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Capacity analysis of a bypass of roundabouts

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Abstract: The capacity of the roads network mainly depends on the capacity of its nodal points - intersections. A connecting branch or a bypass is a lane or lanes inserted between two adjacent branches of a roundabout, providing redirection of vehicles, that would otherwise burden a circular lane. A bypass effect to the capacity of roundabouts, but also other types of level intersections, is undeniable. A connecting branch increases the total capacity of an intersection that takes a part of vehicles performing a manoeuver of the first right turn completely out of an intersection area. Redirecting vehicles reduces delay times at intersections and reduces queues at the entrance to an intersection. Bypasses improve the quality of transport. Limiting for the capacity of bypasses is the point of disconnection from the entrance into the roundabout and the connection point into the exit from the roundabout. Central parts of the bypasses have minimal effects on the capacity. The length of a bypass has to match with the maximum length of a queue of waiting vehicles at a given intensity level. The article deals with analysis of the bypass capacity at the roundabouts.

1. Introduction

The bypass (SV) increases the capacity of a roundabout by adding separate lane (one way road) for turning the vehicles going to the right see [6, 8]. The bigger the demand for the first right turn is, the bigger influence of increased capacity we can see. The situation at the entrance to a roundabout has to enable the early elimination of the vehicles to the bypass. At the same time the smoothly flowing connection from the exit of the bypass to the superior lane must be secured. The capacity of the bypass depends on the capacity of the point of connection and disconnection of the bypass, the central part of the bypass influences the capacity only marginally. The length of the connecting branch should correspond to the maximum length of a queue of vehicles, that is formed in the bypass at a given intensity level. If the length of the connecting branch is short, the queue can reach before the point of the disconnection of vehicles at the entrance, which results in increasing of delay time at the entrance and in total decreasing of quality of transport (UKD) at the intersection. The identical situation can occur at the entrance when it is clogged by vehicles and the queue reaches before the point of disconnection of the bypass.

Empirical evaluation and observing of bypasses was aimed at the simplest but the most used type of the roundabout (roundabout with 1 lane at the circle/1 lane at the exit) with corresponding disposition of bypasses "wedge - wedge" (Figure 1). The given type was also selected because of clear determination of critical time gaps (tg), subsequent time gaps (tf) and minimum time gaps (t0).

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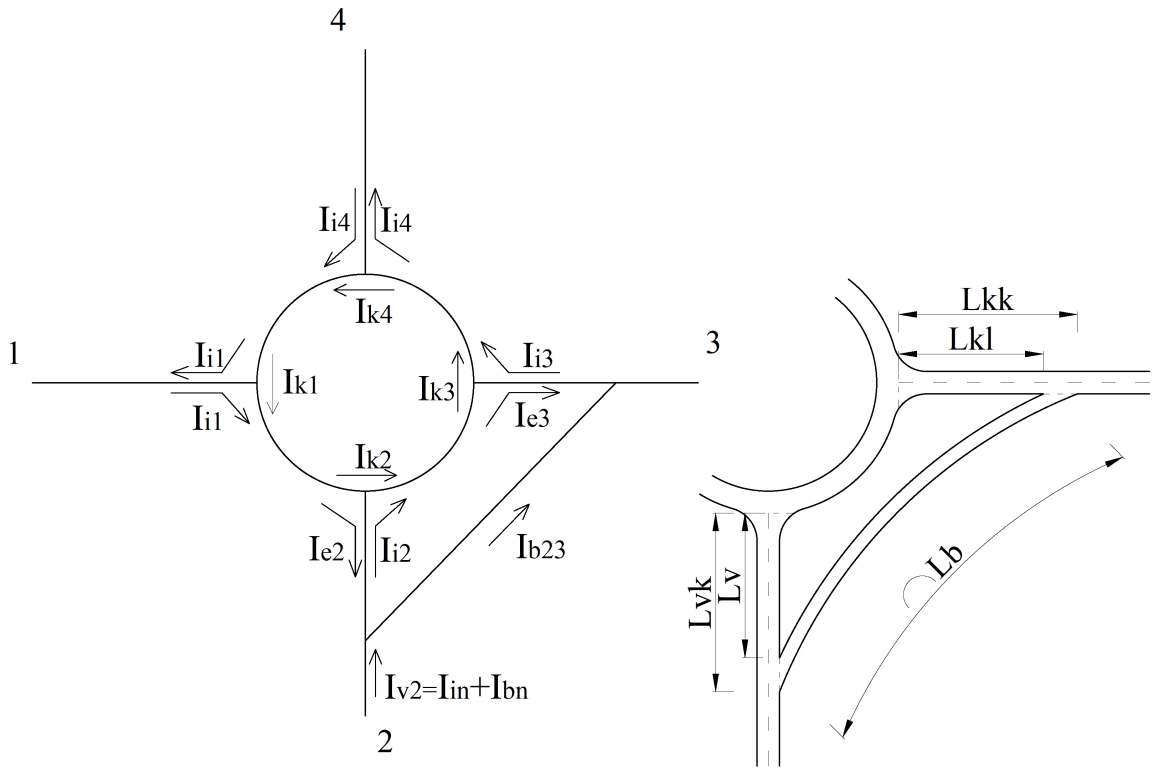


