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# ENVIRONMENTAL BENEFITS OF TURBO ROUNDABOUT: A CASE STUDY OF NOISE AND AIR POLLUTION MODELLING IN THE VILLAGE OF KOŠŤANY NAD TURCOM, SLOVAKIA

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**Abstract**

Road transport represents a significant source of environmental pollution by air pollutants and noise. An important task is therefore to find ways to reduce these negative impacts. One option is also to change the conditions of the road transport infrastructure, for example by re-arranging the spatial layout of intersections and thus changing the driving mode of vehicles. The task of this study is to analyze the impact of the potential reconstruction of the intersection on the noise and air pollution load in its surroundings using modelling with the CadnaA program. This is a proposal to change the intersection (PK) to a turbo roundabout (TOK), with a specific structural layout and driving mode. As part of the study, a traffic survey was carried out to obtain detailed information about the volume and directions of road traffic at the intersection. The traffic volume at the intersection is specific to a high proportion of trucks, which also significantly affected the (un)change in the environmental load by noise and emissions. From the modeled variants, a reduction in noise pollution was observed, but no significant positive change in air pollution was demonstrated at TOK. At the observation point MP1, an increase in noise by 2 dB was recorded, and at MP4 a decrease of 3.6 dB. $PM_{10}$ concentrations did not decrease at any observation point and increased most at MP1 by 7 μg/m$^3$ according to the model.

**Keywords:**

Noise;
Emisions;
Road transport;
Turbo roundabout;
Air pollution;
Particulate matter.

## 1 Introduction

A large number of cars, vans, trucks and buses transport people and goods on the road transport infrastructure. Despite the shift to electric vehicles in recent years, most vehicles in the EU still rely on petrol and diesel, which emit air pollutants that harm our health and greenhouse gas emissions that contribute to climate change. Transport contributes to around a quarter of greenhouse gas emissions in the EU. Three quarters of them come from road transport. Noise pollution is also a serious and often underreported impact on the health of people who live or work near major roads. In addition, our roads are increasingly frequented and overcrowded. The transport sector's transition to sustainability is hampered by the increasing demand for transport and the slow growth of sustainable modes of transport for moving both people and cargo [1, 2].

In general, the outdoor environment around residential buildings is perceived more intensely by several modalities, including sight, smell, sound and touch [3]. In general, residents of residential areas consider anthropogenic noise to be the most disturbing emissions limiting environmental quality [4–6]. The continued expansion of urban areas, highways, and airports worldwide has made anthropogenic noise almost ubiquitous. Road traffic noise is perceived by the public as one of the most disturbing types of anthropogenic noise, with negative effects on public health, including annoyance, decreased mental health, hypertension, and increased risk of myocardial infarction [7]. In EU countries, noise has become a scientific and political topic over the past two decades. In recent years, several European research projects have also addressed the issue of road traffic noise, including SILVIA (Sustainable Road Surfaces for Traffic Noise Control) [8], SPENS (Sustainable Pavements for European New member States) [9].

Road transport is also a source of exhaust and non-exhaust emissions of particulate matter (PM). Non-exhaust PM emissions include wear of road surfaces, tires, brakes and resuspension of road dust [10–16]. An important part of PM in urban air is made up of particles that are created by the resuspension of road dust [14, 17]. In many European countries, it is a problem to comply with the limit values for $PM_{10}$ and $PM_{2.5}$ in cities. PM can come from natural sources, regional anthropogenic sources, long-range transport and local anthropogenic sources. PM is health-limiting due to its size and chemical composition (organic and elemental carbon, mineral dust, marine aerosol, secondary particles, especially sulfates and nitrates, heavy metals and other substances) [18–20].

The regional background in cities is increased by road traffic, especially diesel engines, local industry and heating, resuspension of particles from streets, and other sources. The toxicity of particles generally increases with their decreasing size.

Furthermore, road transport is responsible for the production of greenhouse gases (GHG ) that contribute to climate change worldwide. Road transport is the largest contributor to transport GHG emissions, accounting for 73.2% in 2022 (and 21.1% of all EU-27 GHG emissions in the same year). The road sector's contribution to transport emissions varied very little in the 1990-2022 period. Passenger cars are responsible for more than 75% of transport activity in Europe (measured in passenger kilometres). This activity has increased significantly in the last 26 years, peaking in 2019 and already recovering in 2021 after a decline following the COVID-19 pandemic. While public transport offers a more sustainable profile compared to private modes of transport, its share in total passenger transport has changed very little. Passenger cars are still the preferred mode of transport, and their number has increased in recent years [1, 2].

A major problem is the unsustainable increase in the number of vehicles on the roads, which is causing gradual damage to all parts of the environment [21].

Recently, the staff of the Department of Highway and Environmental Engineering of the Faculty of Civil Engineering of the University of Žilina have been paying significant attention to the contextual design of roads, including their intersections and environmental and economic optimization [22–24].

As part of this research, an analysis of the impact of the reconstruction of the intersection on the noise and air pollution in its surroundings was carried out. Attention was paid to the assessment of the environmental impacts of road traffic on the external environment of the intersection in Košťany nad Turcom, which affects the public health of the residents of its surroundings. Public health is the level of health of a society, which corresponds to the level of health care provided, health protection and support, and the economic level of a society. Environmental and working environment factors harmful to health are physical, chemical and biological factors that, according to current scientific knowledge, cause or may cause health disorders, and factors burdening the human body resulting from living conditions that adversely affect the physiological and psychological functions of people.

The existing PK and the proposed TOK, which could be built, were analyzed. The analysis was carried out using the CadnaA program, where the PK and TOK variant was modelled. Noise emissions and air pollutants ($PM_{10}$, $NO_x$) produced by road transport were assessed.

The main objective of this research was to identify possibilities for reducing environmental impacts from road transport (noise, air pollutants) in the vicinity of the proposed TOK compared to PK. Changes in transport infrastructure may in some cases lead to changes in noise production and emissions from road transport [25, 26]. A positive change was found in a study regarding noise production in urban environments [24] and a study on the change in $PM^{10}$ and $PM_{2.5}$ concentrations around a new roundabout in an urban environment [27]. Given some of the conditions characterizing the location analyzed in this study (traffic flow character, spatial layout of the intersection), the reduction of environmental noise and emissions by constructing a TOK may not be so clear-cut.

## 2 Methodology

### 2.1 Intersection location

The village of Košťany nad Turcom is located south of the district town of Martin at a distance of approximately 3.0 km. The middle of the built-up area in the north-south direction is crossed by the I. class road I/65 (Martin – Turčianske Teplice – Žiar nad Hronom), which is included in the network of expressways as part of the R3 route (Šahy - Zvolen - Martin - Trstená alt. Zvolen - B. Bystrica - T. Teplice). The I/65 road in this section is included in the basic network of Multimodal corridors "TEN-T".

This I. class road connects the village to the D1 highway - the superior road network, the main transport corridor Bratislava - Žilina - Košice - Ukraine (Fig. 2.1).


Fig. 2.1: Location of the investigated intersection in the village of Košťany nad Turcom

The basic communication system of the village consists of the aforementioned road I/65, road III/2141 in the direction Košťany – Žabokreky – Belá-Dulice and road III/2143 in the direction Košťany – Turčiansky Peter – Trebostovo, which are connected by an intersection at a level railway crossing.

The intersection of roads I/65, III/2141 and III/2143 is located in the wider center of the village, under the number 2633A011 at km 117.25 of road I/65 (Fig. 2.2).

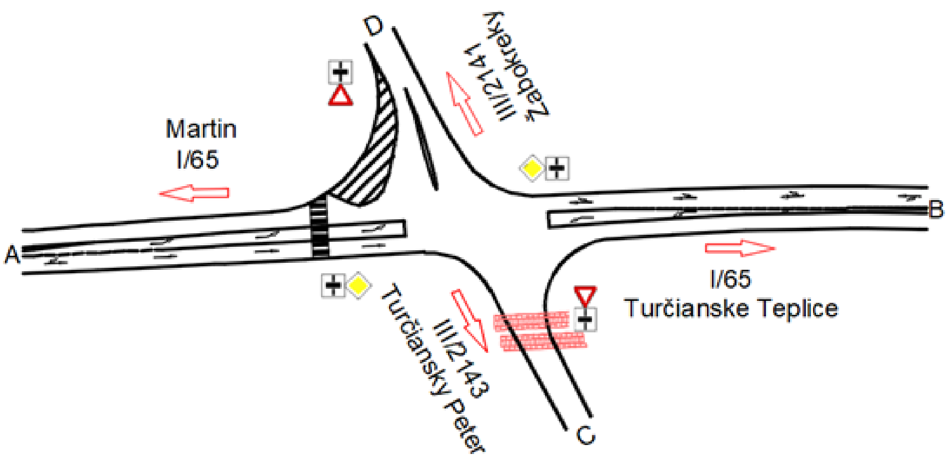



Fig. 2.2: Schematic representation of PK

The potential change should be in the layout of this intersection and a TOK should be created (Fig. 2.3). This type of intersection was created in the Netherlands in 1998, where it replaced the standard two-lane roundabout. The great advantage is their higher performance and road safety, ensured mainly by lower speeds (20-40 km/h), simplified traffic situation with only right turns and a significantly lower number of collision points. Compared to a classic two-lane roundabout, the increase in performance is estimated at 25 to 35% [28].

