Original Research Article

Analysis of the suitability of road mirrors for future telematics solutions

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Abstract: A huge and quite important role in safe exit from the street with limited visibility plays traffic mirrors. Traffic mirrors, also known as safety mirrors or blind spot mirrors, have a significant impact on road safety. These mirrors are designed with a curved surface that allows for a wider field of view, making it easier for drivers to see objects and vehicles that may be in their blind spots. In order to commit a safe maneuver driver should be confident that the car moving down the street is at a sufficient and safe distance from the exit. Of course, the driver needs to have a perception of the time of the moving car to the place of exit from the street. All of these things play a significant role in safety exit and avoiding collisions. Traffic mirrors ensure an overview of the situation on the road. Moreover, the driver can measure the approximate distance by counting time for approaching the car. The experiment presented in the work is based on the time of the car's approach. The purpose of this article is to detect the optimal time as well as distance before the street with limited visibility in order to exit the street safely and to avoid collisions. In this paper, we provide systematic approach to the research of a data and statistics of this data.

Keywords: safety; traffic mirror; intersection with limited visibility; blind spot; transport; telematics

1. Introduction

When considering the impact of road mirrors, which are used to improve road safety, especially in areas of limited visibility, it appears that the vehicle driver needs to know the time and distance of the approaching car. However, the shape, size of the road mirror and the angle at which it is installed play a very important role in assessing these aspects. Well, when approaching an exit from a street with limited visibility, it can very often be difficult for the vehicle driver to feel how far away a vehicle travelling on the main road is. After analyzing the number of road accidents in Poland for 2021, which were caused by failure to yield the right of way (5566 accidents)[1], it can be seen that this is quite serious. To make matters worse, in many cases in their current form, mirrors, and in fact the lack of skills to use them, contribute to an increased number of road accidents[2].

Observation of the moving vehicle by means of a road mirror helps drivers to feel the approximate distance of the vehicle to the street intersection[3]. In addition, a method of calculating a car's travel time can be used to help identify the above aspects[4]. Thus, a vehicle driver looking into a road mirror using his or her perception of time calculates the time it takes for the vehicle visible in the mirror to move from the moment it is seen in the mirror to the moment it reaches the intersection[3]. In this way, it is possible to ensure a safe exit from the street by knowing the time needed for the exit and the time for the car to reach the intersection in order to avoid a collision. It is also very important to consider the time of day and the weather, as these aspects have a direct impact on the safety of any maneuvers. This article presents the results of a study on the example of intersections in the city of Opole, Poland, and an observation on safe exit from a street with a blind spot in relation to time. And also proposed changes to improve existing solutions using modern telematics solutions. Road mirrors are used to improve road safety and to allow drivers better visibility especially on streets with

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limited visibility, as well as tunnels[5–7]. There are several types of road mirrors. According to the Regulation of the Minister of Infrastructure of 3 July 2003 on the technical conditions for road signs and signals and road traffic safety devices and the conditions for their placement on roads, Dz. U. No. 220 of 23.12.2003, item 181—Annex No. 4 to the regulation presents recommended road mirrors depending on the angular observation distance[8].

If we compare these requirements with the requirements for mirrors used on vehicles enshrined in UNECE Regulation 46—Uniform provisions concerning the approval of rear-view mirrors and vehicles with regard to the placement of rear-view mirrors, the conclusions are as follows:

1) The type of convexity, i.e., the radius of curvature of a section of a sphere, a cylinder or any other surface which the mirror should be, is not specified for mirrors on roads,
2) The permissible deviations of the radius of curvature which determine the distortion of the image transmitted by the mirror are therefore not specified,
3) The minimum value of the reflectance of the mirror surface, which is particularly important at night, is not specified,
4) Arbitrary dimensions of the mirror within the discretized series have been introduced,
5) The following terms were introduced: mirrors with increased angle of observation, minimum angular distance angular observation[5,8].

In the literature of the subject, many studies can be found on the use of road mirrors to improve road safety[7,9]. Additionally, a noticeable trend is the use of modern technology to improve the performance of such mirrors[10–12].

2. Materials and methods

A study of car travel time to a junction with a street with limited visibility was carried out in the city of Opole, Poland. Namely on two different streets with different traffic volumes. The tests were carried out during daytime and night time. And also, with different distances from the mirror of 50 m, 130 m and 250 m. The first study was carried out at the intersection of two Pużaka-Grabowa streets (**Figure 1**). The measurement distance was 50 m during daytime and 130 m during nighttime. The second survey was carried out at Partyzancka—Agnieszka Osiecka streets (**Figure 1**). The measurement interval was 50 m during daytime and 250 m during nighttime. In addition, two different types of road mirrors were considered for the study, namely a round U-18a mirror with a diameter of 600 mm at the Pużaka-Grabowa intersection and a U-18b rectangular mirror with dimensions of 600 × 800 mm at the Partyzancka-Agneska Osiecka intersection (**Figures 2** and **3**).

It is worth noting that the measurement at night time is carried out with a different distance, because the spotting of a vehicle in a road mirror directly depends on the shape of the mirror, its size, as well as on the individual characteristics of the road[12]. This means that the maximum distance at which a vehicle is spotted in the mirror differs at the two intersections studied. But it also means that the appearance in the road mirror of a car moving can be seen further away at night time.