Figure 1. The scheme of intensities, scheme of geometric layout of the bypass - type "wedge -wedge".

2. Capacity of the point of disconnection from the entrance into the roundabout

The capacity of the point of disconnection of the bypass was determined according to the interactive models in the programme PTV Vissim; the tg, tf, t0 values were not detected.

The capacity of the beginning of the bypass mainly depends on the amount of demand for right turn, i.e. intensities percent at the common lane that enter the roundabout (Iej) and intensities of turning to SV (Ibj,j+1). The sum of these intensities makes so called total intensity of an entrance (Ivj). Another important aspect is the position of the start of SV before the border of a roundabout, i.e. Lvk (Figure 1).

From the Figure 2 we can read:

- Whether the connecting branch is necessary, i.e. if the point with coordinates of superior values of intensity on the circle Ikj and entrance Iij is situated above the limit of capacity of an entrance for UKD of level D; in order to make comparison, there is also level B in the figure.
- For the given ratio of intensities Iij a Ibj,j+1 we can read the increase of total capacity Ivj when using the bypass. For the ratio of intensities from 80:20% to 50:50% this increase is approximately 550 - 150 nveh/h, set for UKD of level D and the range of values of intensity at the roundabout 200 – 1200 nveh/h.

This figure can be used when deciding whether the bypass should be built.

