Efficient Improvement of the Visibility of Pedestrians on Junctions in Tempo–30 Zones

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Abstract. Tempo–30 zones are used with increasing frequency as a traffic calming measure. They are intended primarily to make the drivers slow down and increase the safety of traffic. In the Tempo–30 zones the drivers must pay particular attention to vulnerable road users (VRU) who can travel across the street at any place. The drivers are warned of the traffic calmed area ahead of them by the specific street and junction geometry and the street furniture, compelling them to reduce the driving speed. One of the most often used design measures used for Tempo–30 junctions is narrowing of the junction legs and extending their corners. Reducing the driving speed increases the driver’s central vision area resulting in quicker and easier spotting of pedestrians about to cross the roadway. Bulb-outs (a.k.a. build-outs) provided at junction corners shorten the pedestrian crossing distance and offer a better view onto the oncoming vehicles. They are usually combined with on-street parking lanes dedicated to local residents. Taking the above facts into account, the author carried out speed measurements on a chosen downtown street located in a Tempo–30 zone. In the survey several speed measuring devices were deployed to automatically measure and record the operating speed and volume of traffic at different test locations at the same time. At least one hundred (100) measurements were taken per measurement site and direction of traffic. During the survey the weather was dry and such was the pavement surface. The results were subjected to statistical analyses. The statistical inference part of research included, inter alia, nonparametric test of independence and median test performed to confirm the null hypothesis $H_0$ that the measurement results do not depend on the measurement site location. The alternative hypothesis $H_1$ – was confirmed in almost all cases, meaning that the vehicle speed actually depends on the measurement site location. The locations of the measurement sites were chosen considering the direction of traffic, bulb-out location and the approach and departure conditions. The measurement data and the statistical test results have confirmed that in Tempo–30 zones bulb-out corners have an actual effect on speed reduction on the approach to the junction, enhancing the driver’s ability to spot any pedestrians about to cross the street. With the bulb-outs in place, the vehicles parked before the junction do not obstruct the pedestrian’s central vision area, thus enhancing their ability to spot any oncoming vehicles.

1. Introduction

In urban areas the need of calming the traffic in order to improve the safety of drivers and, most importantly, of the vulnerable road users (VRU) is becoming an issue in an ever growing number of locations. To address this issue Tempo–30 zones are being implemented in neighbourhoods and in suburbs.
The Tempo–30 zones are provided with traffic calming measures such that the speed limit of 30 km/h is not exceeded there. Without the Tempo–30 zone in place, the official speed limit for built-up areas in Poland is 50 km/h. According to the reports of British and Japanese researchers [1, 2] the size of the **central visual field** is related to the accuracy of evaluation of the path of travel, the surrounding environment and the traffic conditions on the road depending on the speed of travel. With the increase of speed the angle of view decreases and the driver focuses on more distant points located down the road, as shown in Figure 1 and Figure 2. Similar research projects, with the scope including built-up areas have been recently carried out by French researchers.

The results of these projects published in [3, 4, 5] demonstrate narrowing of the **driver's central visual field** at the speed of 50 km/h, as compared to 30 km/h which has a bearing on the perception of the surrounding environment. Figures 3 and 4 show narrowing of the **driver's central visual field** between the speeds of 30 km/h and 50 km/h. According to the research results published in [3, 4, 5] the **central visual field** depends primarily on the speed of travel and decreases from the angle of 120° at 30 km/h to 80° as the speed rises to 50 km/h. The central visual field is surrounded by peripheral vision areas where the driver, while focusing on the central portion of the street, can see only outlines of objects. The remaining part of the surrounding environment can be seen by the driver only upon moving the head or directing the eyes to the particular features located there.

Thus, the driver’s capability to identify the details of the environment and the pedestrians is greater at the maximum permitted speed in Tempo–30 area, i.e. 30 km/h as compared to driving at 50 km/h. This said, the speed of 30 km/h should be used as the target in designing all the traffic calming measures, so that all the features intended to be seen by the driver are in the central vision area. The driver’s visual field when driving straight ahead is presented in Figures 3–6. In a Tempo–30 area a pedestrian can travel across and along the street at any place which eliminates the need of marked pedestrian crossings (for example with P-10 line). This is associated with the primary objective of the Tempo–30 zone, i.e. to make the driver slow down and pay more attention to the surrounding environment where vulnerable road users can be present.
Figure 3. Schematic division of the driver’s field of vision

Figure 4. Difference in perception of pedestrians in the driver’s field of view

Figure 5. Visualisation of the driver’s field of vision when driving at 50 km/h in urban environment, 80° angle of view

Figure 6. Visualisation of the driver’s field of vision when driving at 30 km/h in urban environment, 120° angle of view
In order to ensure spotting of a pedestrian travelling across a street in the Tempo–30 zone bulb-outs are designed at corners of junctions with side streets in order to shorten the distance of travel across the carriageway as the primary function and to provide parking space without obstructing the view both to the pedestrian and to the driver. The driver's and pedestrian's fields of view in conventionally designed junctions and junctions with bulb-out corners are presented in Figures 7-9.