Figure 1. Studied intersections—top view in google maps. **(a)** Agnieszka Osiecka-Partyzancka street; **(b)** Grabowa-Pużaka street.

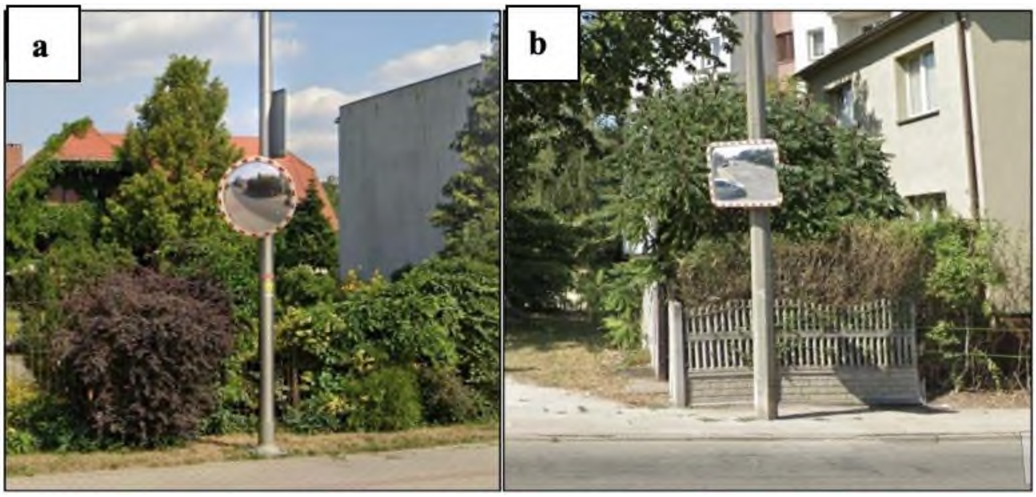

Figure 2. Road mirrors in daytime. **(a)** Agnieszka Osiecka-Partyzancka street; **(b)** Grabowa-Pużaka street.

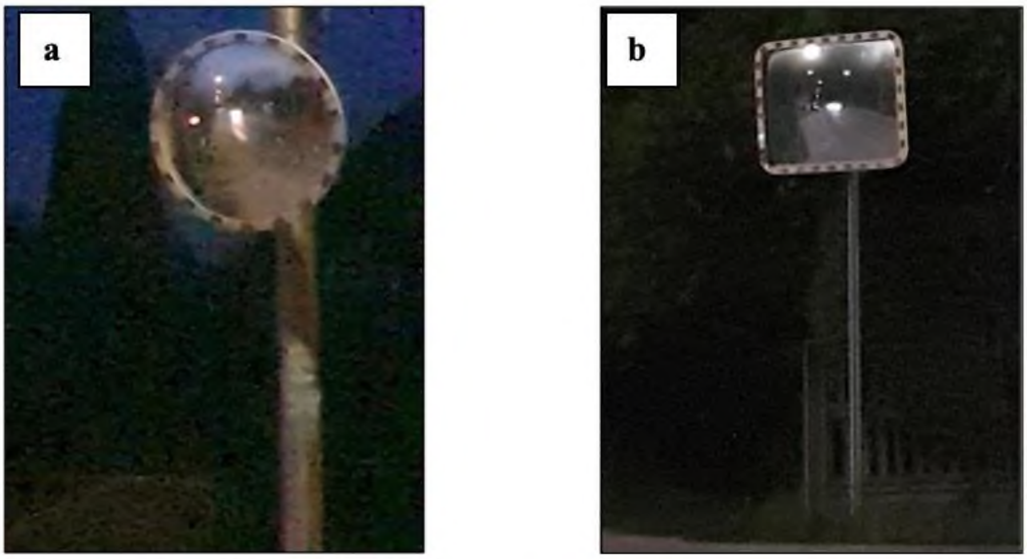

Figure 3. Road mirrors at night time. **(a)** Agnieszka Osiecka-Partyzancka street; **(b)** Grabowa-Pużaka street.

The research carried out was developed using Program: Statistica. First of all, the normality of the distribution (Gauss curve) was tested, which is the most important theoretical probability distribution in statistics. The distribution describes situations where the majority of cases are close to the average result, and the more a given result deviates from the average, the less it is represented. Most cases are close to the average. The further one moves away from the average score, the fewer cases there are. The resolution of normality is made on the basis of a graph in which the values of the analyzed data set are represented as points - if the points line up approximately in a straight line, without a clear curvilinear tendency, this is a sufficient argument for normality. Normality charts were also produced for the individual test results. By analyzing the graphs obtained, it can be concluded that the results obtained have a normal distribution, as the graphs obtained do not express a curvilinear tendency.

In addition, the descriptive statistics used allow the calculation of mean values, standard deviations, variances, asymmetry coefficients and kurtosis of the variables. The mean value is a measure of the average or central tendency of a continuous distribution. Standard deviation and variance are measures of the dispersion (variability) of the data. The coefficient of asymmetry is a measure of the asymmetry of a distribution i.e., the degree to which the distribution is concentrated to the left or right of the mean value. Kurtosis is a measure of the flattening of a distribution i.e., it tells you to what extent the distribution is slender around the mean value.