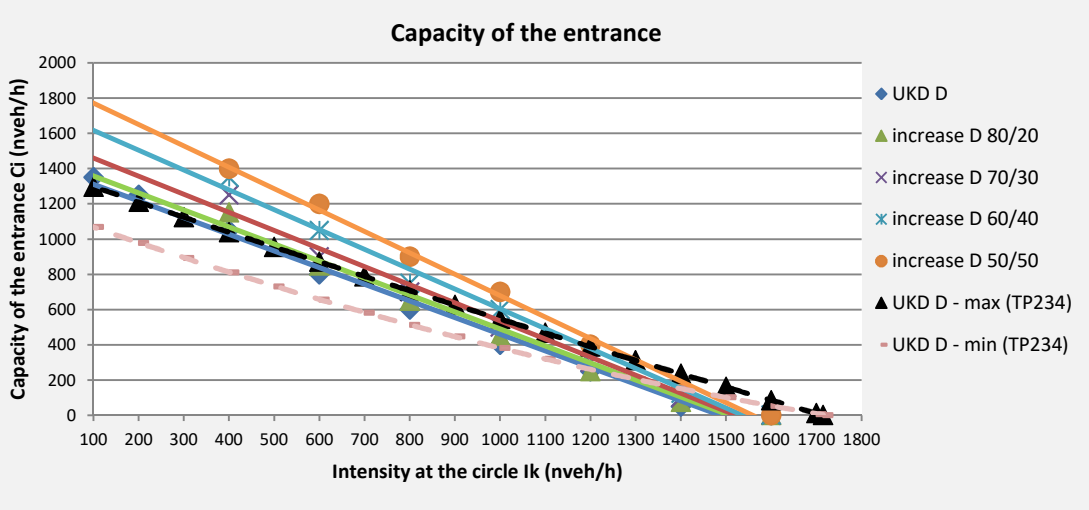


Figure 2. Capacity of the entrance to the roundabout.

The crucial aspect for the capacity of turning is the length of the queue at the entrance to the roundabout. From the Figure 3 we can roughly read the average length of the queue 10m, 20m, 30m, 40m, 100m at the entrance depending on the intensity of vehicles behind the point of disconnection of the bypass and intensity of vehicles at the circle.

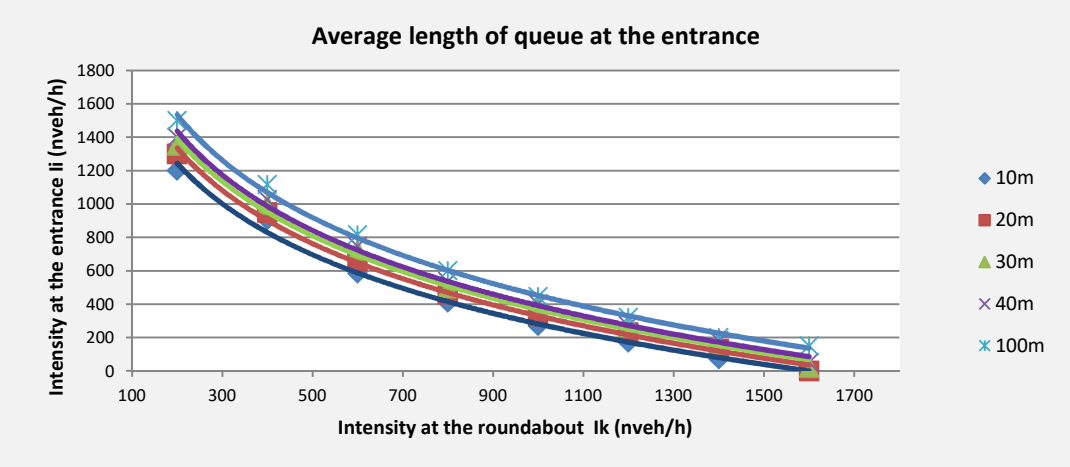


Figure 3. Average length of the queue at the entrance to the intersection.

The length of the queue at the entrance has to be smaller than the distance of the circle and the limit of the point Lv. At the same time the length of the queue that is formed at bypass has to be smaller than the length of bypass, i.e. Lb.

3. Capacity of the connection point into the exit from the roundabout

To be able to determine the conclusion of the capacity assessment of the roundabout it is necessary to verify whether for the intensity of traffic at the entrance the limit value of the medium time of delay (tw) is not exceeded, based on the conditions for the particular levels of UKD according to [1,2,7]:

$$t_w^n \leq t_{w,lim} \quad (1)$$

t_w^n – medium time of delay of a vehicle in the stream of traffic (s)
$t_{w,lim}$ – the longest permissible medium time of delay according to the required level of UKD (s)

For calculation of the capacity of the entrance to the roundabout and the point of bypass connection we use the same formula as for the basic capacity according to [1, 7]:

$$C_i = 3600 * (1 - \frac{\Delta * I_k}{n_k * 3600})^{n_k} * \frac{n_{i,koef}}{t_f} * e^{-\frac{I_k}{3600} * (tg - \frac{tf}{2} - \Delta)} \quad (2)$$