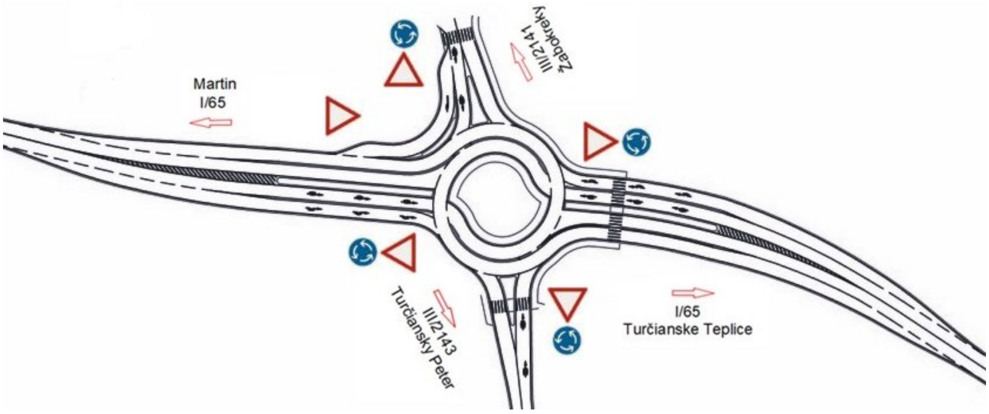



Fig. 2.3: Schematic representation of TOK

The proper functioning of the TOK assumes the division of vehicles into lanes for individual directions (destinations) of travel before the intersection. Vehicles in the intersection move along the spiral-guided lanes of the circular roadway, which ensure smooth passage through the intersection without the need to change lanes, eliminating interweaving on the circular roadway and cross collision points at the exit.

The main reason for the possible reconstruction is the construction of a capacity-compliant intersection. The proposed solution considers the construction of a two-lane basic standard TOK (Fig. 2.3).

For spatial reasons (proximity to the railway line and railway crossing on branch III/2143), the intersection in question will be offset from the existing state in a southerly direction along road III/2141.

## 2.2 Road traffic survey

In order to obtain traffic engineering data, a 24-hour video camera directional traffic survey of the intersection was carried out on 22.02. – 23.02. 2024 (Tuesday, Wednesday) from 19:05 to 19:05 the following day. The Sony HDR – CX405 camera was placed near the intersection to monitor individual entrances to the intersection and the routing of vehicles through the intersection (Fig. 2.4).

The aim of the survey was to obtain data for determining the hourly road traffic volume, traffic flow composition and traffic routing during the survey period.

Fig. 2.4: Video camera placement during traffic survey (left, red dot) and view of the intersection (right)

### 2.3 Modelling noise and air pollution from road transport

We performed the modeling of noise and air pollution from road traffic in the area of interest for the existing PK and the planned TOK. The modeling was carried out in the CadnaA program. The software calculates and predicts noise and air pollution near commercial and industrial areas, sports and recreational facilities and transport systems, such as roads and railways, airports and runways, etc. The CadnaA software is suitable for predicting noise and air pollution in supraregional and local studies, as well as for detailed analysis of noise map scenarios in cities. In the CadnaA program, it is possible to choose from several methods for calculating noise levels from various sources [29]

The basic input parameters that entered the modeling were:

- urbanization structure of the assessed area (map base),
- building height, which was considered in the range of 5 to 10 meters,
- general wind rose (Fig. 2.5),
- type of road surface,
- results of the implemented traffic survey – volume, direction and composition of road traffic on the assessed traffic sections.

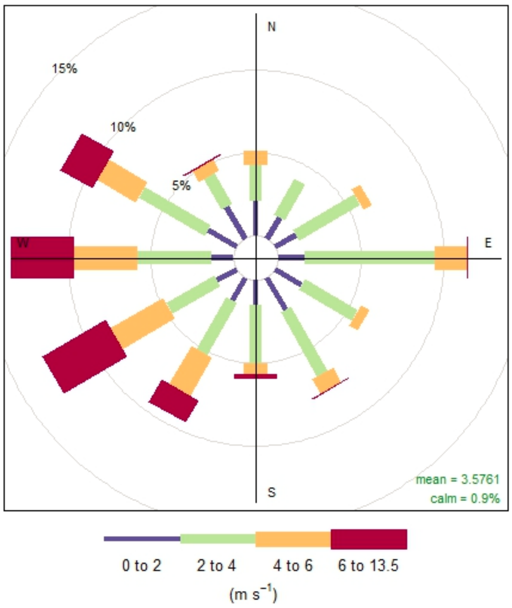



Fig. 2.5: Wind rose used for modeling in CadnaA program

We divided the traffic flow into two groups of noise and air pollution sources. One group represented light vehicles – OA, which included passenger and small commercial vehicles, and the second group represented freight vehicles over 3.5 t – NA, which included trucks and buses. For the purposes of noise prediction, we entered the percentage of freight traffic.

Traffic on adjacent local roads and the impact of rail transport were not subject to noise and air pollution modeling.

Within the framework of the modelling, 4 points of interest MP1 to MP4 were selected, at which noise levels and pollutant concentrations between PK and TOK were measured. Their location is identical in both cases of intersections.

The levels of noise emissions in the outdoor environment from line noise sources were determined by a calculation method using the CadnaA program according to the NMPB-Routes-96 (transport) methodology adapted for the conditions of the Slovak Republic.

The emission parameter used in NMPB-1996 is the A-weighted sound power level per octave band LAw,i point as a sub-source Sja in dB(A). This level is calculated:

$$L_{Aw,i} = 10lg\left(10^{\frac{(E_{VL}+10lgQ_{VL}}{10}} + 10^{\frac{E_{PL}+10lgQ_{PL}}{10}}\right) + 20dB + 10lgl_i + R(i) \tag{1}$$

where: $E_{VL}$ - sound power level of light vehicles [dB(A)],
$Q_{VL}$ - light vehicle volume (< 3500 kg) [veh/h],
$E_{PL}$ - sound power level of heavy vehicles [dB(A)],
$Q_{PL}$ - heavy vehicles volume (≥ 3500 kg) [veh/h],
$I_i$ - length of sub-source $S_{ja}$ [m],
$R(i)$ - octave values of the reference spectrum for road traffic noise [dB(A)]
$i$ - is a floating octave number.

CadnaA reports the total traffic flow Q (veh/h) and the percentage of heavy vehicles p (%). The relationships between these data and the data described above are:

$$Q = Q_{VL} + Q_{PL} \tag{2}$$

$$p = \frac{Q_{PL}}{Q} \tag{3}$$

The calculated emission parameter is the A-weighted total sound power level per unit lengthy $L'_{Aw,i}$ in dB(A), which is determined according to the modified equation:

$$L'_{Aw,i} = 10lg\left(10^{\frac{(E_{VL}+10lgQ_{VL}}{10}} + 10^{\frac{E_{PL}+10lgQ_{PL}}{10}}\right) + 20dB + \Psi \tag{4}$$

This value includes corrections for vehicle type, traffic flow type, road gradient and road surface Ψ.

By the option CadnaA-APL the range of applications of CadnaA are extended by the calculation, the assessment, and the presentation of air pollutants impact [30]. The option CadnaA-APL makes use of the calculation model AUSTAL2000 being developed by the German Federal Environmental Agency

The calculation of the emission from road traffic is based on the „handbook emission factors for road transport (HBEFA)“. This manual specifies road-specific emission factors for different traffic situations (route type and flow type). The emission factors specified in this publication had to be rearranged in order to obtain reasonable results when using CadnaA-APL in conjunction with AUSTAL2000 [31]. The program system AUSTAL2000 calculates the atmospheric dispersion of substances and odourants. AUSTAL2000 is the official reference implementation of the instructions given in Appendix 3 of the German Regulation on Air Quality Control (TA Luft) [32]. The model on which AUSTAL2000 is based is described in guideline VDI 3945 Part 3. This standard deals with the numerical calculation of trace species dispersion using a Lagrangian particle model [33]. This model tracks point-like particles representing a trace species on their path through the atmosphere. Austal2000 calculates the emission concentration of $NO_2$ in an indirect way via the decay rate of NO. The road traffic-specific $NO_x$ emission is mainly caused by NO and only to a minor extend by $NO_2$. Thus, emission factors for road traffic are not given for NO and $NO_2$ separately, but always as sum of nitrogen oxides. This allows to treat $NO_x$ during the calculation of distribution as an inert compound.