Figure 7 presents a conventionally designed junction and the driver's and pedestrians fields of view on a typical street with 50 km/h official speed limit. The junction presented in Figure 8 is similar to that in Figure 7 except that here the footpath and carriageway surfaces are brought to the same level and the vehicles are allowed to park closer to the junction. Analysing the driver's fields of view presented in Figures 7 and 8 it can be seen that allowing to park vehicles close to the pedestrian crossings on all the junction legs inhibited the driver’s capability of spotting the pedestrian about to cross the street (the fields in Figure 7-9 marked with cardinal directions of intersection legs). The same applies to the pedestrian who could have a problem to see the oncoming vehicle (the pedestrian's view fields are marked with numbers 1, 2, 3 and 4). The driver's fields of view presented in Figure 7 and Figure 8 were analysed to reveal that for 50 km/h speed of travel the pedestrians waiting at the crossing are beyond the driver's field of view limits (Figure 7, leg W and leg E). The driver approaching the crossing at a speed of 30 km/h has an obscured view of pedestrians due to the vehicles parked in the analysed legs, which reduce the driver's field of view. The pedestrian waiting at the crossing could be spotted by the driver no sooner than at the P-14 line marking placed 2 m upstream of the crossing (Figure 8, leg E). The pedestrians' vision of oncoming vehicles was obscured by the parked vehicles, both for 30 km/h and 50 km/h speeds.

Considering the above presented analyses, various modifications of the junction layout are designed a traffic calming measure. One of the most popular engineering measures are bulb-out corners combined with a parking lane up to the bulb-out location. This results in narrowing the junction leg, making the driver aware of the traffic-calmed area ahead. This design is pictured in Figure 9. The bulb-out corners give the driver good visibility of the pedestrians waiting at the crossing. In Tempo–30 zones there are

![Figure 7 Driver's and pedestrian's fields of view in junction area, 50 km/h speed of travel](image1)

![Figure 8 Driver's and pedestrian's fields of view in junction area, with 30 km/h speed limit posted on B-33 sign](image2)
typically no marked crossings in the junction area since it is the very essence of any traffic calmed area that the drivers should slow down and attend to pedestrians at all times. Bulb-out corners shorten the distance of travel across the street, thus reducing the hazards and, in addition, give the pedestrians more visibility of the oncoming traffic. Both these factors largely enhance the safety of traffic in Tempo–30 zones.

Figure 9 Driver's and pedestrian’s visual fields in a four-way junction with bulb-out corners in a Tempo–30 zone

2. Research section
Taking into account the above design guidelines to use bulb-out corners on junctions in Tempo–30 zone, the author carried out travel speed surveys following street reconstruction project in order to verify reduction of travel speed in the vicinity of altered junctions with bulb-out corners. The survey was carried out on two junctions located in Tempo–30 zone. During all the speed measurements the weather was dry and such was the pavement surface.

The first of the two is a four-way staggered junction located in the downtown area between two main thoroughfares. In this case, the footpath and carriageway surfaces were brought to the same elevation and the bulb-out corners were combined with parking lanes, separated from the footpath area by vintage safety posts. Stone block paving is used both on the footpath and on the carriageway, distinguished by different colours only. In the absence of designated crossings, pedestrian are allowed to travel across the street at any point. The junction area has also stone paving in different colour.

The second of the two analysed junctions is a three-way junction located in the single-family residential area in the suburbs. Here, traffic calming treatment was limited to one leg, where the corner was extended with a triangular shape bulb-out. This kerb extension is combined with the pedestrian crossing. The whole junction was provided with red concrete block paving, raising the surface 7 cm above the previous grade.