C_i – capacity of the entrance, points of bypass connection (nveh/h)
I_k – intensity of traffic at the roundabout, exit (nveh/h)
n_k – number of lanes at the roundabout, exit
$n_{i,koef}$ - coefficient taking into account the number of lanes at the entrance, bypass
$n_{i,koef} = 1{,}00$ – for one-lane entrances
$n_{i,koef} = 1{,}50$ – for two-lane entrances
t_g - critical time gap (s)
t_f - subsequent time gap (s)
Δ (t0)- minimum time gap between vehicles going on the circle or exit (s)

It is necessary to emphasize that in case of calculating the capacity of the entrance to the roundabout the more precise entrance values according [1] are used. To determine the capacity of the point of bypass connection it is necessary to determine new values.

3.1. Entrance values of the capacity assessment of the connection point
Non - reduced entrance values were set by empiric evaluation of 25 videorecordings of total length of 21 hours (table 1).

- tg (critical time gap) – they were set by using the Raff method a subsequently verified by the Modified method of maximum credibility (Troutbeck) according to [3]
- tf (subsequent time gap) – they were set using two ways: as the average of time gaps between vehicles of side traffic lane and from the departure functions of vehicles at the side stream of traffic according to [4]
- t0 (minimum time gap) – they were set using the departure functions of vehicles at the side stream of traffic according to [4]; it is the biggest time gap between vehicles in the main stream of traffic, that is not yet accepted by the vehicle waiting in inferior stream of traffic.

Table 1. Empirically determined non-reduced entrance values.

	Raff			Departure function			Troutbeck	D	Lkk	Lkl	Lb	Slow vehicles (%)		Intensities (nveh/h)	
	tg (s)	tf (s)	t0 (s)	tg (s)	tf (s)	t0 (s)	tg (s)	(m)	(m)	(m)	(m)	bypass	exit	bypass	exit
Litoměřice 2012	4.3	2.9	2.9	4.5	3.2	2.9	4.2	35	18	11	66	12.38	5.00	366	320
Mělník 2007	4.2	2.7	2.8	4.2	2.8	2.8	4.2	37	25	15	31	15.70	8.02	420	533
Mělník 2014	3.8	2.7	2.4	4.1	2.9	2.7	-	37	25	15	31	14.24	5.77	349	528
Říčany	3.8	2.6	2.5	4.2	3.3	2.5	4.2	38	26	14	29	2.72	3.56	220	366
Šeberov	3.8	2.6	2.4	4.1	3.4	2.4	3.9	33	44	20	71	1.34	3.35	149	537
Svitavy	-	2.9	-	4.3	3.3	2.6	-	45	50	15	59	0.00	0.25	90	396
Jaroměř	4.0	2.6	2.7	3.9	2.7	2.5	-	32	26	14	76	1.48	2.04	337	393
Teplice	4.7	3.0	3.2	4.9	3.9	3.0	-	34	71	23	105	5.23	6.07	153	595

3.2. Capacity of connection point of the connecting branch

Capacity of the bypass connection was determined according to the interactive models in the programme PTV Vissim.

Capacity of the connection point directly depends on the distance of the end of wedge Lkk. The longer the distance Lkk is, the smaller is the critical time gap tg. In practice it means that the driver has better view from the vehicle and therefore affords to accept shorter gap between vehicles in superior stream of traffic. With the help of correlation and under condition that the difference in the capacity of connection point is not bigger than 50 nveh/h, this assumption was found as crucial according to [5].

In practice the connection is usually made using the connecting wedge.