The total emission factors for $PM_{10}$ result from the sum of emission factors for combustion processes and for abrasion and whirlin up. The modelling involved road traffic data (similar to noise modelling) obtained from a traffic survey. The modelling was carried out for the pollutants $PM_{10}$ and $NO_x$, $NO_2$.

## 3 Results

### 3.1 Traffic survey - road traffic volume, traffic flow composition and traffic routing

Based on the traffic survey, the road traffic volume in each direction at the intersection was determined. The highest traffic volume was recorded in the main directions A-B 9841 veh/24h and B-A 9404 veh/24h (Tab. 3.1). The highest traffic volume was on the secondary direction D-A 2272 veh/24h (Tab. 3.2).

Table 3.1: Traffic volume and direction of main traffic flows in 24 hours

| vehicle/ direction | Traffic volume and routing of main traffic flows veh/24h | | | | | |
|---|---|---|---|---|---|---|
| | **A-B (straight)** | **A-C (right)** | **A-D (left)** | **B-A (straight)** | **B-C (left)** | **B-D (right)** |
| OA | 7812 | 1587 | 1775 | 7643 | 192 | 274 |
| NA | 2029 | 101 | 94 | 1761 | 5 | 38 |
| S | 9841 | 1688 | 1869 | 9404 | 197 | 312 |

Note: S = OA+NA

Table 3.2: Traffic volume and direction of secondary traffic flows in 24 hours

| vehicle/ direction | Traffic volume and routing of secondary traffic flows veh/24h | | | | | |
|---|---|---|---|---|---|---|
| | **C-A (left)** | **C-B (right)** | **C-D (straight)** | **D-A (right)** | **D-B (left)** | **D-C (straight)** |
| OA | 1644 | 372 | 280 | 2071 | 191 | 213 |
| NA | 228 | 51 | 17 | 201 | 16 | 10 |
| S | 1872 | 423 | 297 | 2272 | 207 | 223 |

Note: S = OA+NA

The ribbon diagram graphically shows the direction of traffic flows recorded during the traffic survey. The highest traffic volume was at entrance A with 13,398 veh/24h. At entrance B the traffic volume was 9,913 veh/24h, at entrance C 2,592 veh/24h and at D 2,702 veh/24h (Fig. 3.1).

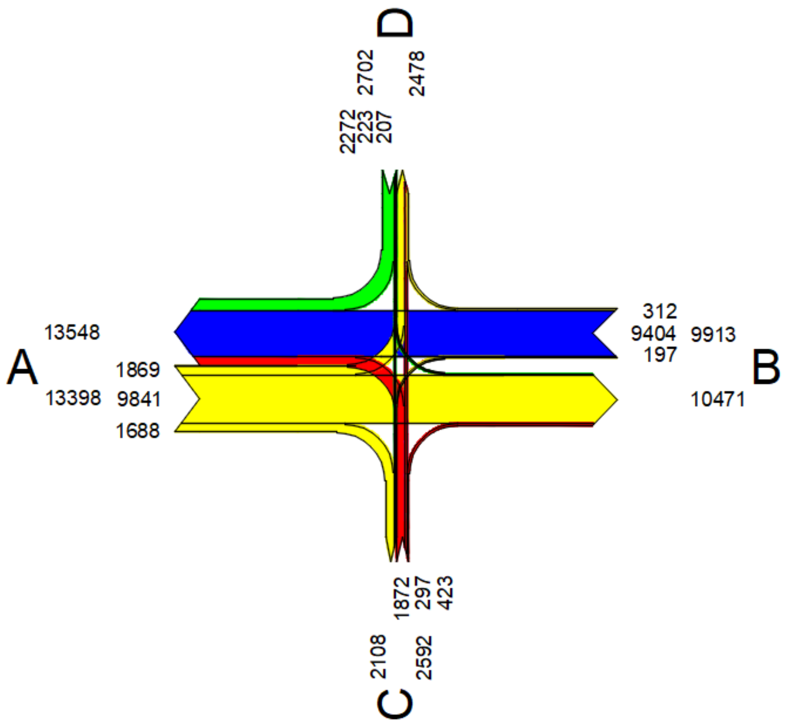



Fig. 3.1: Ribbon diagram of traffic volume at the intersection in Košťany nad Turcom according to the traffic survey conducted

### 3.2 Model setup

The following specific calculation parameters were used for acoustic and air pollution modeling in the vicinity of the intersection:

- road surface: AC11 - rough – old,
- calculated speed on the road:
  - I/65 - 50 km/h (max. permitted speed for the municipality), (entrance A and B),
  - III/2141 - 50 km/h for OA and 40 km/h for NA (entrance D),

- III/2143 - 30 km/h (reduction due to crossing the railway crossing) (entrance C),
- number of vehicles and share of freight vehicles (Tab. 3.3),
- longitudinal slope of the road: 0%,
- territory: built-up area (urban area),
- sound absorption factor of building facades: 0.21
- calculated height of isophone: 1.5 m above the terrain.

Acoustic modeling is based on the redistribution of traffic volume into partial parts (intersection branches), which form homogeneous line noise sources. From the results of the traffic survey (Tab. 3.1, 3.2), the respective traffic volumes on individual profiles (entrances to the intersection) were calculated (Table 3.3). Noise emission models were determined for individual calculation time periods – day, evening, night. The results of the traffic survey also indicate a high share of freight traffic, especially at night. This share represents up to 41% at entrance B (Table 3.3).

Table 3.3: Traffic volume and share of freight traffic at individual entrances to the PK

| Branch of the intersection | day 6:00 - 18:00 veh/h | | | | evening 18:00 - 22:00 veh/h | | | | night 22:00 - 6:00 veh/h | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OA | NA | S | % NA | OA | NA | S | % NA | OA | NA | S | % NA |
| A (I/65) | 1509 | 233 | 1742 | 13% | 795 | 228 | 1023 | 22% | 156 | 88 | 244 | 36% |
| B (I/65) | 1132 | 217 | 1349 | 16% | 488 | 161 | 649 | 25% | 119 | 82 | 201 | 41% |
| C (III/2143) | 251 | 12 | 263 | 4% | 270 | 59 | 329 | 18% | 24 | 4 | 28 | 15% |
| D (III/2141) | 305 | 16 | 321 | 5% | 230 | 35 | 265 | 15% | 28 | 5 | 33 | 15% |

TOK is characterized by movement in a precisely defined lane. For the purposes of noise and air pollution modeling, we divided the intersection into 27 homogeneous sections (Fig. 3.2).

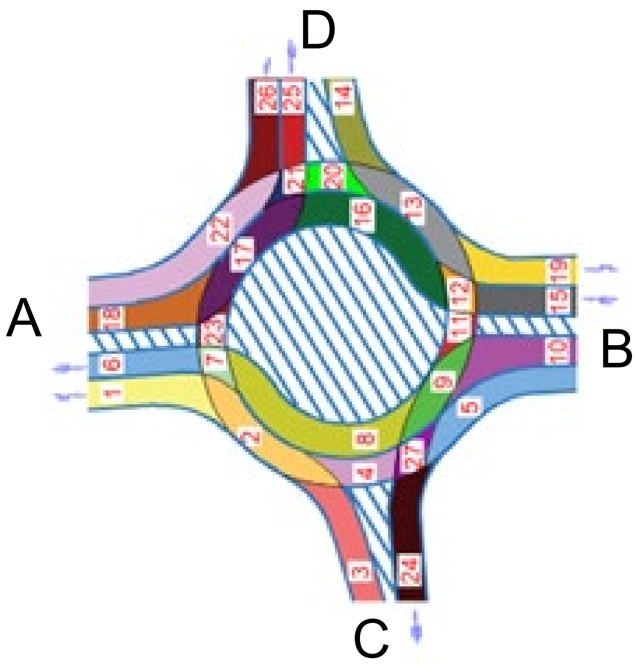



Fig. 3.2: Division of TOK into individual sections for modeling purposes in the CadnaA program

According to NMPB Routes 96, which is mandatory for the creation of strategic noise maps, different road surfaces are distinguished with respect to noise with specified correction values in dB in the spectral range [24]. These are directly included in the calculation. For the new TOK, some input parameters have been adjusted - new road surface, calculation speed, traffic intensity on individual partial sections of the TOK.