3. Results and discussions
Speed surveys were carried out on both junctions at a few measurement sites located along either traffic direction on double lane two-way streets. The traffic volume was similar in both cases under analysis, i.e. ca. 450–500 veh./h. The speed measurements were carried out during weekday peak hours simultaneously in the whole junction area using a few traffic counters with automatic volume and speed
data recording. The survey was continued until at least one hundred (100) measurements were obtained per section. The measurement locations were sited at key points along the respective sections of the path of travel and directions of traffic. Each measurement site characterised the junction approach speed, the section right before and after the junction and the departure section. The numbering scheme of the measurement sites and of the directions of traffic is presented in Figures 10 and 11.

Considering the traffic calming effect the percentages of speeds below or equal to 30 km/h and higher than 30 km/h were estimated for the measurement data. For statistical analysis of the effect of the measurement site location on the result of measurement nonparametric test of independence and median test were performed to confirm the null hypothesis $H_0$ that the measuring results do not depend on the measurement site location, with the alternative hypothesis $H_1$ stating that the results depend on the measurement site location. In almost all cases the results of the statistical tests confirmed that the null hypothesis $H_0$ should be rejected as the speed data were found to depend on the measurement point location. This means that bulb-out corners influenced the operating speeds of vehicles at a statically significant level. The speed distribution parameters and the results of statistical tests are presented in Table 1 - for the four-way junction and in Table 2 - for the three-way junction. In addition, Table 1 presents the speed data obtained on the side street sections (western PW and eastern PE) of the four-way junction.

### Table 1. Speed distribution parameters (km/h) and the results of statistical tests for the four-way junction

| Measurement site numbers in the direction of traffic | Traffic direction |  
|----------------------------------------------------|-------------------|
| S–N traffic direction |  
| P8 | P7 | P6 | P5 | PE |  
| Speed distribution parameters | $v_{85}$ | 33.9 | 34.4 | 28.9 | 28.9 | 25.6 |  
| | $v_{av}$ | 33.6 | 29.9 | 25.3 | 24.1 | 22.3 |  
| Percentage of $v \leq 30$ km/h | % | 26 | 54 | 87 | 91 | 98 |  
| Percentage of $v > 30$ km/h | % | 74 | 46 | 13 | 9 | 2 |  
| Compared measurement sites | – | P7, P8 | P6, P7 | P5, P6 | – |  
| $\chi^2$ test of independence at $\alpha = 0.05$ | $\chi_2^2$ = 3.84 | – | 16.3 | 27.6 | 0.83 | – |  
| $\chi^2$ median test at $\alpha = 0.05$ | $\chi_2^2$ = 3.84 | 33.6 | 63.7 | 9.1 | – |  

| Measurement site numbers in the direction of traffic | Traffic direction |  
|----------------------------------------------------|-------------------|
| N–S traffic direction |  
| P1 | P2 | P3 | P4 | PW |  
| Speed distribution parameters | $v_{85}$ | 33.5 | 29.3 | 32.7 | 29.7 | 22.6 |  
| | $v_{av}$ | 28.7 | 25.1 | 27.0 | 24.4 | 19.8 |  
| Percentage of $v \leq 30$ km/h | % | 64 | 89 | 72 | 88 | 100 |  
| Percentage of $v > 30$ km/h | % | 36 | 11 | 28 | 12 | 0 |  
| Compared measurement sites | P1, P2 | P2, P3 | P3, P4 | – | – | – |  
| $\chi^2$ test of independence at $\alpha = 0.05$ | $\chi_2^2$ = 3.84 | 18.7 | 10.2 | 8.2 | – | – |  
| $\chi^2$ median test at $\alpha = 0.05$ | $\chi_2^2$ = 3.84 | 45.4 | 4.8 | 53.7 | – | – |  

The value in bolds is the only case where the site location did not have any bearing on the measurement result and the data from the analysed measurement sites numbered P5 and P5 made up a single population. In fact, in this case the value of 85th percentile speed does not deviate much from the average speed (Table 1 and Figure 8). The measurement sites P4, P5 and P6 are located in the street section including numerous shops and boutiques which increases pedestrian traffic travelling across the street at any point along the section. This being so, lower speeds were recorded there.
Conversely, much higher speeds, as compared to the neighbouring sites were recorded at the P3 station. There the road is separated from the footpath by a row of safety bollards and the pedestrian traffic across the street is scarce. Similar speeds were obtained at P1, P7 and P8 sites located at the northern side of the street. This is caused, most probably, by a small probability of occurrence of

Figure 10. Charts of speed data and percentages of speed ranges placed on the picture of the analysed four-way junction with bulb-out corners located in the Tempo–30 zone in downtown area
pedestrian traffic on the section where there are only two entrances to public buildings, with the remaining part occupied by residential townhouses.

