Change of Acoustic Climate Following Introduction of Road Narrowing on Divided Street

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Abstract. Challenges involving road safety in town and cities have increased recently, due to development of motoring. Local authorities are facing the dilemma of how to decrease the number of road accidents through the use of various traffic calming devices. Moderate traffic calming devices are used on throughways crossing towns with higher permissible speeds and occasional pedestrian traffic. One of such divided streets in Szczecin was narrowed on both sides by the introduction of traffic separators and U-21 road sign. The authors conducted a series of speed and road noise measurements of the street. Measurements were performed at the same traffic volume levels to assess changed road conditions and probably changed acoustic climate. The paper presents speed measurement results along the applied road narrowing and acoustic maps before and after the application of road narrowing on both sides. The narrowing resulted in non-uniform speed changes along the device. Only motorists in the inside lane, moving along heavy vehicles on the outside lane, reduced their speeds. The presented Leq measurement results of road noise along the road narrowing on both sides, on divided road, showed that the narrowing did not produce rapid changes of road noise levels. Differences of ΔLeq noise levels at successive test sections in the vicinity of the narrowing were 1-2.5 dB(A). Analysis of the applied traffic calming devices of slight lane narrowing (0.5-0.6 m) was conducted. It showed that although speed changes occurred compared to the period before the narrowing had been introduced, the narrowing was not effective and can be used only at preliminary stage, i.e. before more restrictive measures of traffic calming may be introduced. It is crucial, however, that since the narrowing was introduced no road accidents involving pedestrians have been reported so far.

1. Introduction
The increasingly rapid pace of life brings about transport problems in towns and cities. The need to move faster increases the hazard of traffic accidents on traffic arteries connecting the different parts of cities where higher speeds of travel are permitted. In Poland since 2011 the default speed limit for built-up areas is 50 km/h in the period between 5 a.m. and 11 p.m. which is increased to 60 km/h in the period between 11 p.m. and 5 a.m.

However, there are streets and through routes in cities where a higher allowed speed is posted on the speed limit signs. These are generally through roads running through areas occupied by allotment gardens, away from any residential buildings. The typical occupancy types found along the road include predominantly storage yards, warehouses, less frequently supermarkets and any residential buildings are located further away from the street (50-150 m). There are footpaths on either side with only sporadic traffic. In the recent years a few serious traffic accidents happened in Szczecin on pedestrian crossings on dual carriageways with higher posted speed limits (70 km/h). Among the casualties were pedestrian´s crossings the street and heading to bus stops. Having in mind the safety of vulnerable road users in 2017
the city authority decided to provide chokers (mid-block narrowings) right before sensitive pedestrian crossings at simple intersections (Figures 1 and 2) to get drivers slow down as they approach the crossing. Chokers are placed upstream of pedestrian crossings on both carriageways by placing U-21 signs in three places per choker, accompanied with U-25 traffic barriers placed at different angles in the range from 45° to 80° in relation to the straight line perpendicular to the lane centreline. As a result, each lane is narrowed down by ca. 0.5-0.6 m.

The test section under analysis is located near a three-leg intersection without traffic signals, (Figure 3). Transverse traffic is sporadic with pedestrians crossing in this direction when heading to allotment gardens or to the bus stop. There were, however, a few fatal traffic accidents on both crossings in the recent time.

The drivers tend to increase speed tempted by long sections between signalized intersections and the surroundings devoid of residential buildings (Figure 3).

2. Input assumptions
The research included carrying out speed measurements in free flow condition after installation of chokers on both carriageways on the sections upstream of the pedestrian crossings at three leg intersection without traffic signals, in accordance with the guidelines of [1]. The traffic volumes and the levels of noise were also measured, separately for each carriageway, in accordance with the guidelines of [1]. Since all the tests were carried out simultaneously the traffic volumes on the three sections: upstream, within and downstream of the chokers did not vary much. The traffic volume ranged from 750 veh./h to 1100 veh./h (per carriageway) including 3.7-7.5% of heavy goods vehicles (HGV). The only variables in these tests were the speed and noise measurement points on the three sections: upstream, within and downstream of the chokers on each carriageway and the associated levels of generated noise $L_{eq}$.