For acoustic modelling of noise and air pollution at TOK, the following parameters were adjusted in the program settings:

- road surface: asphalt mastic carpet - SMA, closed pores
- design speed: 35 km/h for OA and 20 km/h for NA,
- traffic volume on designated sections of TOK (Tab. 3.4).

Table 3.4: Traffic volume and share of freight transport on individual sections of the TOK

| Section | day 6:00 - 18:00 veh/h | | | | evening 18:00 - 22:00 veh/h | | | | night 22:00 - 6:00 veh/h | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OA | NA | S | % NA | OA | NA | S | % NA | OA | NA | S | % NA |
| **1** | 321 | 49 | 370 | 13% | 166 | 45 | 211 | 21% | 23 | 19 | 42 | 44% |
| **2** | 361 | 51 | 412 | 12% | 190 | 46 | 236 | 19% | 29 | 19 | 48 | 40% |
| **3** | 132 | 6 | 138 | 5% | 86 | 11 | 97 | 11% | 10 | 1 | 11 | 6% |
| **4** | 229 | 45 | 274 | 16% | 104 | 35 | 139 | 25% | 19 | 18 | 37 | 49% |
| **5** | 247 | 46 | 293 | 16% | 140 | 45 | 184 | 24% | 21 | 18 | 39 | 47% |
| **6** | 445 | 72 | 517 | 14% | 211 | 56 | 267 | 21% | 34 | 28 | 62 | 46% |
| **7** | 485 | 74 | 559 | 13% | 235 | 57 | 292 | 19% | 39 | 29 | 68 | 46% |
| **8** | 445 | 72 | 517 | 14% | 211 | 56 | 267 | 21% | 33 | 28 | 62 | 46% |
| **9** | 545 | 78 | 623 | 13% | 362 | 95 | 457 | 21% | 47 | 29 | 76 | 38% |
| **10** | 326 | 66 | 392 | 17% | 144 | 52 | 196 | 27% | 25 | 27 | 52 | 52% |
| **11** | 219 | 12 | 231 | 5% | 218 | 43 | 261 | 17% | 22 | 2 | 24 | 8% |
| **12** | 444 | 52 | 496 | 10% | 298 | 69 | 367 | 19% | 54 | 18 | 72 | 25% |
| **13** | 554 | 75 | 629 | 12% | 341 | 82 | 423 | 19% | 69 | 26 | 95 | 27% |
| **14** | 151 | 9 | 160 | 6% | 106 | 7 | 113 | 6% | 12 | 2 | 14 | 14% |
| **15** | 224 | 41 | 265 | 16% | 81 | 26 | 107 | 25% | 30 | 14 | 44 | 32% |
| **16** | 224 | 41 | 265 | 15% | 81 | 26 | 107 | 24% | 30 | 14 | 44 | 32% |
| **17** | 235 | 58 | 293 | 20% | 90 | 37 | 126 | 29% | 32 | 16 | 48 | 34% |
| **18** | 211 | 41 | 252 | 16% | 75 | 26 | 101 | 26% | 28 | 14 | 42 | 33% |
| **19** | 334 | 64 | 398 | 16% | 124 | 39 | 163 | 24% | 45 | 21 | 66 | 32% |
| **20** | 403 | 66 | 469 | 14% | 236 | 75 | 311 | 24% | 57 | 24 | 81 | 30% |
| **21** | 429 | 68 | 497 | 14% | 253 | 76 | 329 | 23% | 59 | 24 | 83 | 29% |
| **22** | 530 | 72 | 602 | 12% | 343 | 102 | 445 | 23% | 71 | 27 | 98 | 28% |
| **23** | 39 | 2 | 41 | 5% | 23 | 1 | 24 | 4% | 4 | 0 | 4 | 0% |
| **24** | 119 | 6 | 125 | 5% | 185 | 49 | 234 | 21% | 16 | 4 | 20 | 20% |
| **25** | 26 | 2 | 28 | 7% | 17 | 1 | 18 | 6% | 2 | 0 | 2 | 0% |
| **26** | 127 | 6 | 133 | 5% | 107 | 27 | 134 | 20% | 14 | 3 | 17 | 18% |
| **27** | 348 | 51 | 399 | 13% | 290 | 84 | 374 | 22% | 34 | 19 | 53 | 36% |

### 3.3 Noise pollution around intersections

Modelling of noise pollution near the PK and TOK brought differences in the ambient road traffic noise levels at all assessed points (Table 3.5).

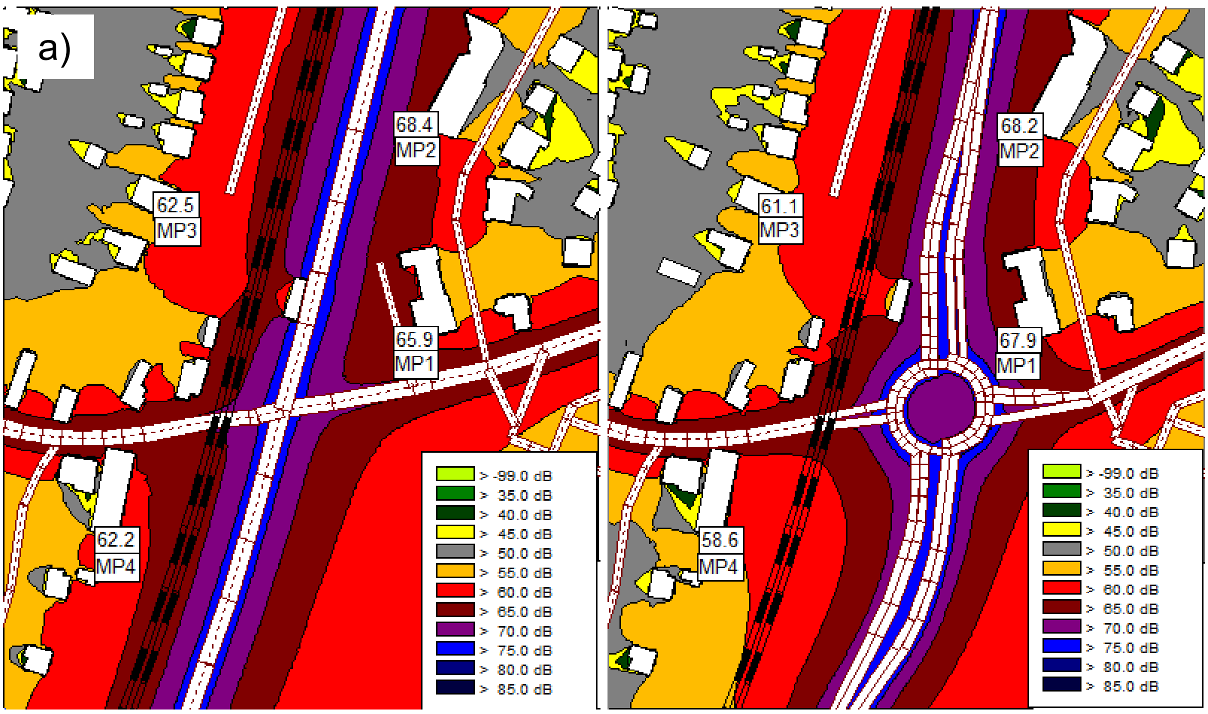
Table 3.5: Change in noise levels at individual assessed points between PK and TOK for day, evening, night

| | $L_{Aeq}$ (dB) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference interval/ interest point | $MP1_{PK}$ | $MP1_{TOK}$ | Difference | $MP2_{PK}$ | $MP2_{TOK}$ | Difference | $MP3_{PK}$ | $MP3_{TOK}$ | Difference | $MP4_{PK}$ | $MP4_{TOK}$ | Difference |
| day | 65.9 | 67.9 | +2.0 | 68.4 | 68.2 | -0.2 | 62.5 | 61.1 | -1.4 | 62.2 | 58.6 | -3.6 |
| evening | 66.7 | 68.4 | +1.7 | 68.4 | 68.2 | -0.2 | 62.8 | 61.8 | -1.0 | 62.1 | 59.8 | -2.3 |
| night | 61.9 | 64.1 | +2.2 | 64.4 | 64.1 | -0.3 | 59.3 | 58.1 | -1.2 | 59.0 | 55.6 | -3.4 |

Note: „+“ – increase of noise level, „-“ – decrease of noise level

The noise level increased only at the assessed point MP1 for all reference intervals. This is mainly due to the smaller distance of the point MP1 from the traffic lane. At the new TOK intersection, the arrangement of the individual branches of the intersection was changed, with the geometric parameters of the intersection and the spatial arrangement of the intersection surroundings being limiting. Point MP1 was originally 46 m away from the axis of the I/65 road lane (entrance A), while the distance from the axis of the outer TOK lane decreased to 20 m. The noise level value increased by 2.0 dB during the day, by 1.7 dB during the evening and by 2.2 dB at night.

