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A CASE STUDY ANALYSIS OF ROUNDABOUTS ENTRY CAPACITY LOCALISED ON ONE OF THE MAIN ROAD IN SOSNOWIEC CITY (POLAND)

Summary. This paper is a case study, which among other things includes the analysis of the three roundabouts entry capacity: a turbo- and two spiral-roundabouts. These intersections are located in one of the main road localised in Sosnowiec city (Poland). Before reconstruction, this road was characterised by unfavourable road and traffic conditions, insufficient capacity and low traffic safety level. The traffic congestion decreased significantly, traffic and road conditions, as well as the level of road traffic safety, were improved after the rebuilding of this route and the designing of three roundabouts on it. Results obtained from field measurements enabled comparative analysis of theoretical and empirical capacity values: lanes on the entry of turbo-roundabout and entries of the spiral-roundabout. This paper presents also characteristics of turbo- and spiral-roundabouts with methods, which are dedicated to entry capacity calculation.
Keywords: methods of capacity calculation, turbo-roundabouts, spiral-roundabouts, traffic conditions

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1. INTRODUCTION

The road network of each city consists of various types of intersections, which enable the handling of collision traffic flows and which can be bottlenecks of the transport system. The main criterion for selection of the intersection type at a concrete point of the transport network is to ensure efficient traffic flow. Additionally important is the increasingly high level of road traffic safety. The selection of the intersection type is determined by many factors and it is carried out in multistage analysis. In recent years, roundabouts designed in Poland, provide high levels of road traffic safety with simultaneous high traffic flow efficiency and entry capacity. Roundabout described in [1] is an intersection with central island and one-way traffic road around the central island where vehicles are obliged to drive around it in a counter-clockwise direction. In road traffic engineering, roundabouts are the subject of multi-aspect researches both in terms of microscopic, macroscopic and mesoscopic analysis as well as many others topics, for example, [2-21].

A smaller number of collision points characterises one-lane four-entry roundabouts in comparison with one-lane four-entry intersections. By analogy, a smaller number of collision points are characterised by four-entry double-lane solutions (Fig. 1).

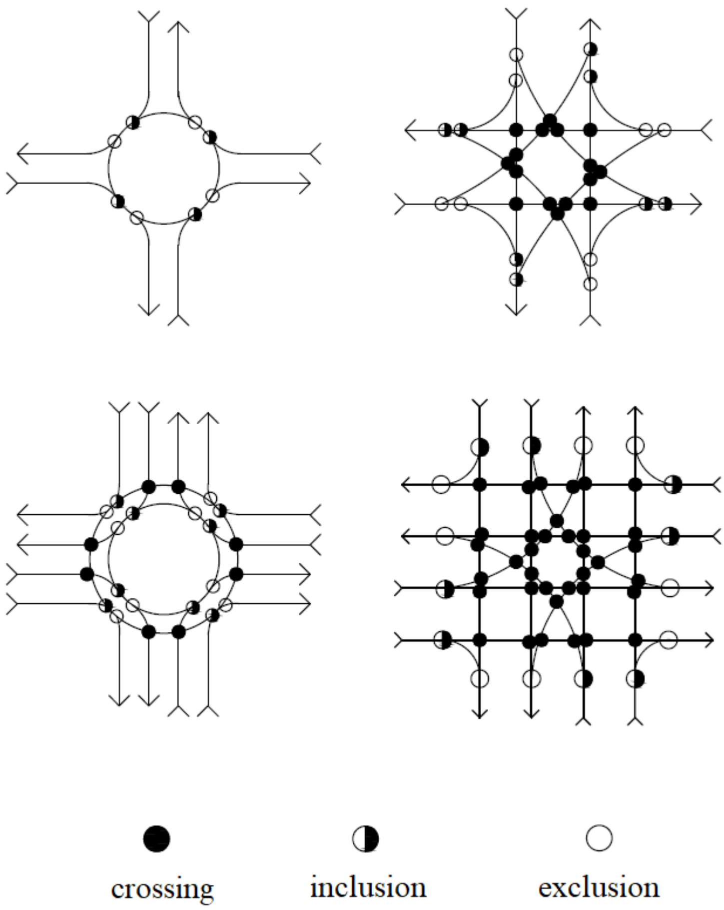


Fig. 1. Comparison of the number of collision points on a single-lane four-entry roundabout and give-way intersection, as well as double-lane four-entry roundabout and give-way intersection

In Poland, the above single-lane roundabouts, multilane roundabouts and turbo-roundabouts have been successfully designed and built for over twenty years because of their many advantages. There are no collisions points at the turbo-roundabouts of crossing vehicles streams or points of collision at the exclusion of traffic streams from the roundabout circulatory roadway (Fig. 2).

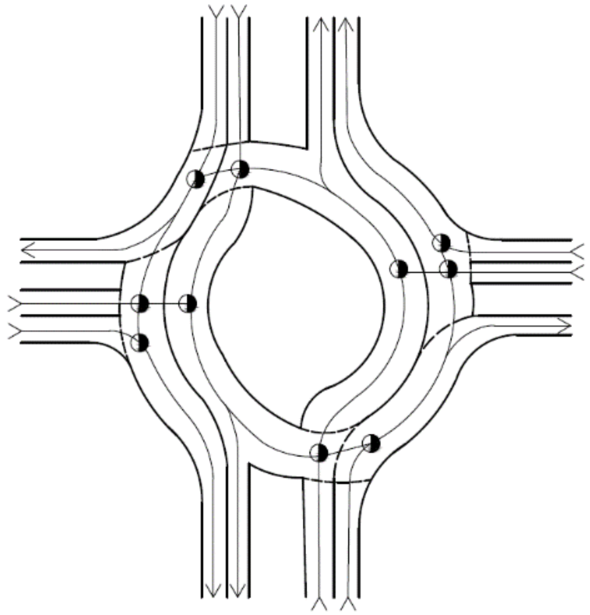


Fig. 2. Number of collision points on the turbo-roundabout

The first turbo-roundabout was built in 1996 in the Netherlands and was designed by L.G.H. Fortujin. It was a multi-lane roundabout with a spiral shaped central island. The capacity of this intersection is greater than a single-lane roundabout and in many cases, greater than the capacity of a double-lane roundabout. Turbo-roundabout is characterised by the inability to change lanes in the roundabout circulatory roadway and in the entries by using specially shaped elements - raised lane dividers. This solution results in the lack of the possibility of interlacing vehicles from the inner and outer lane on the roundabout circulatory roadway and leading drivers to the exit of the roundabout without any collision. It is important that the turbo-roundabout be correctly marked in order for drivers to choose correctly their desired destination and lane.