Figure 1. Inbound traffic direction (towards the city centre)
Figure 2. Outbound traffic direction (from the city centre)
3. **Analysis of the change of acoustic environment on urban streets according to local and international research projects**

The issue of alteration of the sound environment in relation to traffic calming treatments is consequential and related to obtaining (or not obtaining) the planned speed reduction. The level of noise generated by road traffic has been studied by a number of researchers in different countries. Changes to the traffic noise level should be checked especially when considering traffic calming and speed reduction problems. The research on the effect of small speeds of travel on the level of noise was advanced by Finish researchers [3] who modelled the level of noise generated at the tyre/road interface and the level of noise generated by the engine during operation. Problems of similar nature were investigated also by Polish researchers, except that their focus was the relation between the noise level and the type of road surface [4] and [5]. More attention to small speeds and their effect on the level of generated noise was put by Swiss researchers [6], who focussed on distinguishing the different types of noise generated by vehicles, i.e. starting-up noise and noise generated by rolling of wheels (tyre noise). In relation to passenger cars, the guidelines [6] conclude that for speeds up to 35 km/h the primary source of noise is the vehicle’s powertrain and above it the tyre noise starts to prevail. This is different in the case of HGV’s where the powertrain remains the main source of noise up to the speed of 60 km/h upon exceeding of which it is overcome by the tyre noise.

4. **Analysis of the changes of speed**

The speed limit in the analysed section between signalized intersections is 70 km/h as posted on the B-33 sign (Figure 4). On one carriageway carrying traffic coming from the city centre and heading to the district of Krzekowo near the sensitive pedestrian crossings where fatal accidents with pedestrian casualties took place speed was limited to 50 km/h. The B-33 sign is placed ca. 150 m upstream of the pedestrian crossing after the vertical curve apex (Figure 5).
Bearing in mind that the level of road traffic noise depends primarily on the traffic volume and on the speed of travel, the changes of speed on the test sections were analysed in the first step. Speed measurements in free flow conditions were carried out also before installation of chokers, yet only on the intersection approach section. In the current investigation the test sections were located upstream, within and downstream of chokers on both carriageways. In addition, the speed of passenger cars travelling along the fast lane was also measured when a lorry or bus/coach travelled on the nearside (slow) lane providing side restriction and apparent narrowing of the road. The measurement data were subjected to a statistical analysis whose results are presented in Table 1. The analysis of the data presented in Table 1 showed that the confidence intervals with 95 percent probability include the average values of measured speeds in free flow condition.

Table 1. Values of speed distribution parameters, standard deviation and confidence interval limits on the test sections.

| Analysed parameter, km/h | Location of the test section on the carriageway heading to the city centre | Location of the test section on the carriageway heading to the district of Krzekowo |
|--------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
|                         | Before traffic calming treatment | Section A upstream of choker | Section B within choker | Section C downstream of choker | Section B (additional measurements) | Before traffic calming treatment | Section D upstream of choker | Section E within choker | Section F downstream of choker | Section E (additional measurements) |
| $v_{85}$ in free flow condition | 81.8 | 59.0 | 62.7 | 69.5 | 54.6 | 86.7 | 70.7 | 70.4 | 70.5 | 56.9 |
| $v_{av}$ in free flow condition | 66.9 | 52.2 | 56.7 | 61.5 | 51.9 | 71.7 | 58.2 | 57.8 | 56.2 | 51.2 |
| standard deviation $s$ | 11.7 | 7.7 | 7.5 | 9.6 | 4.1 | 12.9 | 12.5 | 10.2 | 10.9 | 5.4 |
| lower confidence limit | 64.6 | 50.4 | 54.7 | 58.9 | 50.7 | 69.1 | 54.9 | 55.3 | 53.1 | 50.0 |
| upper confidence limit | 69.3 | 54.0 | 58.7 | 64.1 | 53.0 | 74.3 | 61.5 | 60.3 | 59.3 | 52.4 |