3. Results

3.1. Grabowa-Pużaka (disclaimer 50 m)

Firstly, the Grabowa-Pużaka intersection was analyzed for the studied distance of 50 m. In accordance with the research methodology, a statistical analysis was carried out to present the normality of the distribution (**Table 1**, **Figure 4**) and descriptive statistics were presented for two variables: time and speed of vehicles travelling on the section in question.

Table 1. Normality of distribution for measurements at the intersection of Grabowa-Pużaka streets (50 m. interval).

Variable	N	W	P
Time (seconds)	10	0.929908	0.446989
Speed (km/h)	10	0.968290	0.874549

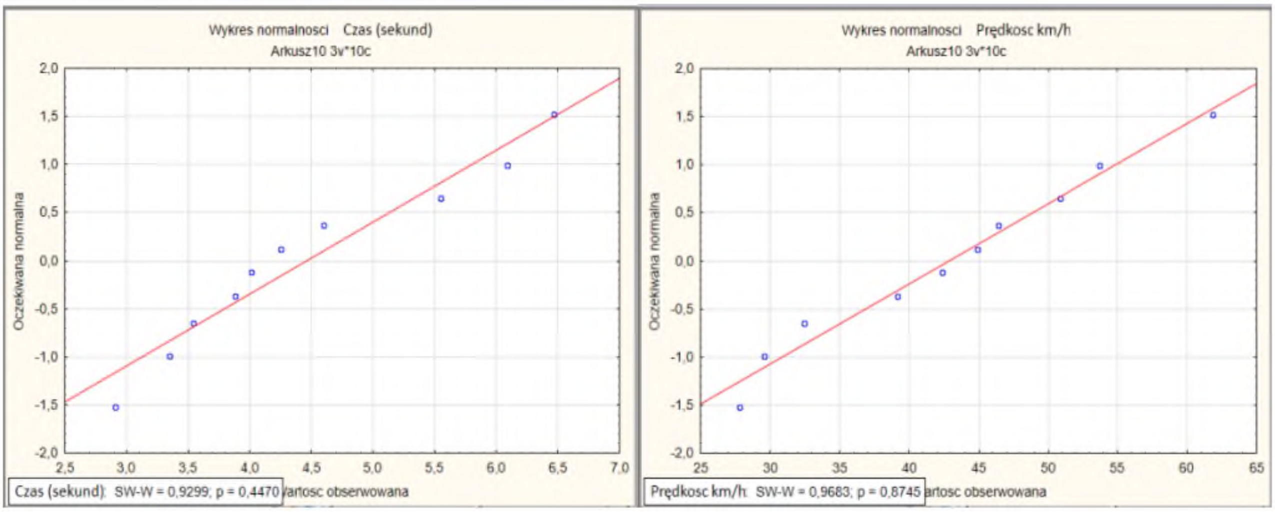

Figure 4. Diagram of normality of time and speed distribution for measurements at the intersection of Grabowa-Pużaka streets (50 m interval).

In the case of the investigated commuting time, it can be concluded that the distribution is normal, as the obtained p-index, which indicates the normality of the distribution, is greater than p = 0.05 (**Table 1**). The speed of the car was calculated on the basis of the travel time and the distance at which the car was visible in the mirror, this distance being 50 m from the intersection of Pużaka-Grabowa streets. The speed results obtained also have a normal distribution because $p > 0.05$ and is $p = 0.87$ (**Table 2**).

Table 2. Descriptive statistics for time and speed measurements at the intersection of Grabowa-Pużaka streets (50 m interval).

Descriptive statistics for time measurements		**Descriptive statistics for speed measurements**	
X	Vehicle travel time to the junction Grabowa-Pużaka 50 m was investigated	X	Vehicle approach speed to the junction Grabowa-Pużaka 50 m was investigated
n = 10	The travel time of 10 vehicles was measured.	n = 10	The speed of 10 vehicles was measured
$x_{min} = 2.9$, $x_{max} = 6.4$	It turned out to have a minimum time of 2.9 and a maximum time of 6.4 s to cover 50 m.	$x_{min} = 27.8$ $x_{max} = 61.85$	The minimum speed was found to be 27.8 and the maximum 61.85 km/h.
R = 3.56	Therefore, the difference between the largest and smallest value equaled 3.56 s.	R = 34.03	Therefore, the difference between the highest and lowest value of 34.03 km/h.
x = 4.46	On average, the commute time represents 4.46 s.	x = 42.9	The average vehicle speed is 42.9 km/h.
$Q_1 = 3.54$	At least 25% of drivers arrive at an intersection in at most 3.54 s.	$Q_1 = 32.43$	At least 25% of drivers drive at most 32.43 km/h.
$Q_2 = Me = 4.13$	At least 50% of drivers reach the junction in at most 4.13 s.	$Q_2 = Me = 43.62$	At least 50% of drivers drive at most 43.62 km/h.
$Q_3 = 5.55$	At least 75% of drivers reach the junction in at most 5.55 s.	$Q_3 = 50.84$	At least 75% of drivers drive at most 50.84 km/h.
s = 1.2	On average, vehicle arrival times differ by 1.2 s from the average value.	s = 10.98	Vehicle speeds differ on average by 10.98 km/h from the average value.
$V_s = 26.88\%$	Since Vs > 10% there is a statistically significant variation in the trait under study.	$V_s = 25.59\%$	Since Vs > 10% there is a statistically significant variation in the trait under study.
$x - s < x_{typ} < x + s$ $3.26 < x_{typ} < 5.66$	The typical driver takes between 1.22 and 5.76 s to reach an intersection.	$x - s < x_{typ} < x + s$ $31.98 < x_{typ} < 53.88$	The typical driver has a speed of between 31.98 and 53.88 km/h.
A = 0.59	There is right-sided asymmetry (tilt of the distribution to the left).	A = 0.17	There is right-sided asymmetry (tilt of the distribution to the left).
$E = K - 3 = -0.89$	There is less concentration of values around the mean than in a theoretical normal distribution.	$E = K - 3 = -0.69$	There is less concentration of values around the mean than in a theoretical normal distribution.

