometric configuration can affect significantly vehicular emissions. At crossroads, the vehicles usually slow down and often stop, thus interrupting traffic flow in varying patterns. The main aim of one study was to compare the environmental performance of roundabouts and signal-controlled crossroads. Comparison of the crossroads was performed by a microsimulation model [8]. This paper
discusses real air and noise pollution in the vicinity of the two types of crossroads (three-arm crossroad - TAI and roundabout - ROA) and models of noise emissions prediction of the two types of crossroads are processed.

Noise pollution from surrounding roads presents relevant factor determining environmental quality in built-up areas of Slovakia as well as influencing values of surrounding properties respectively rent prices. Act no. 355/2007 Coll. in regards to discussed topic states, that individual - enterpreneur and corporate entity which uses or operates source of noise, in our case road administrator is obligated to limit exposure of residents and environment to acceptable equivalent noise levels for day (6-18h), evening (18-22h) and night (22-6h), which are stated in executive regulation. The issue of road transport from the point of view of environmental impacts (noise pollution) is given considerable attention in domestic and foreign literature [9-15].

2. Urban Crossroads and Methodology of Measurements

Road transport produces various pollutants and noise pollution whose concentrations and level are the highest in the vicinity of roads or crossroads. This study is focused on production of pollutants (PM$_{10}$, PM$_{2.5}$, PM$_{1}$) and noise pollution from the road transport at the various crossroad types three-arm crossroad - TAI and roundabout - ROA.

Existing original TAI was located at the point where industrial and recreational zone of the city of Zilina intersect with the built-up area of companies and facilities of recreation and services. It was located near the state road I/18 on the route Zilina-Martin-Kosice. It was a building of local significance that solves the reconstruction of the existing crossroad within the framework of the city development concept of the city of Zilina. In the case of an inconvenient traffic situation on the road I/18, this crossroad has become one of the strategic connections to the city of Zilina (especially from the direction of Martin). The existing crossroad was not a dangerous and accidental traffic locality in its original layout. However, the collision occurs within the encounter of pedestrians, cyclists and vehicles.

The purpose of the reconstruction was to build a roundabout with a diameter of 36 meters in optimal location in terms of fluent and safe transport, as well as in terms of the impact of construction and operation on the population and the natural environment. The main purpose of the reconstruction of existing crossroad was to construct a high-quality and capacity convenient crossroad as a traffic hub for vehicles, but also for pedestrians and cyclists with connection to existing build-up area of companies, facilities and also with connection to residential areas and recreational zones.

Whether this reconstruction has a positive environmental effect is the subject of the following text.

2.1 Air pollution measurements

The first measurement was realised at the TAI in the period from 25th June till 1st July 2016 (Pri celulozke Street and Rosinska Street) before the reconstruction. In that period, the reconstruction of this crossroad from tree-arm crossroad to the roundabout was planned (figure 1). There were areas of parked cars in the solved locality of the existing original crossroad, where was an uncontrolled exit of these cars to the road traffic. The roads were being polluted from these unpaved areas and consequently the road dust was being re-suspended to air.
The second measurement was realised at the ROA in the period from 24th June till 30th June 2016 after the reconstruction (figure 2).

In addition to this, there is a presumption of a change in the production of pollutants by the road transport, as the process of passing of vehicles through crossroad, vehicle speeds and pavement surfaces were changed. This is the subject of the described measurements, namely the change in the concentrations of pollutants for different types of crossroads.

Mobile Air Quality Monitoring Station of University of Zilina (MAQMS) was located next to the crossroads (three-arm crossroad and roundabout) at the same place in the years 2016 and 2017. For the particulate matter measurements, the optical method was used. Fidas® 200 fine dust aerosol spectrometer for simultaneous measurement from company Palas® was used. The particulate matter concentrations of three fractions of PM$_{10}$, PM$_{2.5}$ and PM$_{1}$ were sampled. Furthermore, the traffic volume

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**Figure 1** Three-arm crossroad before reconstruction, predominant winds during the measurement in the year 2016

**Figure 2** Roundabout after reconstruction, predominant winds during the measurement in the year 2017
was measured as the primary source of air pollution at the measuring place and meteorological parameters as secondary factors affecting concentrations of pollutants. All average values of pollutant concentrations were calculated from hourly values.