Based on different geometrical dispositions of connection points of observed bypasses, the reductions of entrance values of tg, tf and t0 were set, depending on the distance of the end of connecting wedge Lkk in the range of 10 - 40m (Figure 1). For capacity calculation is not possible to use the values written in [1], as this is another connecting maneuver.

$$t_g = 5 - \frac{L_{kk}}{30} \tag{3}$$

$$t_f = 2{,}7s \tag{4}$$

$$(t0)\Delta = 3{,}2 - \frac{0{,}7}{30} * L_{kk} \tag{5}$$

With increasing distance of the end of wedge Lkk the capacity of connection point of bypass goes up by 200 nveh/h, see Figure n. 4. The figure hereafter also compares the capacity set by simulation programme for Lkk=10m and determined arithmetically according to the formula (2). It is obvious that in the areas of low and high intensities Ie (0 - 400 nveh/h and 1000 - 1300 nveh/h) the simulation deviates more from the calculated values. This can be due to the lack of empirically measured data at low or high intensities.

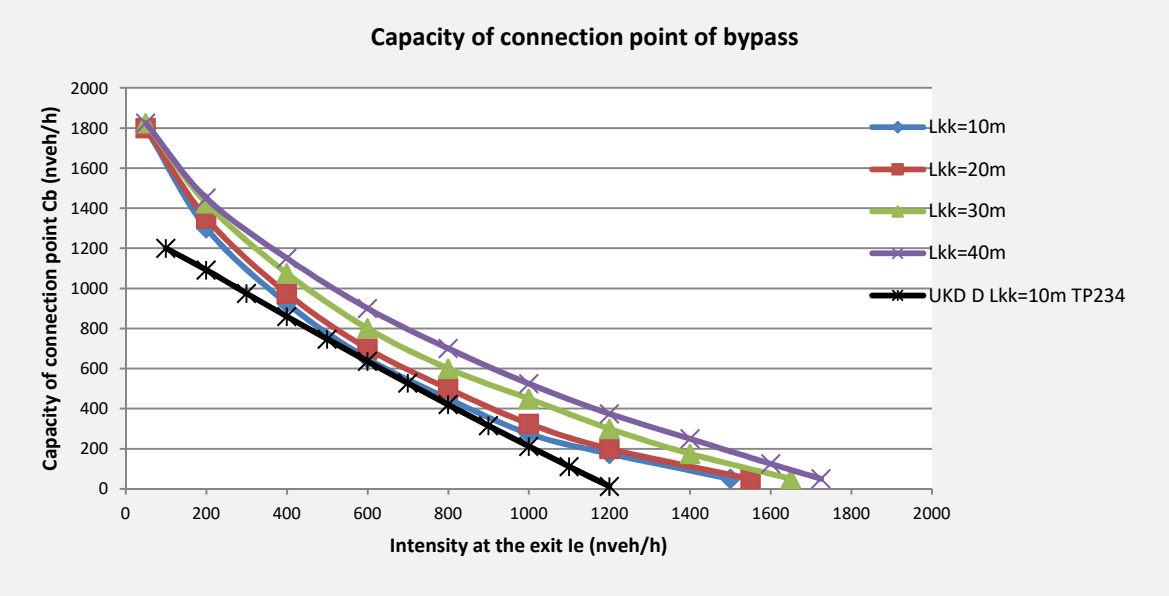


Figure 4. Capacity of connection point of bypass depending on Lkk in the range of 10-40m.

It is always necessary to assess the capacity in relation to the required quality level of traffic UKD. From Figures 5 – 8 we can read the UKD connection points depending on the intensity at the exit Ie, intensity in the bypass Ib and Lkk in the range of 10 - 40m.