3.2. Grabowa-Pużaka (disclaimer 130 m)

Another section concerned the same intersection, but at a study distance of 130 m from the mirror respectively. The survey was carried out at night time due to the variety of mirror use at different times. **Table 3** analogously to the previous presentation of the results shows the normality of the distribution of the survey, and the same is true for **Figure 5**. **Table 4** shows a comparison of the leave descriptive statistics for time and speed.

In the case of the investigated commuting time, it can be concluded that the distribution is normal, as the obtained *p*-index which indicates the normality of the distribution is greater than $p = 0.05$, namely $p = 0.88$ (**Table 3**). The speed of the car was calculated based on the travel time and the distance at which the car was visible in the mirror, this distance being 130 m from the intersection of Agnieszka Osiecka - Partyzancka streets. The speed results obtained also have a normal distribution, as $p > 0.05$ and is $p = 0.74$ (**Table 3**).

Table 3. Normality of distribution for measurements at the intersection of Grabowa-Pużaka streets (130 m interval).

Variable	N	W	P
Time (seconds)	10	0.969278	0.884074
Speed (km/h)	10	0.956758	0.748371

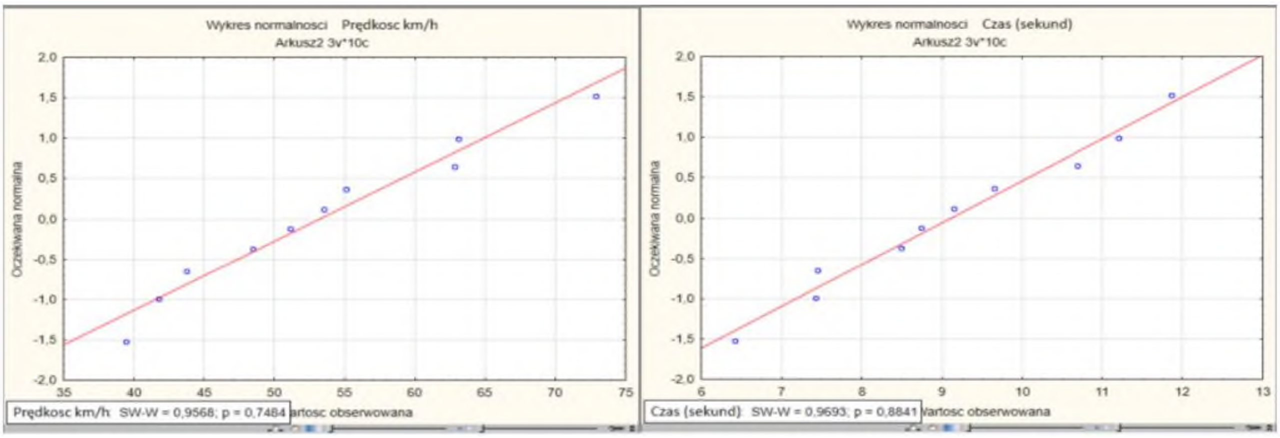

Figure 5. Diagram of normality of time and speed distribution for measurements at the intersection of Grabowa-Pużaka streets (interval 130 m).

Table 4. Descriptive statistics for time and speed measurements at the intersection of Grabowa-Pużaka streets (130 m interval).

Descriptive statistics for time measurements		**Descriptive statistics for speed measurements**	
X	Vehicle travel time to the intersection of Grabowa-Pużaka 130 m was investigated.	X	The vehicle approach speed to the Grabowa Pużaka 130 m intersection was investigated
n = 10	The travel time of 10 vehicles was measured.	n = 10	The speed of 10 vehicles was measured
x_{min} = 6.42, x_{max} = 11.86	It turned out to have a minimum time of 6.42 and a maximum time of 11.86 s to cover 130 m.	x_{min} = 39.46 x_{max} = 72.89	The minimum speed was found to be 39.46 and the maximum 72.89 km/h.
R = 5.44	Therefore, the difference between the largest and smallest value equaled 3.56 s.	R = 33.43	Therefore, the difference between the highest and lowest values is 33.43 km/h.
x = 9.1	On average, the commute time represents 9.1 s.	x = 53.21	The average vehicle speed is 53.21 km/h.
Q_1 = 7.45	At least 25 per cent of drivers arrive at an intersection in at most 7.45 s.	Q_1 = 43.77	At least 25% of drivers drive at most 43.77 km/h.
Q_2 = Me = 8.94	At least 50% of drivers reach the junction in at most 8.94 s.	Q_2 = Me = 52.34	At least 50% of drivers drive at most 52.34 km/h.
Q_3 = 10.69	At least 75 per cent of drivers reach the junction in at most 5.55 s.	Q_3 = 62.81	At least 75% of drivers drive at most 62.81 km/h.
s = 1.76	On average, vehicle arrival times differ by 1.76 s from the average value.	s = 10.62	Vehicle speeds differ on average by 10.62 km/h from the average value.
V_s = 19.39%	Since Vs > 10% there is a statistically significant variation in the trait under study.	V_s = 19.96%	Since Vs > 10% there is a statistically significant variation in the trait under study.
$x - s < x_{typ} < x + s$ $7.34 < x_{typ} < 10.86$	The typical driver takes between 7.34 and 10.86 s to reach an intersection.	$x - s < x_{typ} < x + s$ $42.59 < x_{typ} < 63.83$	The typical driver has a speed of between 42.59 and 63.83 km/h.
A = 0.12	There is right-sided asymmetry (tilt of the distribution to the left).	A = 0.51	There is right-sided asymmetry (tilt of the distribution to the left).
E = K – 3 = −0.95	There is less concentration of values around the mean than in a theoretical normal distribution.	E = K – 3 = −0.41	There is less concentration of values around the mean than in a theoretical normal distribution.