On the other hand, a spiral-roundabout - similarly to a turbo-roundabout - is characterised by a spiral horizontal marking, however, unlike the turbo-roundabout, the central island has the same shape as the island of a typical roundabout (shape of a circle or similar). The geometry of the spiral-roundabout is different from the typical roundabout. At the spiral-roundabout in the main (dominating) direction, two lanes are designed, while in the minor direction, the entries have one lane. Due to spiral marking, moving around the central island at this type of roundabout causes a lot of difficulties for drivers, leading to traffic incidents. This fact has made spiral roundabouts to be considered as safe solutions, for example, single-lane roundabouts.

Both the turbo and spiral roundabouts are recommended when designing those places of the road transport network in which there is an uneven load of entries with traffic flows (dominance of the selected traffic direction).

This paper presents a case study consisting of analysis of converting the three intersections localised on one of the main roads in Sosnowiec city (Poland) to three roundabouts: a turbo-roundabout and two spiral-roundabouts. Before the reconstruction, this road was characterised by unfavourable road and traffic conditions, insufficient capacity and low level of road traffic safety. After the reconstruction and design of the three roundabouts, traffic congestion significantly decreased, and the traffic and road conditions and traffic safety improved considerably.

2. CHARACTERISTIC OF ANALYSED INTERSECTIONS AND MEASUREMENTS IN THE FIELD

The analysed intersections are located on one of the main roads in the Sosnowiec city. There are intersections (Fig. 3):
- Piłsudskiego - Grabowa - Kierocińskiej streets (GK) - turbo-roundabout,
- Piłsudskiego - Mireckiego - Stara (MS) streets - spiral-roundabout,
- Piłsudskiego - Sobieskiego - Kilińskiego (KS) streets - spiral-roundabout,

The intersection GK before the reconstruction to the turbo-roundabout was a four-entry intersection without traffic lights, in the area where there was a tram track. In turn, the other two intersections (MS and KS) functioned as intersections with central islands. The change of traffic control and their reconstruction to the roundabouts took place in 2015. At the GK roundabout, the central island was designed and a new traffic control was introduced. On the other two intersections (MS and KS), only the traffic control was changed with conducting reconstruction works. The localisation of the analysed intersections on the road traffic network of the Sosnowiec city is shown in Fig. 4. This main road is located in the important part of the city, and it provides access to and from the city centre (including, for example, traffic to/from the railway station, main shopping street and shopping centres). In addition, this road permits for access to and from the express road number S86, which enables travel to neighbouring cities, for example, Katowice, Dąbrowa Górnicza, and Będzin.

Analysed intersections are not typical roundabouts, so their division according to Polish guidelines [1] is not possible, because these guidelines do not include turbo and spiral roundabouts in their classification. However, they can be characterised as medium-sized roundabouts, because of size, unusual geometry as well as analysis of the data presented in Table 1.

In May 2017, during rush hours at the above-mentioned roundabouts, traffic measurements and tests were carried out. The following traffic stream characteristics were measured:
- traffic volume at the entries (in the case of multi-lane entries, traffic volume was measured separately for each entry lane),
- traffic volume on the roundabout circulatory roadway (in the case of multi-lane, traffic volume was measured separately for each traffic lane),
- follow-up times for vehicle drivers at the entry lanes,
- critical gaps for vehicle drivers at the entry lanes,
- time intervals between vehicles moving on the roundabout circulatory roadway (with the distinction between the inner and outer lane),
- entry lanes capacity (in the case of a turbo-roundabout),
- entry capacity (in the case of spiral-roundabouts),
- pedestrian traffic volumes at pedestrian crossings.

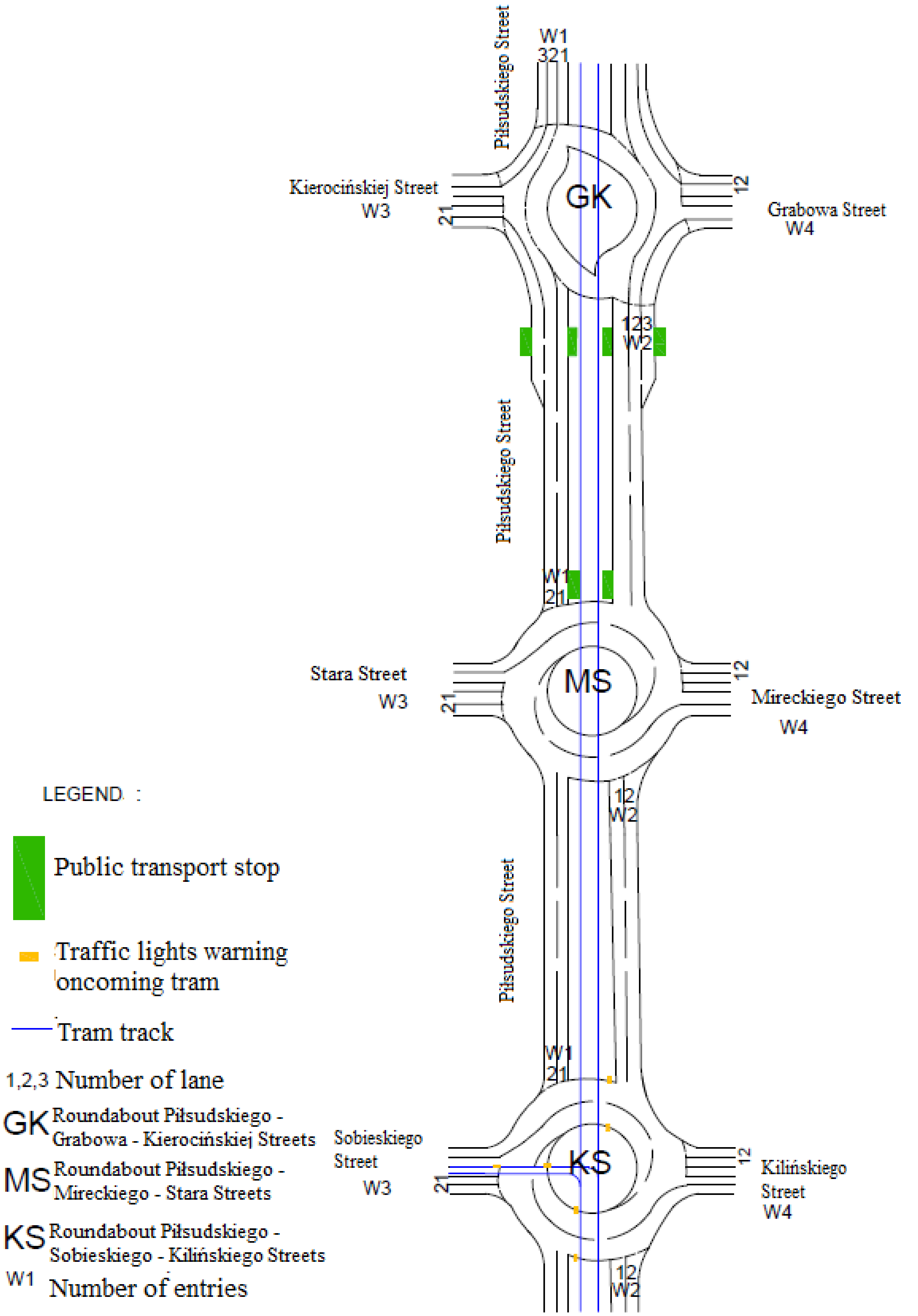


Fig. 3. Scheme of analysed intersections localised on one of the main roads in Sosnowiec city