2.2 Noise pollution measurements

Before the realization of this reconstruction, the measurements of the noise pollution induced by traffic within the junction in the case were taken.

Prediction models of noise pollution were done in programme Cadna A working according to the calculation method "NMPB Routes 96" using french norm "XPS 31" and modifications for conditions in Slovakia.

Apart from the reconstruction of the three-arm crossroad to the roundabout, the project also contained new pavement for the road as well as for adjacent roads in order to connect with the circular lane of the junction.

![Figure 3](image)

**Figure 3** Situation of reconstruction of the 3rd class Roads III/01889 and III/01890, building object 101 - roundabout

Measurement of noise pollution was realised in the vicinity of crossroads during 2016 and 2017 via sound level meter NORSONIC NOR 121 (**figure 3**) on three measurement stations (MS). **Figure 8** and **figure 9** shows positions of measurement sites in noise map of the vicinity of the junction created in programme Cadna A (Com-puter Aided Noise Abatement).

3. Results and discussion to measurements and modelling

3.1 Air pollution

Both periods of measurements (TAI - 1st period from 27th June till 3rd July 2016 and ROA - 2nd period from 26th June till 2nd July 2017) were characterized by very similar meteorological conditions without rainfall. A slight change occurred in the temperature parameter (the temperature was higher by 0.9 °C on average in the year 2017) and the relative humidity parameter (the relative humidity was lower by 5.1 % on average in the year 2017). The average wind speed during the measurement period (7 measuring days) was 1.3 m/s in 2016 and 1.4 m/s in 2017. The prevailing wind direction was predominantly from the road (crossroad) to the measuring station during both measurement periods (**figure 1, 2**). The traffic volume was evaluated in the unit vehicles per 24 hours in individual measuring days. The average traffic volume for the whole measurement period increased by 8.1 % at the ROA in 2017 (15 036 vehicles/24 hours) compared to average traffic volume at the TAI in 2016 (13 910 vehicles/24 hours).

The road transport produces various pollutants, especially particulate matter. Decrease in particulate matter concentrations at the ROA in 2017 was observed compared to the TAI in 2016 (**figure 4, 5**). The average decrease in particulate matter concentrations during the whole measurement period at the ROA was 35 % for PM\textsubscript{10}, 38 % for PM\textsubscript{2.5} and 41 % for PM\textsubscript{1}. Due to the fact that the traffic volume in 2017
has increased compared to 2016, it is necessary to look for the causes of the reduction in particulate matter concentrations in the secondary factors affecting the PM concentrations.

**Figure 4** Concentrations of particulate matter during both periods of measurement at the TAI in 2016 and ROA in 2017

The coarse fraction $\text{PM}_{2.5-10}$ comprises more than 50 % of the fraction $\text{PM}_{10}$ (figure 6). The change can be seen above all in the actual concentrations of the particulate matter. In the summer when the measurements were carried out, the coarse fraction of particulate matter has a higher representation in the $\text{PM}_{10}$ fraction. The coarse fraction $\text{PM}_{2.5-10}$ comes mainly from the resuspension of road dust and the resuspension of particulates from the surfaces around the road. These particulate matters are formed from abrasion of vehicle parts, road surfaces, but also from the earth's crust, which are subsequently deposited on the road surface. By the passing of vehicles through crossroad, the particulate matters are back re-suspended into the air. At the TAI in 2016, the passing of vehicles in the main direction was faster (higher vehicle speed) so the particulates were re-suspended more intensely from the road surface into the air. Concurrently, the road surface before reconstruction was degraded and there were more unpaved areas in the vicinity of the crossroad. From these unpaved areas, the road surface was more...
polluted. At the ROA in 2017, the crossing vehicle speeds were lower, causing the resuspension of particulate matters from the road surface not to be so active. At the same time, the paved areas were built around the crossroad (pavements, parking areas).