3.3. Agnieszki Osieckiej-Partyzancka (disclaimer 50 m)

The second road section concerned the intersection of Osiecka and Partyzancka. This is a road section with higher traffic volumes and therefore the sample size was doubled in order to make the results more specific. The methodology of the study was not changed and is similar to the previous two cases. The 50 m interval was surveyed during the daytime between 1 pm and 3 pm. Analogously to the previous presentation of the results, **Table 5** shows the normality of the distribution of the survey, and the same is true for **Figure 6**. In **Table 6**, a comparison of the descriptive statistics for time and speed is presented.

In the case of the commuting time studied, it can be concluded that the distribution is normal, since the obtained *p*-index which indicates the normality of the distribution is greater than $p = 0.05$, namely $p = 0.26$ (**Table 5**). The speed of the car was calculated based on the travel time and the distance at which the car was visible in the mirror, this distance being 50m from the intersection of Agnieszka Osiecka-Partyzancka streets. The speed results obtained also have a normal distribution, as $p > 0.05$ and is $p = 0.29$ (**Table 5**).

Table 5. Normality of distribution for measurements at the intersection of Grabowa-Pużaka streets (130 m interval).

Variable	N	W	P
Time (seconds)	20	0.941894	0.260316
Speed (km/h)	20	0.945026	0.297817

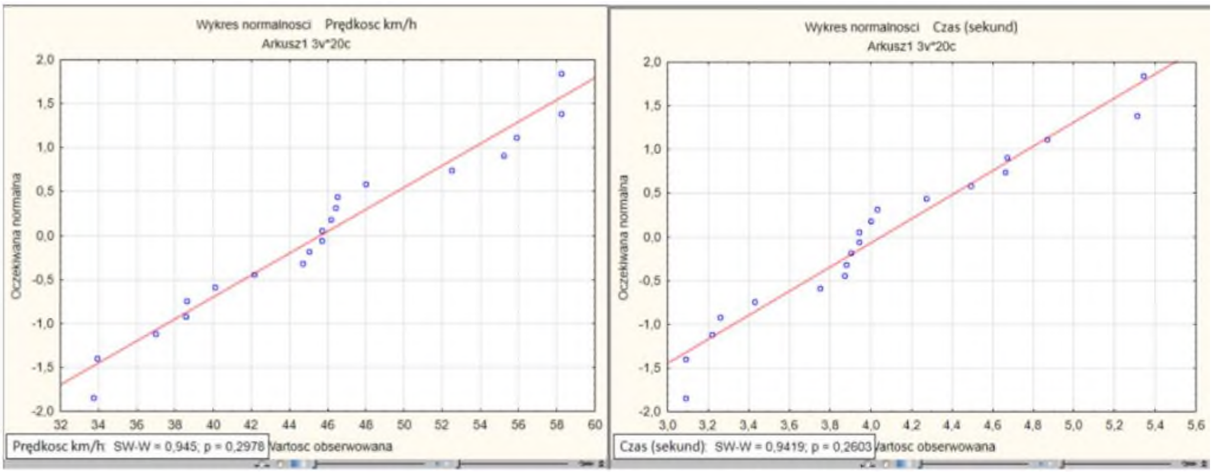

Figure 6. Diagram of normality of time and speed distribution for measurements at the intersection of Agnieszka Osiecka - Partyzancka streets (50 m. interval)

Table 6. Descriptive statistics for time and speed measurements at the intersection of Agnieszka Osiecka-Partyzancka streets (50 m. interval).

Descriptive statistics for time measurements		**Descriptive statistics for speed measurements**	
X	Vehicle travel time to the intersection of Agnieszka. Osiecka-Partyzancka intersection 50 m.	X	Vehicle access speed to the intersection of Agnieszka Osiecka - Partyzancka 50 m was investigated
n = 20	The travel time of 20 vehicles was measured.	n = 20	The speed of 20 vehicles was measured
$x_{min} = 3.09$, $x_{max} = 4.57$	It turned out to have a minimum time of 3.09 and a maximum time of 4.57 s to cover 50m.	$x_{min} = 33.7$ $x_{max} = 58.25$	The minimum speed was found to be 33.7 and the maximum 58.25 km/h.
R = 2.25	Therefore, the difference between the largest and smallest value equates to 2.25 s.	R = 24.54	Therefore, the difference between the highest and lowest values is 24.54 km/h.
x = 4.05	On average, the commute time represents 4.05 s.	x = 45.6	The average vehicle speed is 45.6 km/h.