**Figure 4.** Speed limit of 70 km/h posted on the B-33 sign placed on the carriageway heading to the city centre

**Figure 5.** Speed limit of 50 km/h posted on B-33 sign placed on the carriageway coming from the city centre
The efficiency of the applied traffic calming treatments can be assessed on the basis of speed reduction in relation to the speed before their implementation or with the traffic calming measures already in place to check if the drivers slow down along the section of the street under analysis. The authors have chosen to present the output of their research as a change in the percentages of the respective speed ranges, as presented in Figure 6 and Figure 7 respectively.

**Figure 6.** Distribution of percentages of speeds measured on the test sections located on the carriageway heading to the city centre

**Figure 7.** Distribution of percentages of speeds measured on the test sections located on the carriageway coming from the city centre and heading to the district of Krzekowo

The analysis of the percentages of speed ranges (Figure 6) shows that before installation of chokers 38% of the drivers exceeded the speed limit on the analysed carriageways. Upstream of the choker only 1% of drivers exceeded the speed limit of 70 km/h. The location under analysis offers good view of the street, the footpaths and the pedestrian crossing as a result of which with no pedestrians crossing the street the percentage of drivers driving faster than 70 km/h increases which is attributed to placement of 70 km/h speed limit B-33 sign right after the crossing (Figure 4). The most dangerous test section is where additional measurements were carried out, as then the driver travelling along the fast lane has a
limited view on the pedestrian crossing and on the footpath which are partly hidden by a large vehicle travelling on the nearside lane. On this basis we can conclude that the applied narrowing turned out to be quite effective as 100% of the drivers keep the speed limit. This said, we should not ignore the fact that on the fast lane only 33% of the drivers approach the pedestrian crossing with speeds lower than 50 km/h. Hence, in the authors' opinion the treatment described in this paper can be used in the preparatory period, i.e. before implementation of the proper traffic calming treatments. For example, if the D-4 sign was placed at the edge of the pedestrian crossing (Figures 2 and 3), right on the carriageway, as it has been done on the other carriageway, thus extending the narrowing by over a dozen metres the percentage would probably increase to ca. 60%.

Similar analyses of the percentages of the speed ranges were carried out for the data obtained from the other carriageway. These test sections are quite different than the previously described ones, mainly in terms of features in the vicinity of the road and the driving conditions. The driver enters the section leading to the choker after passing an uphill section and a crest vertical curve where he/she has limited visibility and the 50 km/h speed limit is posted at the end of that section, right before the choker. The analysis of the percentages of speed ranges (Figure 7) shows that before choker installation 100% of the drivers travelled faster than 50 km/h and 58% travelled faster than 70 km/h. With the choker in place only 17% of the drivers travelled faster than 70 km/h. These proportions are valid also for the narrowed section. After passing the choker and seeing signalized intersection ca. 250 m ahead the drivers slightly slow down. Similarly to the previous situation, on the additional measurements section 53% of the drivers were found to slightly reduce the speed before the pedestrian crossing, most probably owing to the D-4 sign placed at the crossing edge right on the carriageway (Figure 8). This said, the percentage of drivers travelling faster than 50 km/h is still high.

![Figure 8. D-4 sign placed at the pedestrian crossing edge, thus extending the choker length](image)

5. Analysis of changes to the sound environment

Table 2 gives the levels of noise $L_{eq}$ measured over 15 minutes in relation to the analysis of the changes in the road traffic noise level along the carriageway with installed chokers. Consistency of input conditions was ensured by carrying out the measurements of speed, traffic volume and noise level on all the test sections at the same time. The noise measurements were carried out, in accordance with the guidelines of [2] on the footpaths along the test sections, at 3 m distance from the kerb and at 1.5 m height to represent the level of noise perception by pedestrians or passengers heading to the bus stops.