The noise level values at point MP2 decreased by 0.2 – 0.3 dB. The highest reduction in noise levels occurred at the assessed point MP4, specifically by up to 3.6 dB during the day (Fig. 3.3a).



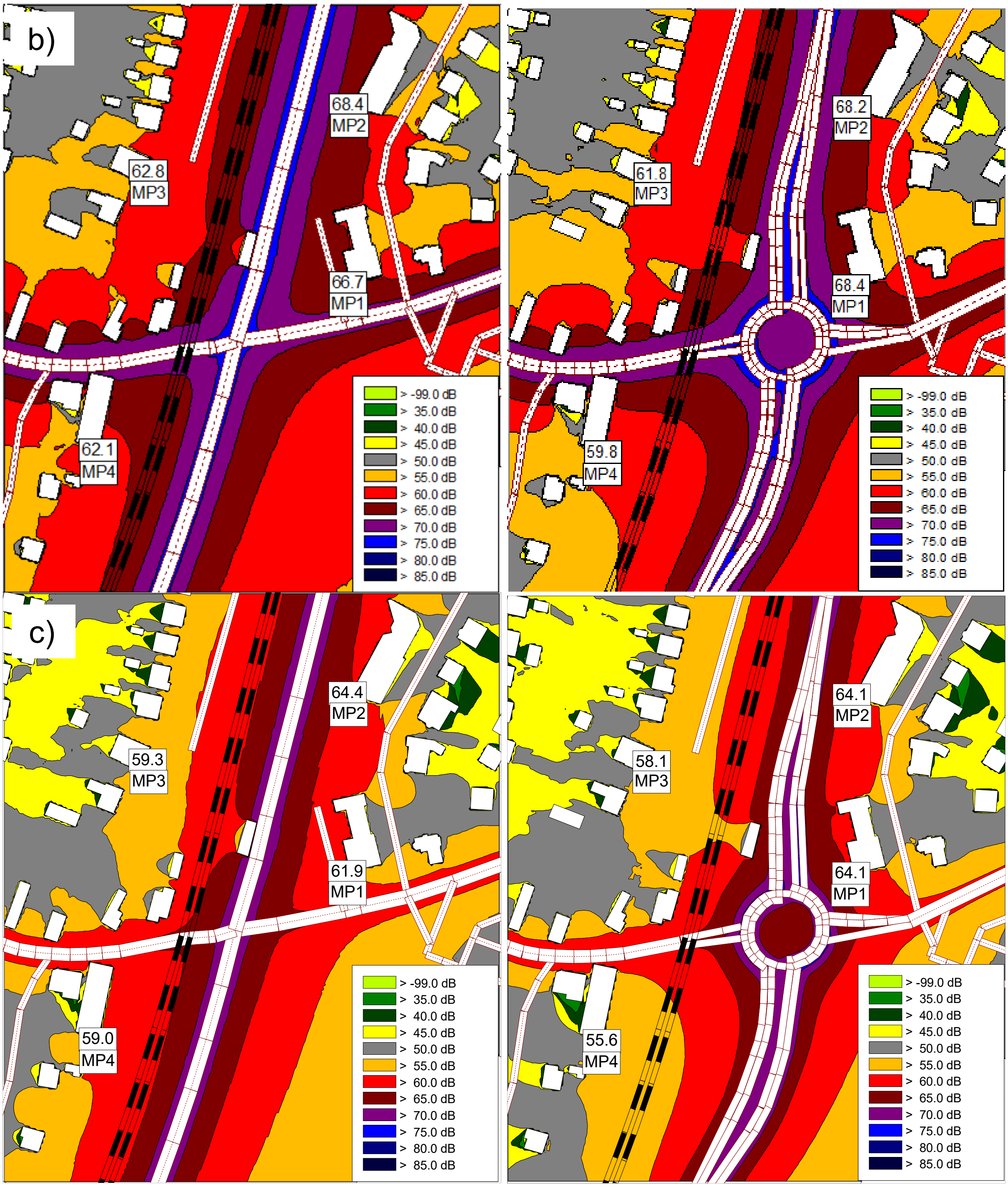



Fig. 3.3: Noise levels from road traffic at PK and TOK for a) day, b) evening, c) night

During the time period 18:00 – 22:00 "evening" there is a decrease in traffic volume, but also a gradual increase in the share of freight transport (up to 25%) (Tab. 3.3). We can observe a slight increase in noise levels at the assessed points at both intersections (Fig. 3.3b). During the time period "night" there is a significant decrease in traffic volume by up to 86%. The decrease in noise levels is only by max. 4.1 dB compared to the time period "day" (Fig. 3.3c). This is due to the significant percentage of freight transport (up to 41%) (Tab. 3.3).

### 3.4 Air pollutant concentrations around intersections

The intersection modeling showed an increase in air pollutants concentrations at almost all assessed points on the TOK. A slight decrease in concentrations occurred at point MP4 for $NO_2$ and $PM_{10}$ (Tab. 3.6).

The largest difference in hourly $NO_2$ concentrations between modeled intersections is at point MP1, there is an increase of 25.7 µg/m³ at TOK. At points MP2 and MP3, we observe an increase of 13.7 µg/m³ and 12.0 µg/m³, respectively. The largest increase in hourly $PM_{10}$ concentrations is observed at point MP1, by 7.0 µg/m³ at TOK (Tab. 3.6).

Tab. 3.6 Change in air pollutants concentration at individual assessed points between PK and TOK

| Air pollutants concentration [µg/m³] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pollutant/ interest point | $MP1_{PK}$ | $MP1_{TOK}$ | Difference | $MP2_{PK}$ | $MP2_{TOK}$ | Difference | $MP3_{PK}$ | $MP3_{TOK}$ | Difference | $MP4_{PK}$ | $MP4_{TOK}$ | Difference |
| $NO_{2,h}$ | 31.2 | 56.9 | +25.7 | 40.4 | 54.1 | +13.7 | 30.0 | 42.0 | 12.0 | 34.3 | 28.6 | -5.7 |
| $PM_{10,d}$ | 3.3 | 10.3 | +7.0 | 6.6 | 11.6 | +5.0 | 2.1 | 2.9 | 0.8 | 3.0 | 3.3 | +0.3 |
| $PM_{10,y}$ | 1.0 | 2.6 | +1.6 | 1.5 | 2.8 | +1.3 | 0.4 | 0.5 | 0.1 | 0.6 | 0.5 | -0.1 |

Note: "h" – hourly concentration, "d" – 24-hour concentration, "y" – annual concentration, „+" – increase of noise level, „-" – decrease of noise level