Table 6. (*Continued*).

Descriptive statistics for time measurements		**Descriptive statistics for speed measurements**	
$Q_1 = 3.59$	At least 25 per cent of drivers arrive at an intersection in at most 3.59 s.	$Q_1 = 39.35$	At least 25% of drivers drive at most 39.35 km/h.
$Q_2 = Me = 3.94$	At least 50% of drivers reach the junction in at most 3.94 s.	$Q_2 = Me = 45.68$	At least 50% of drivers drive at most 45.68 km/h.
$Q_3 = 4.57$	At least 75 per cent of vehicle drivers reach the junction in at most 4.57 s.	$Q_3 = 50.23$	At least 75% of drivers drive at most 50.23 km/h.
$s = 0.67$	On average, vehicle arrival times differ by 0.67 s from the average value.	$s = 7.49$	Vehicle speeds differ on average by 7.49 km/h from the average value.
$V_s = 16.67\%$	Since Vs > 10% there is a statistically significant variation in the trait under study.	$V_s = 16.44\%$	Since Vs > 10% there is a statistically significant variation in the trait under study.
$x - s < x_{typ} < x + s$ $3{,}38 < x_{typ} < 4.72$	The typical driver takes between 3.38 and 4.72 s to reach an intersection.	$x - s < x_{typ} < x + s$ $38.11 < x_{typ} < 53.09$	The typical driver has a speed of between 38.11 and 53.09 km/h.
$A = 0.4$	There is right-sided asymmetry (tilt of the distribution to the left).	$A = 0.21$	There is right-sided asymmetry (tilt of the distribution to the left).
$E = K - 3 = -0.48$	There is less concentration of values around the mean than in a theoretical normal distribution.	$E = K - 3 = -0.71$	There is less concentration of values around the mean than in a theoretical normal distribution.

3.4. Agnieszki Osieckiej-Partyzancka (disclaimer 250 m)

The last survey concerned Osiecka Street with Partyzancka street taken at night between 8 and 10 pm. The sample here was also selected larger due to the increased intensity of the road. Similar to the earlier results presentation, **Table 7** demonstrates the normal distribution of the survey, and the same applies to **Figure 7**. **Table 8**, on the other hand, offers a comparison of descriptive statistics for time and speed.

Table 7. Normality of distribution for measurements at the intersection of Grabowa - Pużaka streets (130 m. interval).

Variable	**N**	**W**	**P**
Time (seconds)	20	0.912787	0.072041
Speed (km/h)	20	0.941970	0.261171

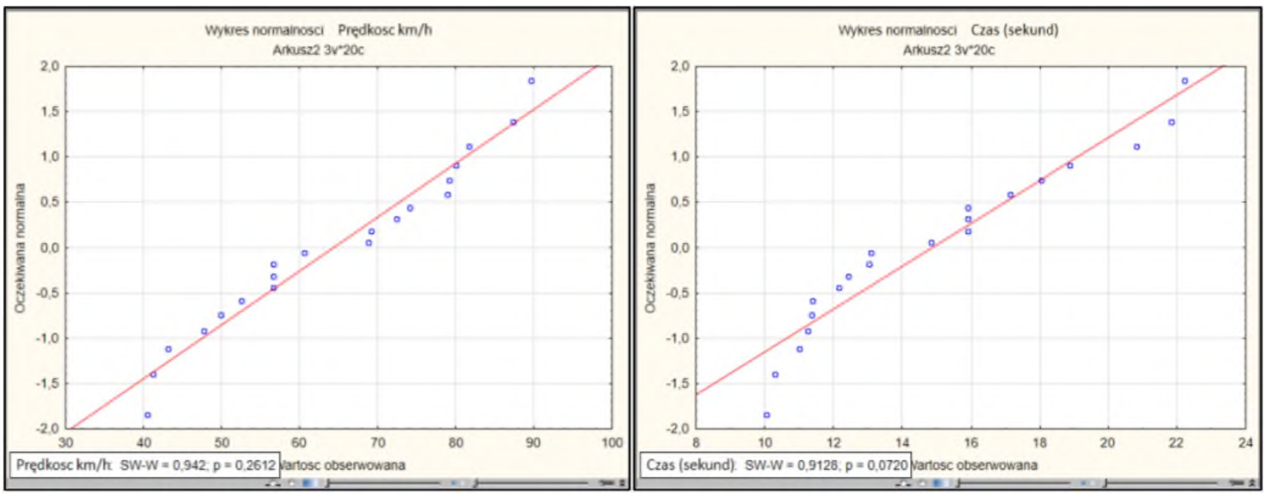

Figure 7. Diagram of normality of time and speed distribution for measurements at the intersection of Agnieszka Osiecka-Partyzancka streets (250 m interval).