As per the Polish code requirements [7] in areas with multi-family and public accommodation occupancies noise levels must not exceed 65 dB(A) during daytime and 56 dB(A) during the night. As we can see from the data in Table 2 the measured values exceed the maximum allowed noise levels. Moreover, on the sections where speed reduction was required the noise level has even increased after installation of chokers. However, in analysing the allowable level of road traffic noise one should take
into account the spatial development situation (features) along the road. On the analysed street the residential buildings are spaced by over 50 metres from the kerb and there is a strip of vegetation including mature trees with extensive crowns separating them from the street (Figure 9). On the other side of the street there are allotment gardens separated from the footpath by a strip of thick vegetation.

Table 2. Levels of road traffic noise measured on the analysed test sections

| Location of the measurement section | Before traffic calming treatment | Section A upstream of choker | Section B within choker | Section C downstream of choker |
|-------------------------------------|---------------------------------|-----------------------------|------------------------|-------------------------------|
| Location of the test section on the carriageway heading to the city centre | | | | |
| Level of road traffic noise $L_{eq}$, dB(A) | 71.8 | 70.6 | 71.7 | 74.0 |

| Location of the measurement section | Before traffic calming treatment | Section D upstream of choker | Section E within choker | Section F downstream of choker |
|-------------------------------------|---------------------------------|-----------------------------|------------------------|-------------------------------|
| Location of the test section on the carriageway heading to the district of Krzekowo | | | | |
| Level of road traffic noise $L_{eq}$, dB(A) | 71.9 | 71.8 | 70.6 | 72.4 |

Figure 9. Aerial view of the vicinity of the street at the test sections

Taking this into account, the authors prepared sound maps taking the input data including traffic volume, average speed, local terrain relief, location of buildings and features present along the street. The traffic noise maps presenting the situation before and after narrowing are presented in Figure 10 and Figure 11. The satellite images used for road traffic noise distribution analyses and for mapping the sound environment are courtesy Google Earth Pro.
The analysis of the road traffic noise distribution (Figure 11) shows smaller variation after installation of chokers, as compared to the situation without chokers (Figure 10). Moreover, the 64 dB(A) noise contour line falls within the vegetated strip in both cases, and as a result, the level of noise reaching the residential buildings spaced from the carriageway by over 50 metres is much smaller than the maximum allowed limit. Conversely, on the allotments side, the level of noise in the gardens...
located nearest to the carriageway is about 64-65 dB(A) i.e. at the maximum allowed limit. The levels of noise recorded on the footpaths and at the bus stops was approximated 66-68 dB(A), this exceeding the maximum allowed limit. Considering sporadic nature of pedestrian traffic in the analysed section of the street and maximum 15-minute waiting time at the bus stops, during which the passengers may be exposed to excessive noise, we can conclude that the implemented traffic calming measures have not significantly changed the sound environment in the area under analysis.

6. Conclusions
The implemented narrowing had varied effect on the speed reduction. The measurement data show that only drivers travelling on the fast lane parallel to a large vehicle travelling on the nearside lane reduce their speed considerably. The road traffic noise measurements performed at the choker sections on dual carriageway road show that installation of chokers does not cause any abrupt changes to the road traffic noise levels. The noise levels differ between the successive sections near the narrowing by 1-2.5 dB(A). The analyses of the implemented traffic calming treatment, namely slight narrowing of the travel lanes show that it has brought about some speed reductions, yet the effect is not satisfactory and this treatment should be used on its own only as a temporary measure before more restrictive traffic calming measures are applied. However, it is worthwhile noting that since the installation of chokers no traffic accidents involving pedestrians have taken place on the analysed section.

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