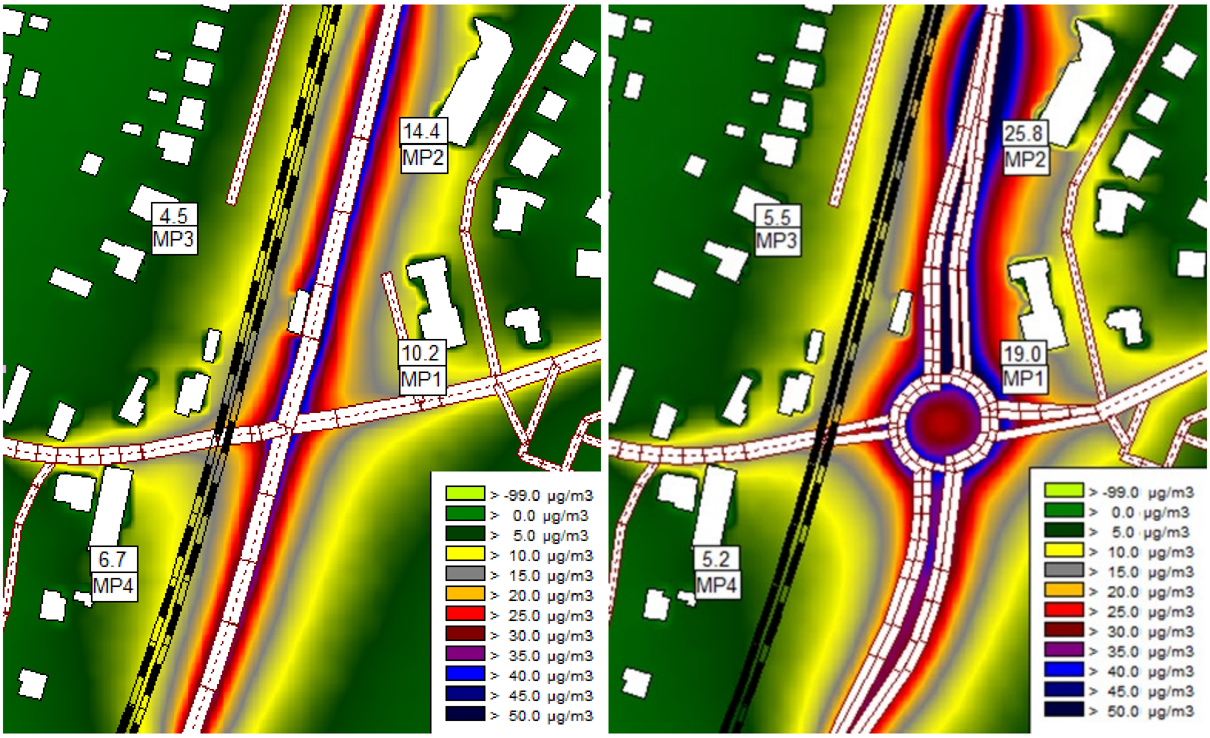



Fig. 3.4: Annual $NO_x$ concentrations from road traffic in the vicinity of PK and TOK

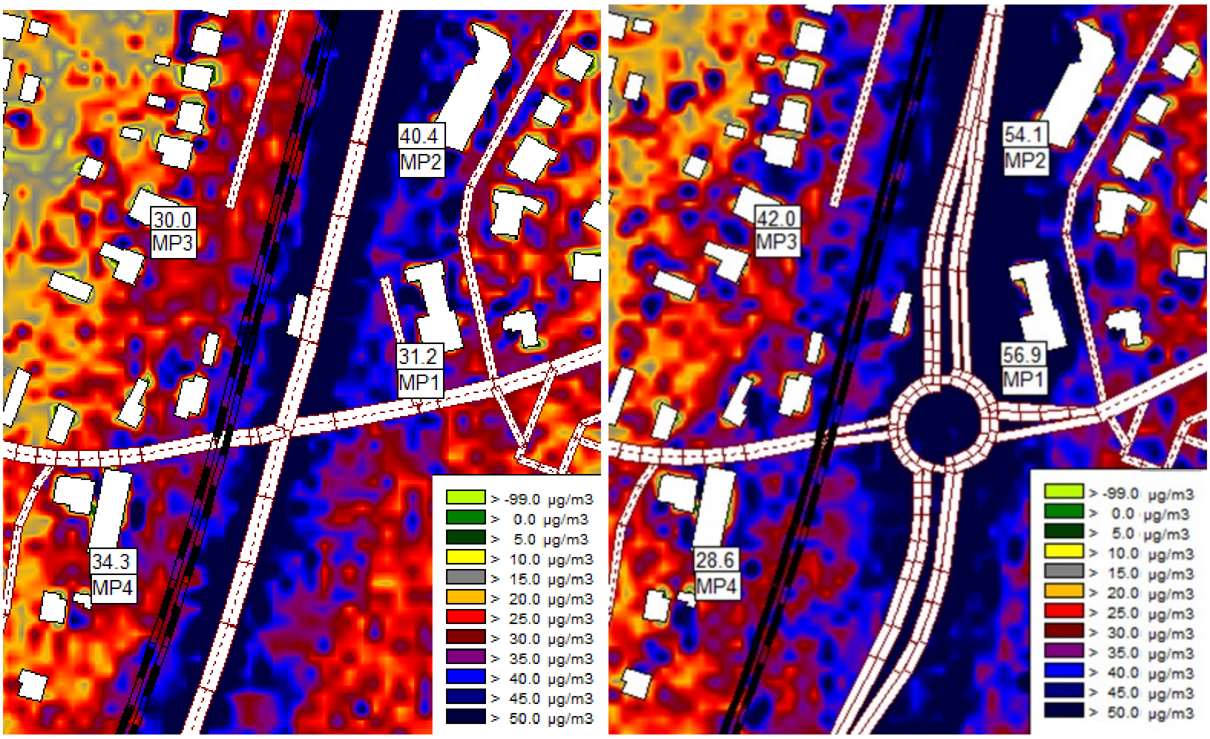



Fig. 3.5: Hourly $NO_2$ concentrations from road traffic in the vicinity of PK and TOK

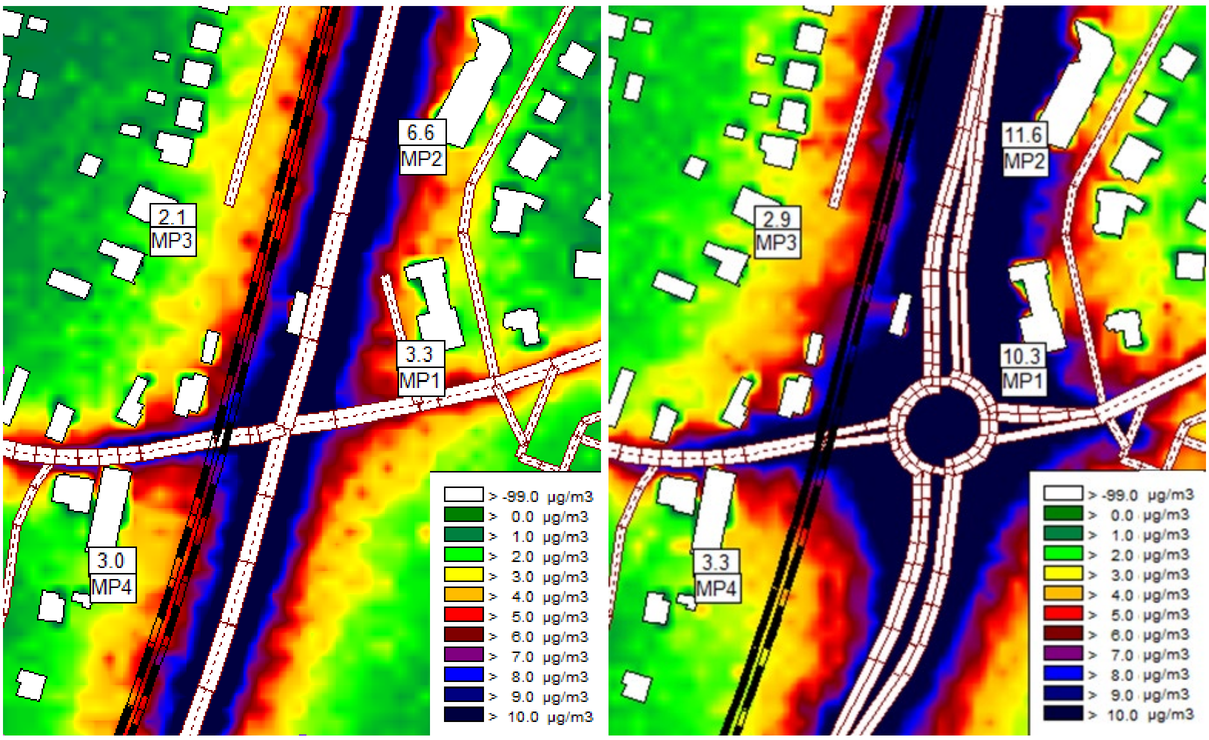



Fig. 3.6: 24-hour $PM_{10}$ concentrations from road traffic in the vicinity of PK and TOK