Table 2 and Figure 11 present the measurement data and the results of analyses obtained on the three-way junction with one bulb-out corner. Nonparametric tests of independence and median tests were carried out for both the analysed directions of traffic, the same as for the four-way junction. With only five vehicles that came into the junction from the side street throughout the whole measurement period, the traffic from this direction was considered close to none and, as such, speed measurements were skipped there.

Table 2. Speed distribution parameters (km/h) and the results of statistical tests for the three-way junction

| Traffic direction | Measurement site numbers in the direction of traffic | P10 | P9 | P8 | P7 | P6 |
|-------------------|-----------------------------------------------------|-----|----|----|----|----|
| S–N traffic direction | Speed distribution parameters | v_{85} | 32.7 | 31.8 | 26.4 | 31.2 | 35.0 |
| | v_{av} | 28.2 | 27.7 | 22.0 | 26.4 | 29.5 |
| | Percentage of v ≤ 30 km/h | % | 69 | 76 | 95 | 74 | 60 |
| | Percentage of v > 40 km/h | % | 31 | 24 | 5 | 26 | 40 |
| | Compared measurement sites | – | P9, 10 | P8, P9 | P7, P8 | P6, P9 |
| | \chi^2 test of independence at a = 0.05 \chi^2 = 3.84 | – | 1.31 | 15.4 | 16.1 | 4.59 |
| | \chi^2 median test at a = 0.05 \chi^2 = 3.84 | 7.78 | 72.2 | 17.2 | 9.0 |

| Traffic direction | Measurement site numbers in the direction of traffic | P1 | P2 | P3 | P4 | P5 |
|-------------------|-----------------------------------------------------|----|----|----|----|----|
| N–S traffic direction | Speed distribution parameters | v_{85} | 33.8 | 29.5 | 31.3 | 35.6 | 34.4 |
| | v_{av} | 27.4 | 23.9 | 25.8 | 31.8 | 29.9 |
| | Percentage of v ≤ 30 km/h | % | 71 | 87 | 80 | 37 | 54 |
| | Percentage of v > 40 km/h | % | 29 | 13 | 20 | 63 | 46 |
| | Compared measurement sites | P1, P2 | P2, P3 | P3, P4 | P4, P5 | – |
| | \chi^2 test of independence at a = 0.05 \chi^2 = 3.84 | 7.8 | 1.6 | 38.1 | 5.8 | – |
| | \chi^2 median test at a = 0.05 \chi^2 = 3.84 | 21.1 | 2.8 | 3.6 | 26.6 | – |

The values in bolds in the above table are the cases where the site location did not have any bearing on the measurement result and the data from both analysed measurement sites made up a single general population. In fact, the values of 85th percentile speeds do not deviate much from the average speed at the compared sites (Table 2 and Figure 11).

Stations P2 and P3 on the three-way junction are a peculiar case, which peculiarity has been confirmed by the results of both nonparametric statistical tests. In this case, in the time spans of smaller traffic density on the oncoming lane the drivers heading in the N-S direction tended to accelerate upon seeing the kerb extension (Figure 11) in order to pass the chicane before the arrival of oncoming traffic. Conversely, a major reduction of the operating speed, attributed to the kerb extension was obtained for the traffic heading in the opposite direction, i.e. S-N and the results of nonparametric statistical test confirmed that narrowing of the street had a bearing on the measurement data at a statistically significant level.
Figure 11. Charts of speed data and percentages of speed ranges placed on the picture of the analysed three-way junction with one bulb-out corner located in the Tempo–30 zone in a single-family residential area in the suburbs
4. Conclusions
The measurement data and the statistical test results confirm that in Tempo–30 zones bulb-out corners have a speed reducing effect in the immediate vicinity of junctions. This effect is, however, limited to a very short stretch of the street. This said, to enhance the traffic-calming effect of bulb-out corners, these features should be provided at all intersection legs.

Bulb-outs are more efficient on downtown junctions with the footpath and carriageway edges brought to the same level. On the other hand, one bulb-out corner on junction with only slightly raised junction table proved to be a less efficient traffic-calming treatment. Moreover, the speed data analyses showed that raising the pavement by 7 cm along the traffic calmed street in Tempo–30 zone had only a minor traffic calming effect.

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