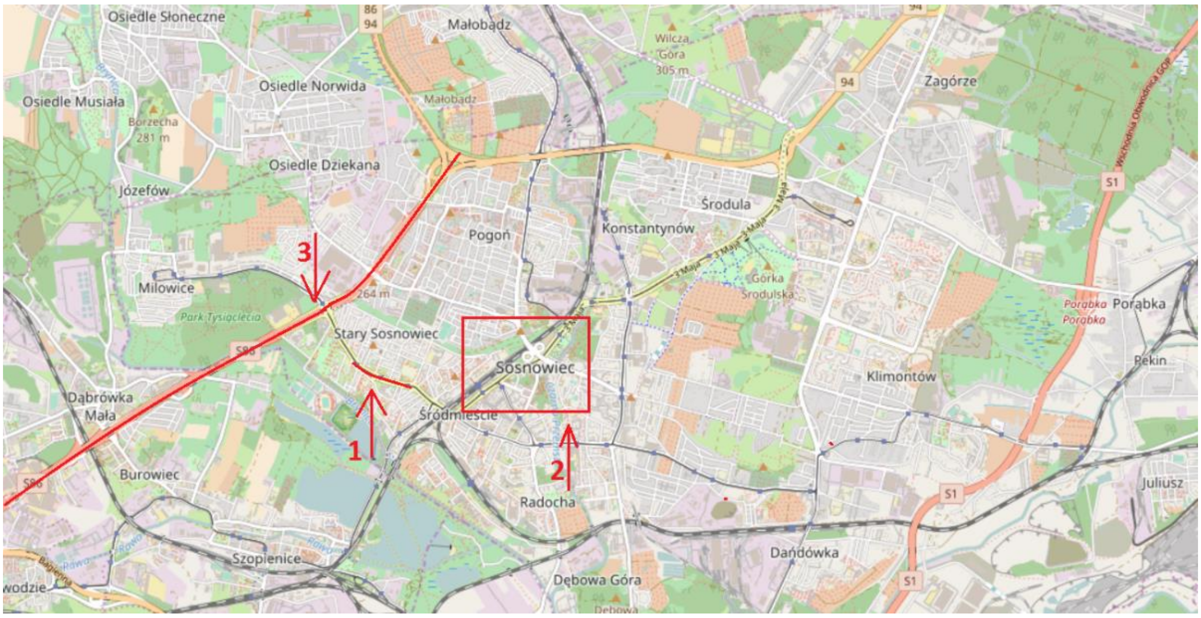


Fig. 4. Location of the analysed intersections on one of the main roads in Sosnowiec city, where: 1 - analysed road, 2 - Sosnowiec city centre, 3 - national road no 86
Source: own elaboration based on [22]

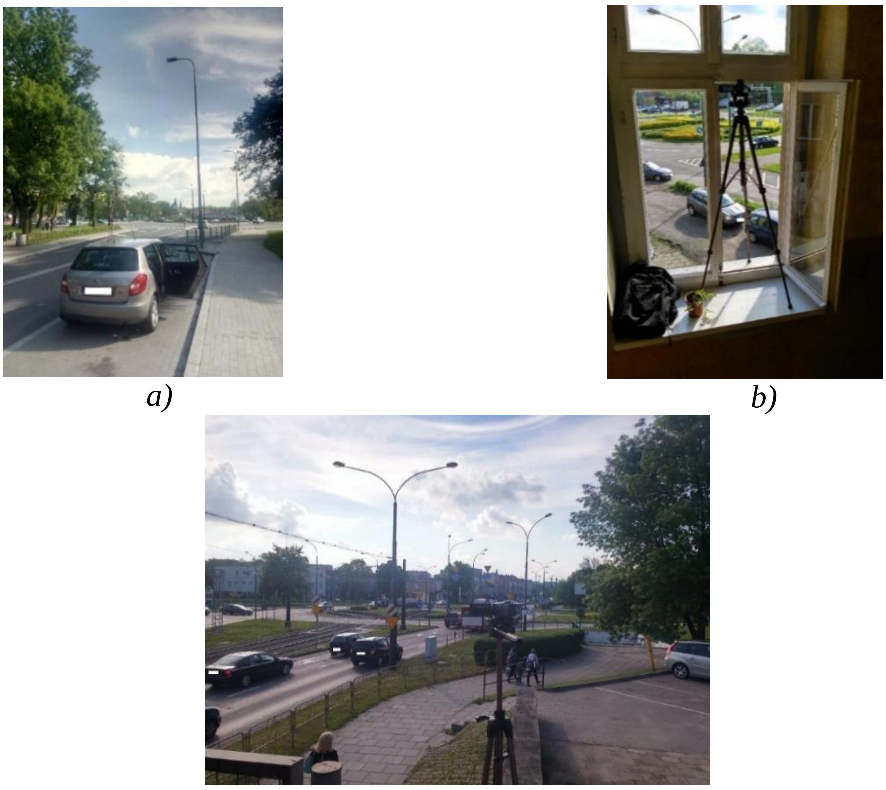
Tab. 1

Characteristics of the analysed roundabouts

	Piłsudskiego - Grabowa - Kierocińskiej	**Piłsudskiego – Mireckiego - Stara**	**Piłsudskiego - Sobieskiego - Kilińskiego**
Directions of traffic lanes, where: L-left, W-straight, P-right	Piłsudskiego Street : 1-WL, 2-W, 3-P	Piłsudskiego Street : 1-WL, 2-WP	Piłsudskiego Street : 1-WL, 2-WP
	Grabowa Street : 1-WL, 2-WP	Stara Street : 1-WL, 2-WP	Sobieskiego Street : 1-WL, 2-WP
	Kierocińskiej Street : 1-WP, 2-WL	Mireckiego Street : 1-WL, 2-WP	Kilińskiego Street : 1-WL, 2-WP
The width of the traffic lane [m]	3,5	3,5	3,5
Diameter of the central island [m]	10,5; 12,5; 17,5	27,0	30,0
External diameter of roundabout [m]	35,0	44,0	45,0