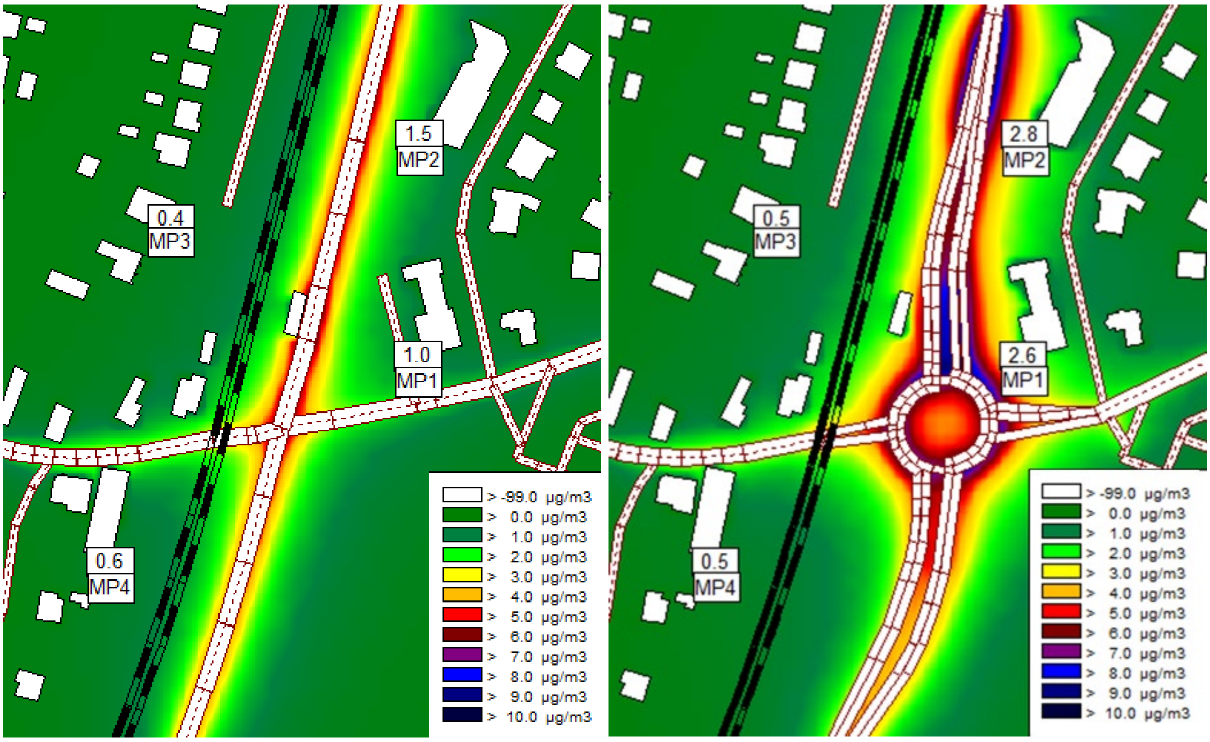



Fig. 3.7: Annual $PM_{10}$ concentrations from road traffic in the vicinity of PK and TOK

The hourly $NO_2$ concentration is highest at the assessed point MP2 40.4 µg/m$^3$ at PK and lowest at the point MP3 30.0 µg/m$^3$ (Fig. 3.5). $PM_{10}$ concentrations also reach the highest values at the point MP2, namely 6.6 µg/m$^3$ 24-hour concentration and 1.5 µg/m$^3$ annual concentration (Fig. 3.6, 3.7). The lowest $PM_{10}$ concentrations are at the point MP3, namely 2.1 µg/m$^3$ 24-hour concentration and 0.4 µg/m$^3$ annual concentration. (Fig. 3.6, 3.7).

In the case of TOK, the highest hourly $NO_2$ concentration at the assessed point MP1 is 56.9 µg/m$^3$ and the lowest at the point MP4 is 28.6 µg/m$^3$ (Fig. 3.5). $PM_{10}$ concentrations reach the highest values at the point MP2, namely 11.6 µg/m$^3$ 24-hour concentration and 2.8 µg/m$^3$ annual concentration (Fig. 3.6, 3.7). The lowest $PM_{10}$ concentrations are at the point MP3, namely 2.9 µg/m$^3$ 24-hour concentration and 0.5 µg/m$^3$ annual concentration. An annual concentration of 0.5 µg/m$^3$ also occurred at the point MP4 (Fig. 3.6, 3.7).

Modelling was also performed for nitrogen oxides $NO_x$. In this case, the highest concentrations were found at point MP2 for PK and TOK, namely 14.4 µg/m$^3$ and 25.8 µg/m$^3$, respectively (Fig. 3.4).

## 5. Discussion and conclusion

The main objective of the presented study was to compare the production of noise and air pollutants during the operation of road transport on PK and TOK. For this purpose, the modelling method in the CadnaA program was chosen. For an objective comparison of individual data, it is necessary to pay attention to three changes that resulted from the arrangement and construction of different types of intersections. Specifically, these are the change in the distance of the intersection branches from the reference points (TOK alignment, while the distance of the individual reference points from the lane axis changes), the change in the road surface from asphalt concrete to mastic asphalt carpet, which according to the available literature can cause a reduction in the noise level by 2 dB [24], the change in the speed on the individual branches of the intersection (adjustment of speeds from 50 km/h at PK to 35 km/h for passenger vehicles and 20 km/h for trucks at TOK).

Changing the intersection type to TOK brought positive results in the form of a reduction in noise levels at the assessed points MP2, MP3, MP4 for all reference times. The largest differences were observed at point MP4, where the noise load was reduced by up to 3.6 dB.

Modelling of air pollutants $NO_x$, $NO_2$, $PM_{10}$ from road transport shows an increase in concentrations at the assessed points MP1, MP2, MP3 on the TOK. The highest increase in concentrations occurred at point MP1, specifically for the hourly concentration of $NO_2$ by 25.7 μg/m$^3$, the 24-hour concentration of $PM_{10}$ by 7 μg/m$^3$.

The results show that various characteristics of the transport infrastructure (structural arrangement - intersection shape, road construction) and also characteristics of the traffic flow (speed and composition of the traffic flow) can significantly influence the environmental impacts of road transport. The modelled intersection variants showed a positive change in noise levels using TOK. The following characteristics significantly contributed to this fact: change in road surface, change in traffic flow speed. Similar results were achieved in a study dealing with the change in noise emissions due to the construction of roundabouts [24, 26].

The modelling also showed an increase in the concentrations of pollutants at the TOK. The main traffic flow A-B and B-A at this intersection is characterized by a high share of freight traffic (up to 41%). TOK has a specific spatial arrangement and lane layout. This arrangement increases safety and capacity on the one hand, but on the other hand reduces the speed of passage in the main direction. A significant negative in this regard was the reduction in the speed of road traffic through the TOK and the associated longer stay of road traffic in the intersection area. Passenger cars and trucks spend a longer time in the intersection area, where they produce pollutants. Acceleration and deceleration also play a significant role in the production of pollutants (intensive braking affects the production of particulate matter from brake and road surface wear) [10].

In the case of this study, there is a certain interruption of the continuous traffic flow in the direction A-B and B-A. A similar study also showed an increase in the concentrations of nitrogen oxides but, on the contrary, a decrease in the concentrations of $PM_{10}$ and $PM_{2.5}$, where field measurements were carried out at the intersection and subsequently at the new roundabout [27].

In conclusion, however, we can generally state that the main environmental benefits of turbo roundabouts lie in a higher level of safety by eliminating collision points, in a reduction in noise levels by adjusting passing speeds and, last but not least, in a possible reduction in air pollution due to an increase in capacity. Their introduction appears to be a beneficial solution from the point of view of achieving transport sustainability goals. Of course, a thorough assessment of the introduction of this type of intersection is important, as it may not be suitable for every traffic situation and location.

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## References

[1] EEA: *Transport and Environment Report 2022 (TERM2022) Digitalisation in the Mobility System: Challenges and Opportunities [No 07/2022]*, 2022, doi:10.2800/47438
[2] EEA: *Decarbonising Road Transport - the Role of Vehicles, Fuels and Transport Demand*, Transport and Environment Report 2021, 2022,
[3] HONG, J. Y. - JEON, J. Y.: The effects of audio–visual factors on perceptions of environmental noise barrier performance. Landscape and Urban Planning, Vol. 125, pp. 28–37, 2014, doi:10.1016/J.LANDURBPLAN.2014.02.001
[4] BABISCH, W. - BEULE, B. - SCHUST, M. - KERSTEN, N. - ISING, H.: Traffic noise and risk of myocardial infarction. Epidemiology, Vol. 16, No. 1, pp. 33–40, 2005, doi:10.1097/01.ede.0000147104.84424.24
[5] VAN KEMPEN, E. - BABISCH, W.: The quantitative relationship between road traffic noise and hypertension: A meta-analysis, Journal of Hypertension, Vol. 30, No. 6, pp. 1075–1086, 2012, doi:10.1097/HJH.0B013E328352AC54
[6] TROLLÉ, A. - TERROIR, J. - LAVANDIER, C. – MARQUIS-FAVRE, C. - LAVANDIER, M.: Impact of urban road traffic on sound unpleasantness: A comparison of traffic scenarios at crossroads. Applied Acoustics, Vol. 94, pp. 46–52, 2015, doi:10.1016/J.APACOUST.2015.02.008
[7] HEGEWALD, J. - SCHUBERT, M. - FREIBERG, A. - STARKE, K. R. - AUGUSTIN, F. - RIEDEL-HELLER, S. G. - ZEEB, H. - SEIDLER, A.: Traffic Noise and Mental Health: A Systematic Review and Meta-Analysis. International Journal of Environmental Research and Public Health 2020, Vol. 17, Page 6175, Vol. 17, No. 17, pp. 6175, 2020, doi:10.3390/IJERPH17176175
[8] MORGAN, P.: *Guidance Manual for the Implementation of Low-Noise Road Surfaces.* FEHRL 2006, Brussels, Belgium, 2006,