In the case of the investigated commuting time, it can be concluded that the distribution is normal, as the obtained *p*-index which indicates the normality of the distribution is greater than $p = 0.05$, namely $p = 0.07$ (**Table 7**). The speed of the car was calculated based on the travel time and the distance at which the car was visible in the mirror, this distance being 250 m from the intersection of Agnieszka Osiecka-Partyzancka streets. The speed results obtained also have a normal distribution, as $p > 0.05$ and is $p = 0.26$ (**Table 7**).

Table 8. Descriptive statistics for time and speed measurements at the intersection of Agnieszka Osiecka-Partyzancka streets (250 m spacing).

Descriptive statistics for time measurements		**Descriptive statistics for speed measurements**	
X	Vehicle travel time to the intersection of Agnieszki. Osiecka-Partyzancka intersection 250 m.	X	Vehicle access speed to the intersection of Agnieszka Osiecka-Partyzancka 250 m was investigated
n = 20	The travel time of 20 vehicles was measured	n = 20	The speed of 20 vehicles was measured
$x_{min} = 10.04$, $x_{max} = 22.21$	It turned out to have a minimum time of 10.04 and a maximum time of 22.21 s to cover 250 m.	$x_{min} = 40.52$ $x_{max} = 89.64$	The minimum speed was found to be 40.52 and the maximum 89.64 km/h.
R = 12.17	Therefore, the difference between the largest and smallest value equalled 12.17 s.	R = 49.11	Therefore, the difference between the highest and lowest values is 49.11 km/h.
x = 14.87	On average, the commute time represents 14.87 s.	x = 64.31	The average vehicle speed is 64.31 km/h.
$Q_1 = 11.38$	At least 25% of vehicle drivers arrive at an intersection in at most 11.38 s.	$Q_1 = 51.21$	At least 25% of drivers drive at most 51.21 km/h.
$Q_2 = Me = 13.96$	At least 50% of drivers reach the junction in at most 13.96 s.	$Q_2 = Me = 64.7$	At least 50% of drivers drive at most 64.7 km/h.
$Q_3 = 17.58$	At least 75 per cent of vehicle drivers reach the junction in at most 17.58 s.	$Q_3 = 79.05$	At least 75% of drivers drive at most 79.05 km/h.
s = 3.9	On average, vehicle arrival times differ by 3.9 s from the average value.	s = 15.76	Vehicle speeds differ on average by 15.76 km/h from the average value.
$V_s = 26.21\%$	Since Vs > 10% there is a statistically significant variation in the trait under study.	$V_s = 24.51\%$	Since Vs > 10% there is a statistically significant variation in the trait under study.
$x - s < x_{typ} < x + s$ $10.97 < x_{typ} < 18.77$	The typical driver takes between 10.97 and 18.77 s to reach an intersection.	$x - s < x_{typ} < x + s$ $48,55 < x_{typ} < 80.07$	The typical driver has a speed of between 48.55 and 80.07 km/h.
A = 0.59	There is right-sided asymmetry (tilt of the distribution to the left).	A = −0,06	There is left asymmetry (skewing of the distribution to the right).
E = K – 3 = −0.82	There is less concentration of values around the mean than in a theoretical normal distribution.	E = K – 3 = −1,3	There is less concentration of values around the mean than in a theoretical normal distribution.

3.5. Analysis of the results

Analyzing the results obtained in the Statistica programmed, it can be concluded that exiting a street with limited visibility with the help of a road mirror is safe only in the situation when the person driving the vehicle that is exiting the street does not see any car in the mirror. The time it takes for a car to exit an intersection is about 2–4 s; this time depends primarily on the skills and experience of the driver, the weather conditions and the technical characteristics of the car. Also, with the help of the mirror, it is not possible to estimate the speed of a car travelling on the main road without the use of auxiliary devices. Without looking at the fact that the maximum speed on the surveyed road sections is 50 km/h, not all drivers maintain the permitted speed. The speed of a vehicle on the main road is influenced by factors such as the volume of traffic, the quality and condition of the road surface and the presence of major intersections, lanes and traffic lights. At the intersection of Agnieszka Osiecka - Partyzancka streets, the main road is the road following Partyzancka street, while at the intersection of Grabowa-Pużaka street, priority is given to cars travelling along Pużaka street.

In the case of both streets, there is a traffic light immediately after the intersections under study, which has a significant impact on the study. Drivers approaching the traffic lights can increase or decrease their speed depending on the situation. In addition, the quality of the road surface differs at the studied intersections. On Partyzancka Street it is much better than on Pużaka Street, for that at night time, when traffic volume is minimal compared to maximum speeds, a significant difference can be observed. Thus, after the study, at night time the maximum speed is 89.64 km/h on Partyzancka Street and 72.89 km/h on Pużaka Street. At daytime, the traffic volume on Partyzancka Street is higher than on Pużaka Street, as the former is one of the roads used by people to commute to the economic zone in Opole. The maximum speed on Pużaka Street at daytime after the study is 61.85 km/h and on Partyzancka Street 58.25 km/h respectively.

After the tests and observations during the tests, it was also found that at night time road mirrors have a higher efficiency and accuracy for the vehicle driver than during day time, because at night it is easier to see the lights of an approaching car. At daytime, on the other hand, the vehicle's headlights are attenuated by the sunlight, so that the car is only visible when the car's outline is visible in the mirror. For this reason, it takes between 2 s and 4 s for a vehicle to drive safely out of a street with limited visibility. By comparing this time with the time it takes for a car to reach the main road, it can be concluded that leaving a street with blind spots onto the main road is risky if the driver can see another car in the mirror.