Category functional and technical	Piłsudskiego Street - main road	Piłsudskiego Street - main road	Piłsudskiego Street - main road
	Grabowa Street - local road	Stara Street – local road	Sobieskiego Street – collective road
	Kierocińskiej Street - local road	Mireckiego Street – collective road	Kilińskiego Street – local road
Pedestrian facilities	Piłsudskiego Street - underground pedestrians crossing	Piłsudskiego Street – underground pedestrians crossing	Piłsudskiego Street – underground pedestrians crossing
	Grabowa Street - pedestrians crossing with refuge island	Stara Street - pedestrians "zebra" crossing	Sobieskiego Street - lack
	Kierocińskiej Street - pedestrians crossing with refuge island	Kierocińskiej Street - pedestrians "zebra" crossing	Kilińskiego Street - pedestrians "zebra" crossing

These measurements were taken in good visibility and good weather conditions, that is, no rain, no strong wind, with dry and clean road surface. In each case, the measuring station was located in a place invisible to the drivers as possible, so that the measurements did not affect the drivers' behaviours. Sony digital cameras were used in this research. The views of exemplary locations of measurement stations are shown in Fig. 5.



a) b)

c)

Fig. 5. The views of exemplary locations of measurement stations at the roundabout a). Piłsudskiego - Grabowa - Kierocińskiej, b). Piłsudskiego - Mireckiego - Stara, c). Piłsudskiego - Sobieskiego - Kilińskiego

3. OVERVIEW OF TURBO AND SPIRAL ROUNDABOUTS ENTRY CAPACITY CALCULATION METHODS

This paper presents one turbo-roundabout and two spiral-roundabout analysis. Due to the fact that both domestic and foreign literature lacks obligatory methods of calculating the entry capacity of spiral-roundabouts, the following section presents an overview of the methods for calculating the entry capacity of turbo-roundabouts. In Poland, there is also no obligatory method of capacity calculation for turbo-roundabouts. In the Polish design practice, a generalised method for double-lane roundabouts is used to calculate the capacity of entries of turbo-roundabouts, after adapting the scheme of traffic control at the entry and the scheme of the roundabout circulatory roadway to the model scheme presented in the method [1]. A similar adaptation is used when calculating the capacity of spiral-roundabouts entries. The next part of the paper presents the methods from Poland (the method for double-lane roundabouts adopted for calculating capacity turbo-roundabouts) and methods from Portugal, Italy and Slovakia used for calculating the capacity of turbo-roundabouts entries.

According to the method used in Poland, the entry capacity of a double-lane roundabout is calculated from the dependence [23]:

$$C_{owl} = \frac{Q_{nwl} \cdot exp(-0{,}85 \cdot \frac{Q_{nwl} \cdot t_g}{3600})}{1 - exp(-0{,}50 \cdot \frac{Q_{nwl} \cdot t_f}{3600})} \text{ [E/h]} \quad (1)$$

where:
Q_{nwl}- traffic volume on roundabout circulatory roadway major for vehicle drivers at roundabout entry [E/h];
t_g - critical gap [s]
t_f - follow up time [s]

According to [24], it is recommended to adopt the following values for double-lane roundabouts:
- for medium roundabouts: t_g=4,1 s, t_f=3,3 s
- for large roundabouts: t_g=3,9s and t_f=2,9 s

In Portugal in 2012, the method was published by A. Vasconelos, A. Silva and A. Seco [24]. The Authors used the O. Hangring capacity model. According to this method, the capacity of the entry lane of turbo-roundabout is calculated from the following formula:

$$C_K = \frac{\exp(-\sum_{i \in I_k} \lambda_i (t_{g,i} - t_{\min,i}))\sum_{i \in I_k} \lambda_i}{1 - \exp(-\sum_{i \in I_k} t_{f,i} \lambda_i)} \prod_{i \in I_k} \frac{\phi_i}{\phi_i + \lambda_i t_{min,i}} \quad \text{[E/h]} \quad (2)$$

where:
C_k - capacity of the *k*-lane in the entry [E/h]
I_k - set of major streams *i* conflicting with the minor stream *k* [E/h]
$t_{min,i}$ - minimum headway between the vehicles on roundabout circulatory roadway [s]
λ_i - scale parameter of Cowan's M3 distribution in *i*-stream [-], calculated from the dependence [23]:

$$\lambda = \frac{\varphi \cdot q_c}{1 - t_{min} \cdot q_c} \text{ [-]} \tag{3}$$

φ_i – proportion of the vehicles moving freely in *i*-stream at roundabout circulatory roadway calculated from the following formula [16]:

$$\varphi = \begin{Bmatrix} 1 & dla\ q_c < 0 \cdot 178 \\ 1 \cdot 553(1 - 2Q_{nwl}) & dla\ 0 \cdot 178 < q_c \leq 0 \cdot 5 \\ 0 & dla\ pozostałych\ przyapdków \end{Bmatrix} \tag{4}$$

t_g - critical gap [s] (Table 2)

t_f - follow-up time [s] (Table 2)

Tab. 2

Parameters t_g and t_f [24]

Minor direction				Major direction			
Inside lane		Outside lane		Inside lane		Outside lane	
t_g [s]	t_f [s]	t_g [s]	t_f [s]	t_g [s]	t_f [s]	t_g [s]	t_f [s]
3,2	2,2	3,9	2,1	3,6	2,2	3,9	2,1
3,2	2,2	3,9	2,1	3,6	2,2	3,9	2,1

O. Giuffrè, M. Guerrieri, A. Granà (Italy) in publication [25], presented models for calculation of the capacity of lanes at the entry of a turbo-roundabout. The dependence, which allows determining the capacity value for the right lane at the entry of turbo-roundabout, can be described according to equation 5:

$$C_p = 3600 \cdot \left(1 - \frac{t_{min} \cdot Q_{nwl}}{n_K \cdot 3600}\right)^{n_K} \cdot \frac{n_Z}{t_f} \cdot e^{-\frac{Q_{nwl}}{3600} \cdot \left(t_g - \frac{t_f}{2} - t_{min}\right)} \text{ [E/h]} \tag{5}$$

Moreover, the capacity of the left lane at the entry of the roundabout is calculated from the dependence [25]:

$$C_{L,W} = Q_{nwl,x} \cdot \frac{e^{-Q_{nwl,x}\frac{t_{g,x}}{3600}}}{1 - e^{-Q_{nwl,x}\frac{t_{f,x}}{3600}}} \text{ [E/h]} \tag{6}$$

The capacity of the left lane at the entry of the turbo-roundabout (leading directly and to the left) is calculated from the following relationships [25]:

$$C_E = \frac{\sum_{i=1}^{n} Q_i}{X} \text{ [E/h]} \tag{7}$$

$$X = \max\left(\frac{Q_i}{C_i}\right) \text{ [-]} \tag{8}$$

where:
C_p- capacity of the right-turn lane at the entry [E/h]
Q_{nwl}- traffic volume on roundabout circulatory roadway major for vehicle drivers at roundabout entry [E/h]
n_K- number of lanes on roundabout circulatory roadway [-]
n_z- number of lanes at roundabout entry [-]
t_g- critical gap [s]
t_f- follow up time [s]
t_{min} - minimum headway between the vehicles on roundabout circulatory roadway [s]
$C_{L,W}$- the capacity of a through and left-turn lane [E/h]
$t_{G,X}$ i $t_{F,X}$- the critical gap and the follow-up time, respectively [s]
X - the degree of saturation [-]

In this paper [25], the following values of model parameters were used in the analyses: t_g = 4.1 s; t_f = 2.9 s; t_{min} = 2.1 s; $t_{g,x}$ = 6.4 s; $t_{f,x}$ = 3.5 s.