![Figure 6](Image)

**Figure 6** Distribution of the PM fractions in the total PM_{10} fraction measurements at the TAI in 2016 and ROA in 2017

### 3.2 Impact of intersection rehabilitation on noise pollution

According to STN 73 6100 Terminology of roads [16] rehabilitation of pavement is construction activity, which enables secure, fluent, fast, economical and comfortable traffic during a given period. The rehabilitation is divided into maintenance, repair and reconstruction of a pavement. In 2015 the Zilina municipal government decided for rehabilitations - reconstruction of the 3rd class Roads III/01889 and III/01890 (Figure 1). The objectification of the impact described rehabilitation on the noise load of its surroundings was made by measuring noise levels in the trenino-octave bands (Figure 7).

**Equivalent A noise level** $L_{Aeq}$ [dB] is the quantity determined by the equation

$$L_{Aeq} = 10 \cdot \log \left( \frac{1}{T} \int_{t_1}^{t_2} \left( \frac{p_A(t)}{p_o} \right)^2 \cdot dt \right)$$

where: $p_A(t)$ is the time function of pressure sound weighted by frequency weighting function A, $T$ is the integration interval, $T = t_2 - t_1$ [s], $p_o$ is the reference sound pressure $p_o = 2 \cdot 10^{-5}$ Pa.

**Frequency band** is the field of frequencies bounded by a lower limit frequency $f_d$ and upper limit frequency $f_h$, characterized by the centre frequency $f_s$, for which applies

$$f_s = \left( f_d \cdot f_h \right)^{1/2}$$

If $f_h = 2 \cdot f_d$, frequency band is octave,

$$f_h = 2^{1/3} \cdot f_d$$

frequency band is one-third octave.
Figure 7 Comparison of measured noise levels at MS1 before and after reconstruction of the intersection to roundabout

Figure 8 3D model of the surroundings roundabout of the 3rd class Roads III/01889 and III/01890 created in the software for the prediction of environmental noise CadnaA [17]

The 3D model of the corresponding vicinity of the junction (figure 8) shows roads, parking lot, surrounding building as well as measurement sites and a wall, which greatly influence the spread of noise emissions in a vicinity of the junction (figure 9).

Figure 9 Traffic related noise maps surrounding of the 3rd class Roads III/01889 and III/01890 before (left) and after (right) reconstruction [17]
4. Conclusions
The changes in concentrations of pollutants and noise pollution may be influenced by different environmental factors. On one hand, there may be primary sources of pollutants and noise pollution, such as the road transport and on the other hand there are secondary factors such as meteorological parameters, shape and segmentation of landscape relief, various artificial barriers in the country-buildings, noise barriers, etc.

With regard to the particulate matter concentrations at the roundabout, the decrease was found. Concentrations of the PM$_{10}$ decreased by 35 %, PM$_{2.5}$ by 38 %, and PM$_{1}$ by 41 %. Therefore, the change of the crossroad shape affected also the PM concentrations. In addition, the process of vehicles passing through the ROA (lower speeds, lower air swirl) caused a reduction in the re-suspended road dust, especially the coarse fraction of the PM$_{2.5-10}$ particulates.

The article shows the objectified reduction of noise load of urban part in Žilina that were induced by reconstructions and transformations of three-arm crossroad into roundabout. Objectified reduction in noise levels by 3 dB was discovered in the immediate vicinity of the newly built roundabout. The 3 dB is theoretically corresponding to noise level reduction by doubling a receiver from the axis of the driving lane.

From the conducted research it can be concluded that the modification of the crossroad can affect the concentrations of pollutants and noise level. In this case, the concentrations of particulate matter and noise level decreased.

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