The main limitation of the study is that too few measurements were made. In order to verify the results efficiently, continuous research should be carried out to successfully confirm the results achieved in the article. Nonetheless, the results obtained may provide fully valuable reference material for other studies as well as for the design of new road systems.

3.6. Proposed telematics solutions to improve road mirror performance

After the study, it became clear that the safe exit from the street is affected by the speed of a car travelling along the main street. Using a road mirror, it is very difficult to estimate the speed of an approaching car. One proposed solution to this problem could be a combination of two devices such as a road mirror and a radar speed display. A radar speed display is a device that aims to improve road safety. Through the use of radar, the device measures the speed of a passing car. If the driver exceeds the speed limit, the display will indicate that the speed limit has been exceeded. In this way, the driver is made aware of his or her irresponsible road behavior. A radar speed display mounted next to the road mirror will display the speed of a vehicle travelling on the main street to the driver on the secondary road. Knowing the speed, it will be easier for the driver to decide whether to leave the street or stop.

A second solution could be the one proposed by Proseche Sdn. Bhd. Proseche. The word 'proseche' comes from a Greek word that means 'beware'. Well, the company's idea is to implement sensor technology and embedded traffic lights on road mirrors and to mount such mirrors at key locations with a high probability of risk, such as intersections or sharp corners where there is blind spot or limited visibility for driveways. The product features are complemented by the presence of a convex mirror with integrated LED, a laser meter consisting of a Doppler sensor and a wireless LED controller[13,14].

Another improvement proposed by Proseche Sdn. Bhd. Proseche is a signal light that easily attaches to the mirror as an alarm sign. The existing convex mirror helps road users to be more aware of the traffic situation on the opposite side of the road. With the use of a built-in light on the mirror, this helps road users to signal possible damage or dangers on the road. The main technology used in the product is a speed-detecting sensor, known as a Doppler sensor. The sensor detects the speed of a vehicle on the road a few meters from the convex mirror. The speed of the vehicles on the road is detected by the speedometer, which works by means of a Doppler sensor that uses the concept of the Doppler effect, in which the sensor detects the speed of vehicles that have violated the speed limit. Based on conceptual tests conducted during the new product development process, it was determined that the best distance to detect a car's speed is 100 m from dangerous areas. Another technology is a wireless LED controller that controls the color of the warning light. It also receives a signal from a sensor about a vehicle that could cause harm to other road users[13].

4. Conclusion

In conclusion, safety is one of the most important aspects in traffic organization. In order to increase safety and improve road conditions, various technical devices are used, including convex mirrors to ensure safe exit from streets with limited visibility, especially at dangerous road junctions.

After analyzing and evaluating two different intersections equipped with road mirrors in the town of Opole, it can be concluded that road mirrors give traffic participants the opportunity to spot a vehicle travelling on the main road and to exit the street safely. The current research can be used to implement telematics solutions in cities using road mirrors. At present, the results have been sent to the municipality in order to broaden the knowledge of both city managers and to obtain relevant data for further studies. But each vehicle driver has to take into account various aspects such as the shape and size of the road mirror, its angle, weather conditions, time of day. Moreover, everyone should be able to observe a sufficiently long enough distance to be able to perform, for example, a braking maneuver to stop and thus avoid a collision[15]. Studies have shown that at a distance within 50 m of an intersection, the average time for a vehicle to cross the road is between 4 and 4.46 s at an average speed of 43–46 km/h. With a required time for exiting onto the main road of 2–4 s, it can be concluded that if a vehicle is already moving when seen in the mirrors, it is safest to wait until then for the car to pass the intersection. On the other hand, at longer distances, the driver has more time for a safe maneuver—between 9 and 15 s on average. So, this means that if you notice the vehicle in the mirror at the initial "moving little dot" stage, you can make a turning maneuver. It is also worth noting that, because there is no standardized distorted visual message for road mirrors, the image transmitted by the mirror may not be clear and understandable in the short term. This can result in erroneous actions being taken and resulting in a collision or accident[16]. So this means that each road mirror has its own individual characteristics. The vehicle driver has to adapt to each situation separately and have the right perception.

And, there should also be uniform rules on the placement of such mirrors in areas with limited direct visibility. The ability to use mirrors on the road should be part of the training provided as part of the courses for obtaining a driving license. The promotion of mirror skills by drivers who have previously obtained a driving license should also be carried out. The driver receives more than 90% of the safety-relevant information necessary for driving with his or her eyes. Attention to an uninterrupted visual message is an essential element of the active safety system for road users in the operation of transport infrastructure[16].

The authors plan to further investigate this much-publicized phenomenon in the future in order to improve urban safety. The object of study will also be extended to include further urban units in order to exclude possible errors in the implementation of the research. In addition to this, the study of other cities will also identify other correlations and links which may influence the use of road mirrors.

In summary, telematic solutions must be used to sufficiently improve safety on these types of roads using road mirrors. Firstly, due to the significant increase in traffic, outdated solutions such as road mirrors may not be sufficient and only provide an aid to traffic and not a clear indication of the execution of a maneuver on the road[17]. Secondly, public campaigns should be introduced to demonstrate the use of mirrors and to train drivers in their use.

Conflict of interest

The author declares no conflict of interest.

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