In turn, in the work [26] by O. Giuffre, A. Grana and S. Marino from 2012, a model of calculation of lane capacity at the entry of a turbo-roundabout based on the method of O. Hangring was presented. This model has the form:

$$C_e = 3600 \cdot \sum_j \frac{\varphi_j \cdot Q_{nwl,j}}{3600 - t_{\min j} \cdot Q_{nwl,j}} \cdot \prod_k \left(\frac{3600 - t_{\min k} \cdot Q_{c,k}}{3600}\right) \cdot \frac{\exp[-\sum_j \frac{\varphi_l \cdot Q_{nwl,l}}{3600 - t_{\min l} \cdot Q_{nwl,l}} (t_{g,i} - t_{\min i})]}{1 - \exp(-\sum_m \frac{\varphi_m \cdot Q_{c,m}}{3600 - t_{\min m} \cdot Q_{c,m}} \cdot t_{f,m})} \tag{9}$$

The right and left lane capacity values as the main entry and the right lane values at the minor entry is determined by the following formula [26]:

$$C_e = Q_{nwl,e} \cdot \left(1 - \frac{t_{min} \cdot Q_{nwl,e}}{3600}\right) \cdot \frac{\exp\left(\frac{-Q_{nwl,e}}{3600} \cdot (t_g - t_{min})\right)}{1 - \exp\left(\frac{-Q_{nwl,e}}{3600} \cdot t_f\right)} \tag{10}$$

The capacity of the left lane at the minor entry is determined from dependencies [26]:

$$C_e = (Q_{nwl,e} + Q_{nwl,i}) \cdot \left(1 - \frac{t_{min} \cdot Q_{nwl,e}}{3600}\right) \cdot \left(1 - \frac{t_{min} \cdot Q_{nwl,j}}{3600}\right) \cdot \frac{\exp[\frac{-Q_{nwl,e}}{3600} \cdot (t_{g,e} - t_{min}) \frac{-Q_{nwl,i}}{3600} \cdot (t_{g,i} - t_{min})]}{1 - \exp[\frac{-(Q_{nwl,e} + Q_{nwl,i})}{3600} \cdot t_f]} \tag{11}$$

where:
C_e- entry lane capacity [E/h]
φ - Cowan's M3 parameter representing the proportion of the vehicles moving freely on roundabout circulatory roadway [-]

Q_{nwl} - traffic volume on roundabout circulatory roadway major for vehicle drivers at roundabout entry [E/h]
t_g - critical gap [s] (Table 3)
t_f – follow-up time [s] (Table 3)
t_{min} - minimum headway between the vehicles on roundabout circulatory roadway [s] (Table 3)
j, k, l, m - indices for conflicting lanes and circulatory roadway [-]

Tab. 3

Parameters t_g, t_f and t_{min} presented in the paper [26]

Entry	Lane	t_g		t_f [s]	t_{min} [s]
		$t_{g,\,in}$[s]	$t_{g,\,out}$ [s]		
Major entries	Left	-	3,60	2,26	2,10
	Right	-	3,87	2,13	2,10
Minor entries	Left	3,19	3,03	2,26	2,10
	Right	-	3,74	2,13	2,10

In turn, E. Pitlova, A. Kocianova (Slovakia) in the publication [27] compared 2 models of calculation of turbo-roundabouts entry capacity. The first model is based on the Tanner model and has the form:

$$C_e = \frac{3600}{t_f} \cdot \left(1 - \frac{t_{min} \cdot Q_{nwl,zew}}{3600}\right) \cdot \left(1 - \frac{t_{min} \cdot Q_{nwl,wew}}{3600}\right) \cdot e^{-\frac{(Q_{nwl,zew} + Q_{nwl,wew})}{3600} \cdot \left(t_g - \frac{t_f}{2} - t_{min}\right)} \quad (12)$$

The second model is based on Plank's relations and for entries with two lanes capacity. It is calculated from the dependence:

$$C_e = \frac{\varphi_{out} \cdot Q_{nwl,zew} \cdot e^{-\lambda_{out} \cdot (t_g - t_{min})}}{1 - e^{-\lambda_{out} \cdot t_f}} \text{ [E/h]} \quad (13)$$

For single-lane entries, the capacity is calculated from the dependence:

$$C_e = \frac{(\lambda_{out} + \lambda_{in}) \cdot \varphi_{out} \cdot \varphi_{in} \cdot e^{-(\lambda_{out} + \lambda_{in}) \cdot (t_g - t_{min})}}{\left(1 - e^{-t_f \cdot (\lambda_{out} + \lambda_{in})}\right) \cdot (\varphi_{out} + \lambda_{out} \cdot t_{min}) \cdot (\varphi_{in} + \lambda_{in} \cdot t_{min})} \text{ [E/h]} \quad (14)$$

where:
$q_{c,out}$,$q_{c,in}$ - traffic volumes in the outer and the inner lanes on circulatory roadway, respectively [E/h],
φ_{out}, λ_{out} and φ_{in}, λ_{in} - distribution parameters for the outer and inner lanes on circulatory roadway respectively [E/h] calculated from the dependence:

$$\varphi = 0{,}75 \cdot (1 - t_{min} \cdot q_c) \text{ [-]} \quad (15)$$

$$\lambda = \frac{\varphi \cdot q_c}{1 - t_{min} \cdot q_c} \text{ [-]} \tag{16}$$

where:
t_g- critical gap [s] (Table 4)
t_f- follow-up time [s] (Table 4)
t_{min}- minimum headway between the vehicles on roundabout circulatory roadway [s] (Table 4).