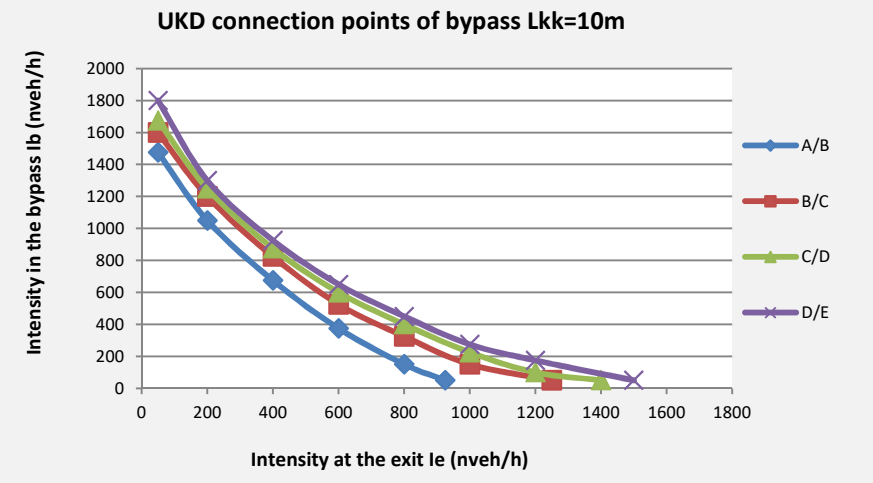


Figure 5. UKD connection points of the bypass Lkk=10m.

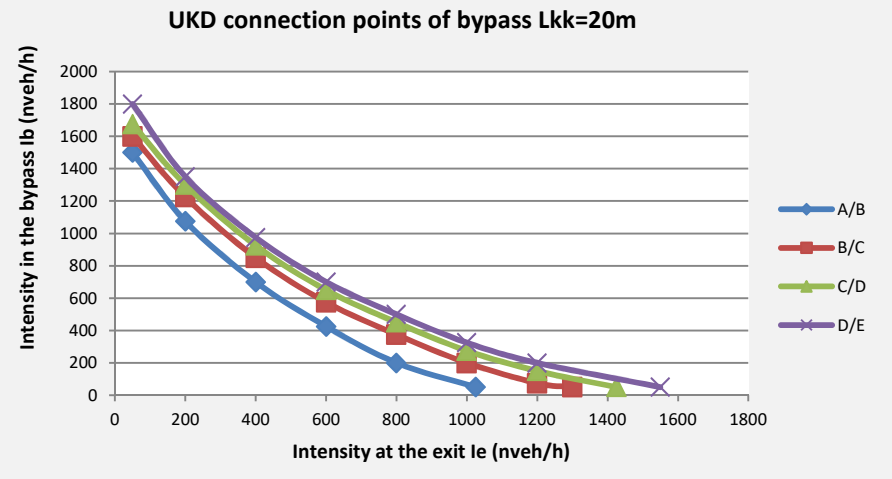


Figure 6. UKD connection points of the bypass Lkk=20m.

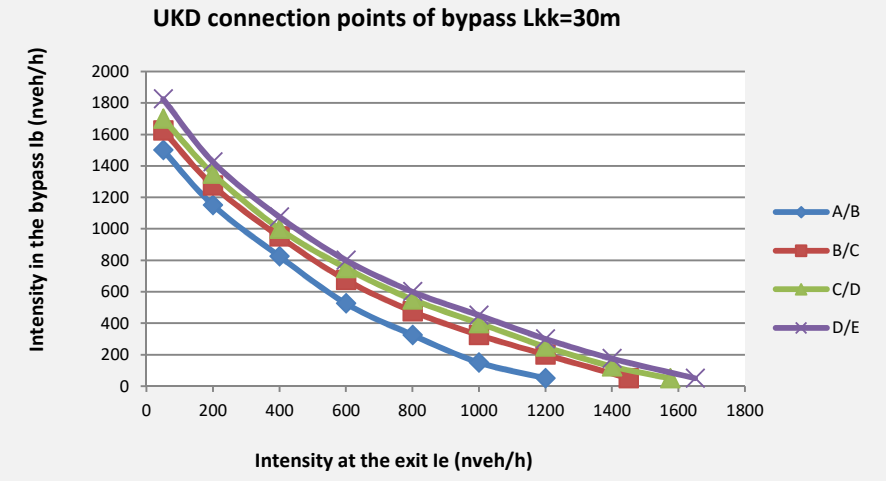


Figure 7. UKD connection points of the bypass Lkk=30m.