[9] DURCANSKA, D. - DECKY, M. - LICBINSKY, R. - HUZLIK, J.: Project spens Sustainable pavement for European new member states, Communications - Scientific Letters of the University of Žilina, Vol. 15, No. 2, pp. 49–55, 2013, doi:10.26552/com.c.2013.2.49-55
[10] OECD: *Non-Exhaust Particulate Emissions from Road Transport*, OECD, 2020, doi:10.1787/4a4dc6ca-en
[11] MATTHAIOS, V. N. - LAWRENCE, J. - MARTINS, M. A. G. - FERGUSON, S. T. - WOLFSON, J. M. - HARRISON, R. M. - KOUTRAKIS, P.: Quantifying factors affecting contributions of roadway exhaust and non-exhaust emissions to ambient PM10–2.5 and PM2.5–0.2 particles. Science of The Total Environment, Vol. 835, pp. 155368, 2022, doi:10.1016/J.SCITOTENV.2022.155368
[12] FUSSELL, J. C. - FRANKLIN, M. - GREEN, D. C. - GUSTAFSSON, M. - HARRISON, R. M. - HICKS, W. - KELLY, F. J. - KISHTA, F. - MILLER, M. R. - MUDWAY, I. S. - OROUMIYEH, F. - SELLY, L. - WANG, M. - ZHU, Y.: A Review of Road Traffic-Derived Non-Exhaust Particles: Emissions, Physicochemical Characteristics, Health Risks, and Mitigation Measures. Environmental Science and Technology, Vol. 56, No. 11, pp. 6813–6835, 2022, doi:https://doi.org/10.1021/acs.est.2c01072
[13] JANDACKA, D. - DURCANSKA, D. - CIBULA, R.: Concentration and inorganic elemental analysis of particulate matter in a road tunnel environment (Žilina, Slovakia): Contribution of non-exhaust sources. Frontiers in Environmental Science, Vol. 10, No. September, pp. 1–17, 2022, doi:10.3389/fenvs.2022.952577
[14] JANDACKA, D. - BRNA, M. - DURCANSKA, D. - KOVAC, M.: Characterization of Road Dust, PMx and Aerosol in a Shopping–Recreational Urban Area: Physicochemical Properties, Concentration, Distribution and Sources Estimation. Sustainability 2023, Vol. 15, Page 12674, Vol. 15, No. 17, pp. 12674, 2023, doi:10.3390/SU151712674
[15] HONG, S. - YOO, H. - CHO, J. - YEON, G. - KIM, I.: Characteristics of Resuspended Road Dust with Traffic and Atmospheric Environment in South Korea. Atmosphere, Vol. 13, No. 8, pp. 1215, 2022, doi:10.3390/atmos13081215
[16] MATARA, C. - OSANO, S. - YUSUF, A. - AKECH, E.: An Assessment of the Contribution of Vehicular Traffic to Ambient Air Quality - A Case Study of Nairobi Expressway Corridor. Civil and Environmental Engineering, Vol. 20, No. 1, pp. 54–67, 2024, doi:10.2478/CEE-2024-0005
[17] HEGROVÁ, J. - PROKEŠ, L. - ANDĚL, P. - BUCKOVÁ, M. - JANDOVÁ, V. - EFFENBERGER, K. - LIČBINSKÝ, R.: Monitoring of the impact of road salting on spruce forest ecosystem in the vicinity of the highway D1 in the Bohemian-Moravian Highlands, Czech Republic. Environmental Science and Pollution Research, Vol. 29, No. 8, pp. 11232–11242, 2022, doi:10.1007/S11356-021-16468-9/METRICS
[18] BOUH, H. A. - BOUNAKHLA, M. - BENYAICH, F. - NOACK, Y. - TAHRI, M. - FOUDEIL, S.: Seasonal Variation of Mass Concentration and Chemical Composition of PM2.5 and PM10, Source Identification and Human Health Risk Assessment in Meknes City in Morocco. Aerosol Science and Engineering, Vol. 7, No. 2, pp. 151–168, 2023, doi:10.1007/s41810-022-00169-y
[29] MICHALICOVÁ, R. - HEGROVÁ, J. - SVOBODA, J. - LIČBINSKÝ, R.: Seasonal and spatial variations of arsenic and its species in particulate matter in an urban environment of Brno, Czech Republic. Environmental Science and Pollution Research, Vol. 31, No. 43, pp. 55251–55262, 2024, doi:10.1007/S11356-024-34645-4/TABLES/1
[20] JANDACKA, D. - DURCANSKA, D.: Seasonal Variation, Chemical Composition, and PMF-Derived Sources Identification of Traffic-Related PM1, PM2.5, and PM2.5–10 in the Air Quality Management Region of Žilina, Slovakia. International Journal of Environmental Research and Public Health, Vol. 18, No. 19, pp. 10191, 2021, doi:10.3390/ijerph181910191
[21] DRLICIAK, M. - CINGEL, M. - CELKO, J. - PANIKOVA, Z.: Research on Vehicle Congestion Group Identification for Evaluation of Traffic Flow Parameters. Sustainability (Switzerland), Vol. 16, No. 5, pp. 1861, 2024, doi:10.3390/su16051861
[22] DECKÝ, M. - TROJANOVÁ, M. - REMEK, Ľ. - JÁTY, L.: Noise polution from roundabut traffic in the outer environment of built-up areas of towns. 12th International Multidisciplinary Scientific GeoConference and EXPO - Modern Management of Mine Producing, Geology and Environmental Protection, SGEM 2012 (Vol. 4), 927–934, 2012, doi:10.5593/sgem2012/s22.v4013
[23] MARGORÍNOVÁ, M. - TROJANOVÁ, M. - DEKCÝ, M. - REMIŠOVÁ, E.: Noise costs from road transport. Civil and Environmental Engineering, Vol. 14, No. 1, pp. 12–20, 2018, doi:10.2478/CEE-2018-0002
[24] JANDACKA, D. - DECKY, M. - HODASOVA, K. - PISCA, P. - BRILIAK, D.: Influence of the Urban Intersection Reconstruction on the Reduction of Road Traffic Noise Pollution. Applied

Sciences 2022, Vol. 12, Page 8878, Vol. 12, No. 17, pp. 8878, 2022, doi:10.3390/APP12178878

[25] AHAC, M. - AHAC, S. - LAKUŠIĆ, S.: Long-Term Sustainability Approach in Road Traffic Noise Wall Design. Sustainability 2021, Vol. 13, Page 536, Vol. 13, No. 2, pp. 536, 2021, doi:10.3390/SU13020536

[26] AHAC, S. - AHAC, M. - DOMITROVIĆ, J. - DRAGČEVIĆ, V.: Modeling the influence of roundabout deflection on its efficiency as a noise abatement measure. Sustainability (Switzerland), Vol. 13, No. 10, pp. 5407, 2021, doi:10.3390/su13105407

[27] JANDACKA, D. - DURCANSKA, D. - KOVALOVA, D.: Concentrations of traffic related pollutants in the vicinity of different types of urban crossroads. Communications - Scientific Letters of the University of Zilina, Vol. 21, No. 1, 2019,

[28] LEONARDI, S. - DISTEFANO, N.: Turbo-Roundabouts as an Instrument for Improving the Efficiency and Safety in Urban Area: An Italian Case Study. Sustainability 2023, Vol. 15, Page 3223, Vol. 15, No. 4, pp. 3223, 2023, doi:10.3390/SU15043223

[29] DataKustik GmbH: *CadnaA - Reference Manual*Gilching, 2020,

[30] DataKustik GmbH: *Manual for CadnaA - Option APL-Calculation of Air Pollutants*, 2017,

[31] Janicke Consulting: *AUSTAL2000 Program Documentation of Version 2.4*Dunum, 2009,

[32] Federal Ministry for Environment, N. C. and N. S.: *Technical Instructions on Air Quality Control – TA Luft*, 2002,

[33] Ausbreitungsmodelle, U. A.: *VEREIN DEUTSCHER INGENIEURE Atmospheric dispersion models Particle model VDI 3945 Blatt 3 / Part 3*, 2020,