Tab. 4

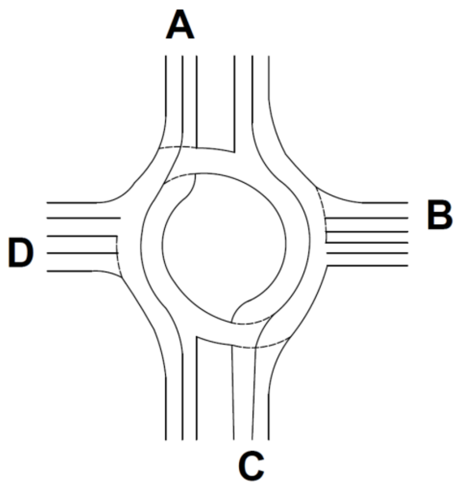
Parameters t_g, t_f and t_{min} presented in the paper [27]

Description	Lane	t_g [s]	t_f [s]	t_{min} [s]
One entry lane/two circulating lanes	Single lane	3,9	2,7	2,1
Two entry lanes/one circulating lane	Left lane	3,8	2,7	2,1
	Right lane	4,0	2,8	2,1
Two entry lanes/two circulating lanes	Left lane	3,9	2,7	2,1
	Right lane	4,0	2,8	2,1

4. Comparative analysis of empirical and theoretical capacity

Empirical capacity values were determined for the roundabouts analysed in the paper. In the case of the turbo-roundabout, the empirical capacity was determined separately for the left and right entry lanes at entry A and C, as shown in Fig. 6a. The empirical capacity of spiral-roundabouts was determined for both lanes at the entries A and C (Fig. 6b).

a).



b).

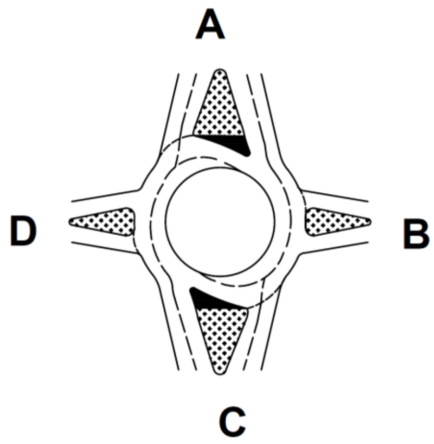


Fig. 6. Scheme of a) turbo-roundabout, b) spiral-roundabout

The empirical capacity values were compared with theoretical ones calculated based on Italian and Slovak methodologies presented in section 3 that is dedicated to the turbo-roundabout. These comparisons were made with accuracy to the lane at the entry. The empirical capacities of spiral-roundabouts entries were compared with theoretical capacities determined from the Polish roundabout capacity method for the case of a medium double-lane roundabout entry. The results of empirical capacity comparison of the lanes at the entry of turbo-roundabout with the theoretical capacity are presented in Figs. 7, 8 and 9. Fig. 10 presents a comparison of the empirical capacity of traffic lanes at the entry of turbo-roundabout with theoretical ones calculated based on models constructed by E. Macioszek.

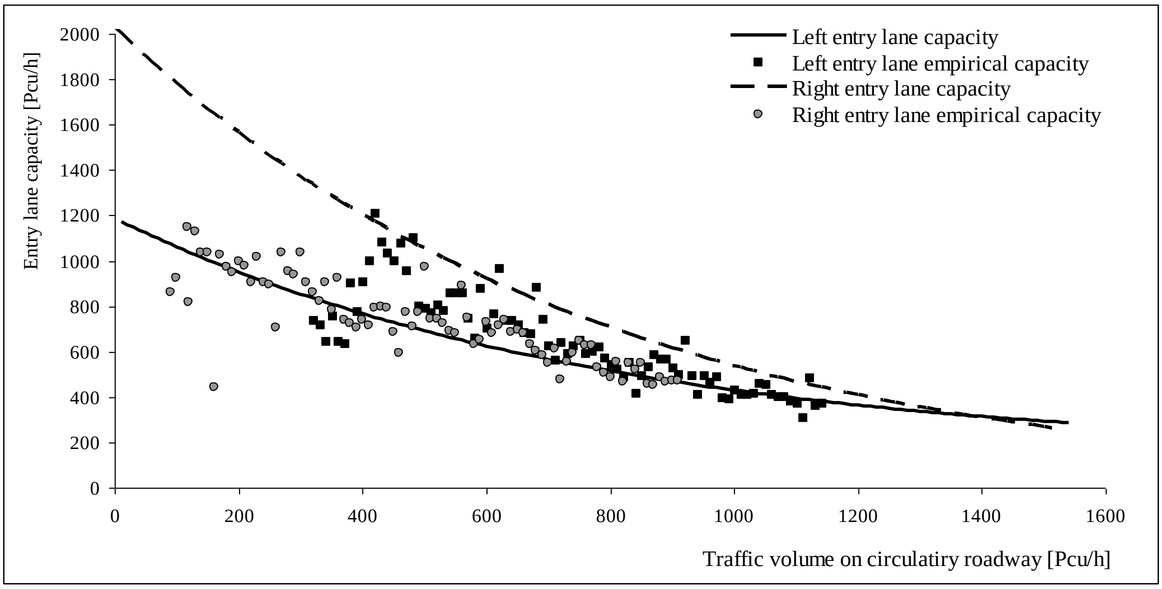


Fig. 7. Comparison of the empirical and theoretical values of the entry lane capacity of turbo-roundabout determined based on the Italian method (Models 5 and 6)