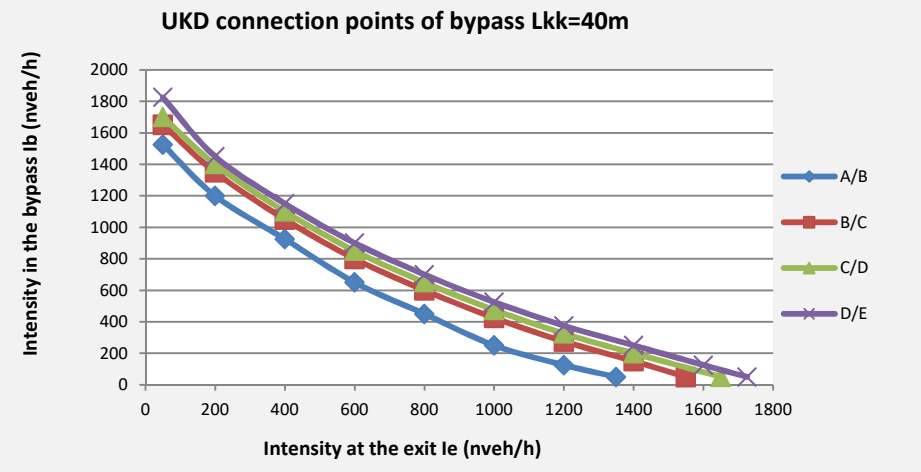


Figure 8. UKD connection points of bypass Lkk=40m.

The important element of capacity assessment of the connection point is the length of queue that is formed in the bypass; the maximum length of queue 10 - 100m depending on the intensities of vehicles and Lkk can be read from the Figure 9.

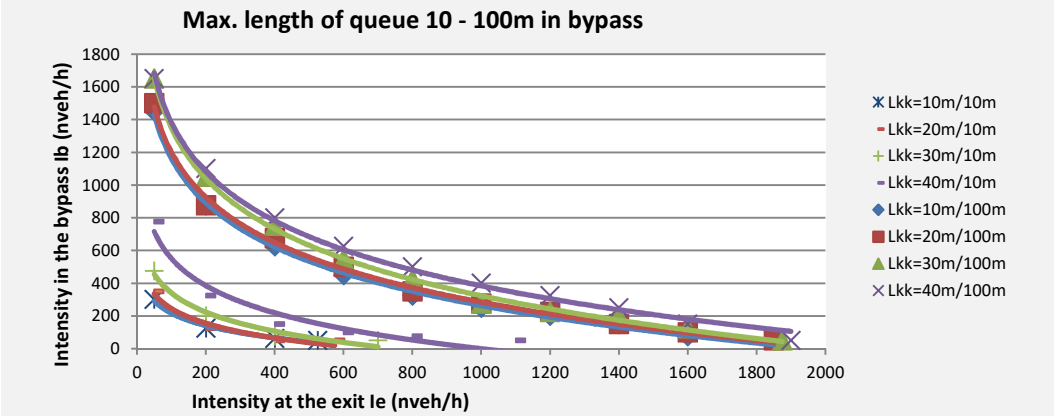


Figure 9. Max. length of queue 10-100m in the bypass depending on Lkk in the range of 0-40m.

4. Conclusion

For effective use of a bypass it is important to design the connection to the exit branch correctly.

For the point of disconnection of the bypass the length of queue of vehicles at the entrance to a roundabout is limiting. If the queue at the entrance reaches behind the point of disconnection of connecting branch, it is necessary to design turning lane or separate lane for entering the bypass; we can read roughly the length of queue from Figure n. 3.

The capacity of connection point is determined apart from intensities of vehicles also by the distance of end of wedge Lkk, that defines how big critical time gap tg a driver is willing to accept. If the bypass is full of waiting vehicles, it is necessary to design the connecting lane or separate lane at the connection point of connecting branch.

The research is aimed at suggesting the complex method of determining the capacity of the bypass as a whole and adding this topic to the rules related to the capacity of roundabouts.

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