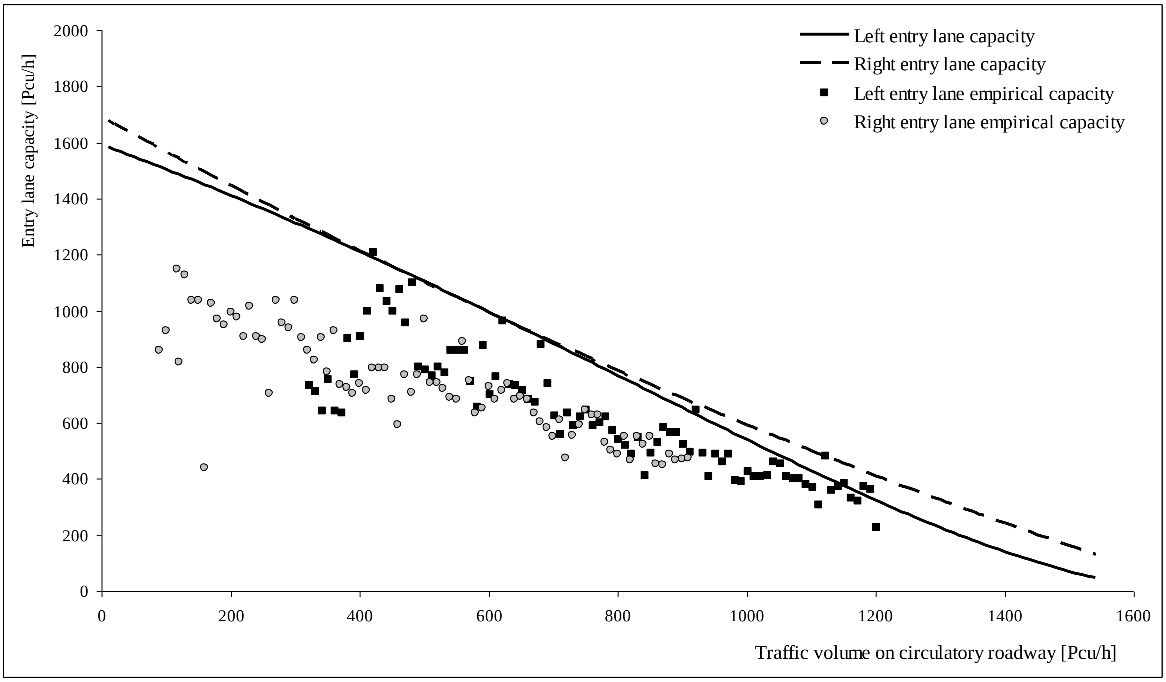


Fig. 8. Comparison of the empirical and theoretical values of the entry lane capacity of turbo-roundabout determined based on the Italian method (Models 10 and 11)

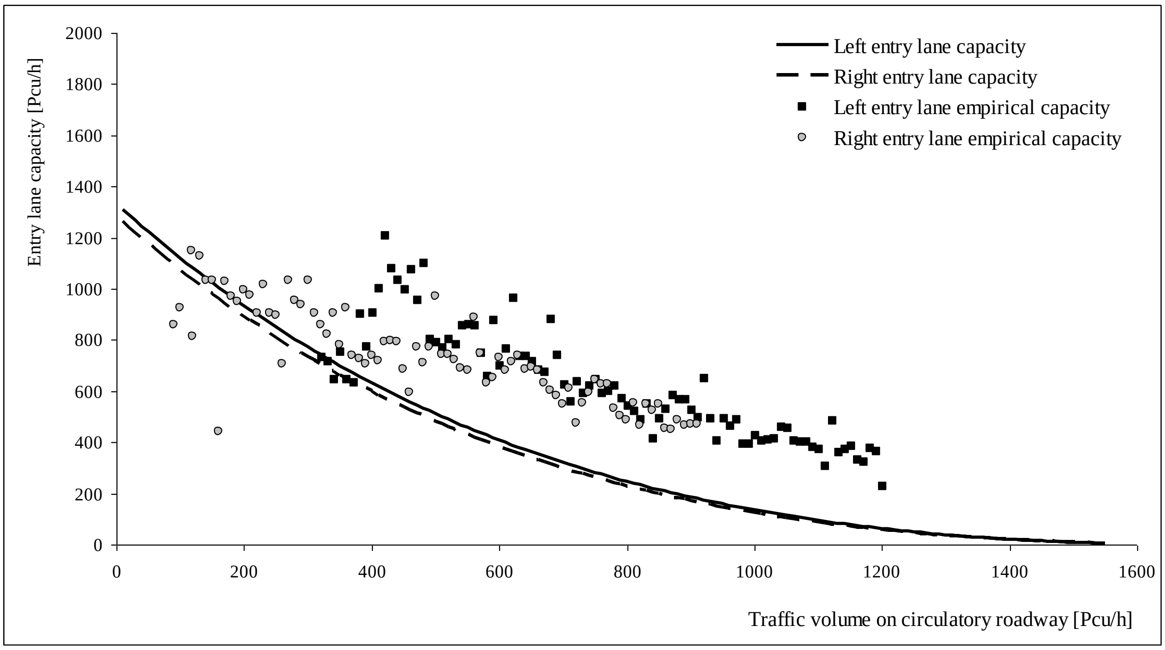


Fig. 9. Comparison of the empirical and theoretical values of the entry lane capacity of turbo-roundabout determined based on the Slovak method (Model 12)

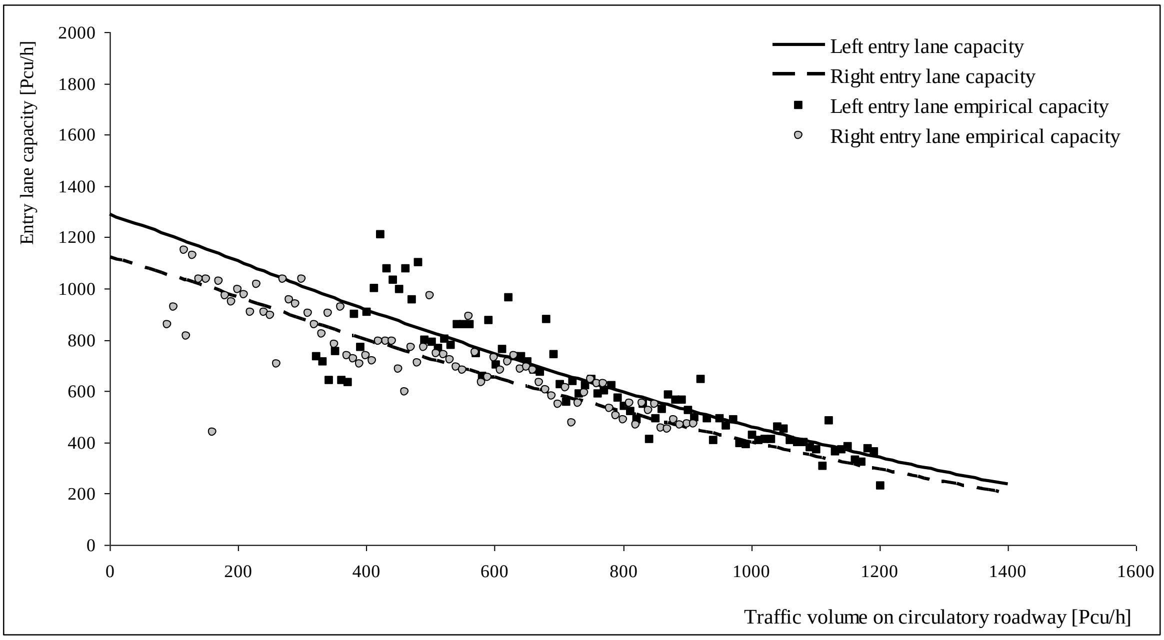


Fig. 10. Comparison of the empirical and theoretical values of the entry lane capacity of turbo-roundabout determined on the basis of the E. Macioszek model

Values of empirical capacities of the entries of spiral-roundabouts MS and KS localised in Sosnowiec city were compared with the values of the theoretical capacity of the entries calculated using the Polish method of roundabout capacity calculation [23]. The results of the comparisons are shown in Figs. 11 and 12.

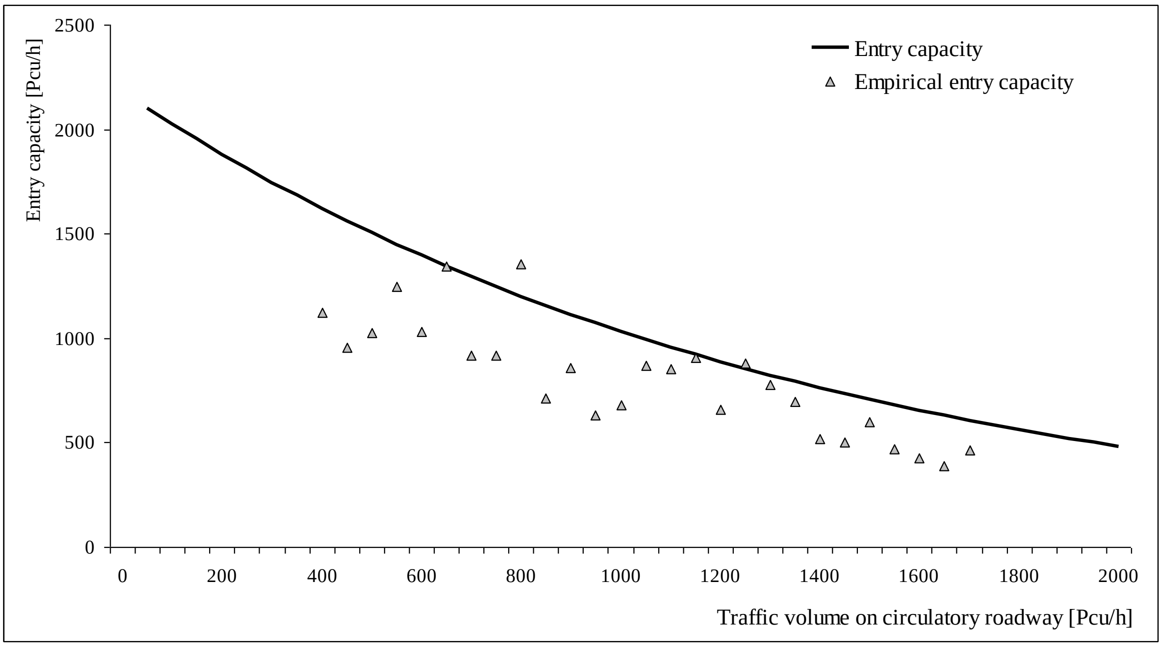


Fig. 11. Comparison of the empirical capacity of the spiral-roundabout entry (MS) with the theoretical capacity entry determined from the Polish method of roundabout capacity calculation (Model 1)

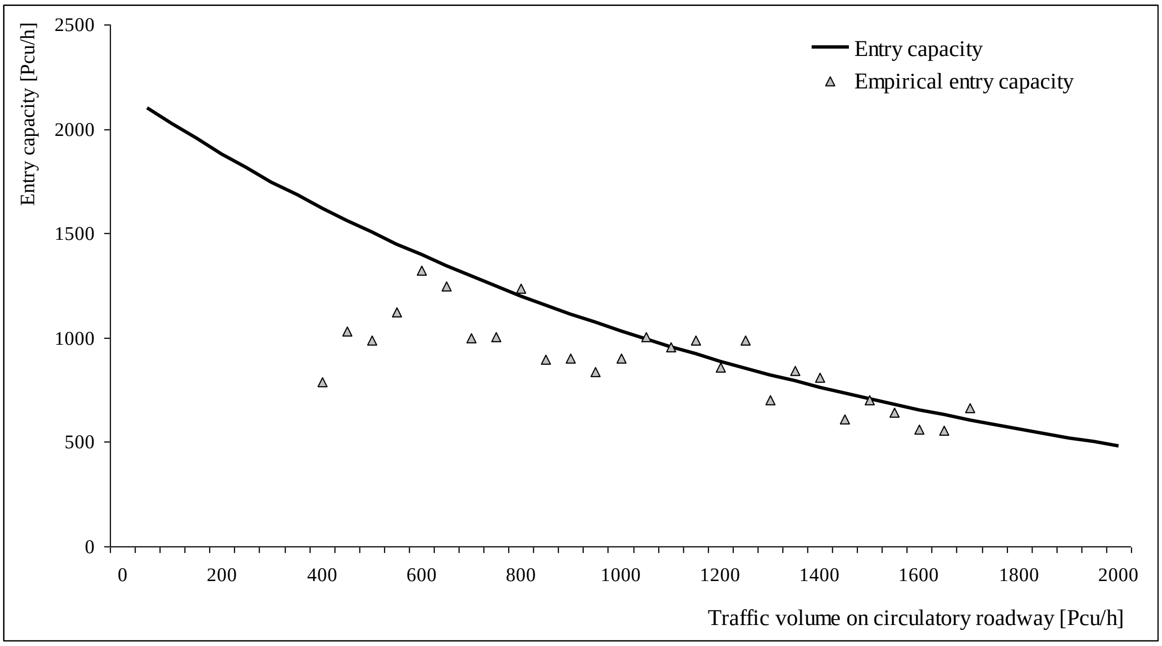


Fig. 12. Comparison of the empirical capacity of the spiral-roundabout entry (KS) with the theoretical capacity entry determined from the Polish method of roundabout capacity calculation (Model 1)

5. CONCLUSIONS

One of the main road in Sosnowiec city (Poland) with three intersections analysed in this paper before reconstruction was characterised by unfavourable road and traffic conditions, insufficient capacity level and low level of road traffic safety, which was visible in the queues of vehicles waiting for the possibility of inclusion to the traffic. After rebuilding the analysed road and designing three roundabouts, the congestion of traffic flow significantly decreased. Moreover, the traffic and road conditions and the level of traffic safety were considerably improved. The comparative analysis of empirical and theoretical capacity values of the analysed roundabouts concludes that:

- as a result of the comparison of the empirical capacity of the left and right entry lanes of the turbo-roundabout with the theoretical capacity values calculated on the basis of the foreign models from Italy and Slovakia, it can be concluded that there are differences between the empirical and theoretical values. These differences result from many different factors, for example, the different drivers' behaviours in different countries, different vehicles sizes, etc.,
- a satisfactory adjustment of the empirical capacity of the left and right entry lanes at the turbo-roundabout to the theoretical capacity values was obtained for the model constructed on the basis of research carried out in Poland (Fig. 11),
- the comparison of empirical and theoretical entry capacity values of spiral-roundabouts allow concluding that the better fit was obtained for the KS roundabout. However, it should be remembered that the empirical data were compared with theoretical values determined from the model dedicated to two-lane roundabouts,
- as presented in this paper, conclusions have a general form. Obtaining information about detailed differences between the analysed capacity values and models requires further complex research and analysis.

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