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Relationship between Critical Gap and Certain Geometrical Parameters in Roundabouts

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Abstract

Gap-acceptance method is one of the classical methods used to analyze capacity of roundabouts. Critical gap has a privileged role in this approach. Different driver behavior and local rules of traffic has a key role in implementing it in the local standard for capacity calculation in each country. Therefore, a reliable method for estimation of critical gap at a certain location can be of great importance. This paper presents the first steps of an experimental investigation and analysis on whether it is possible to find correlation between video-based gap acceptance data and certain design parameters of roundabouts in Hungary. Ten single lane roundabouts of different size were recorded for hours in different locations in and around Budapest to assess gap acceptance data and relate it to certain design parameters like diameter, distance of neighboring entries, entry width, width of splitter island, number of entries over time, and entry angle – or any combination of those. Using only a linear approach, strong positive correlation was found between measured critical gap and distance between legs. There is correlation (not so strong however) between critical gap and (approach) entry width as well as splitter island width, and enough data were examined to say that there is no correlation between central island diameter and critical gap.

Keywords

critical gap, roundabout, design parameter, geometry, linear regression

1 Introduction

Roundabouts are very popular in Europe and worldwide as they represent a type of intersection without signals due to the circular geometric layout. The United Kingdom developed the modern roundabout to solve the problems aligned with these traffic circles. In 1966, the Give-way rule was presented and adopted at all existing roundabouts, which required the entering vehicles to either give way or yield to circulating traffic. This rule restricted vehicles from entering the roundabout until there were sufficient gaps in circulating traffic [1].

Two consecutive vehicles circulating the carriageway (see Fig. 1) generate these gaps. The distribution of the size of these gaps is an influential parameter that affects the capacity of roundabouts because the entering vehicle either accepts and merges into the gap in the circulating traffic or rejects it and waits for a sufficient gap to accept (see Fig. 1). While gaps can be observed on site, critical gap itself can only be calculated from the observation of accepted and rejected gaps. As such, the critical gap depends a lot on

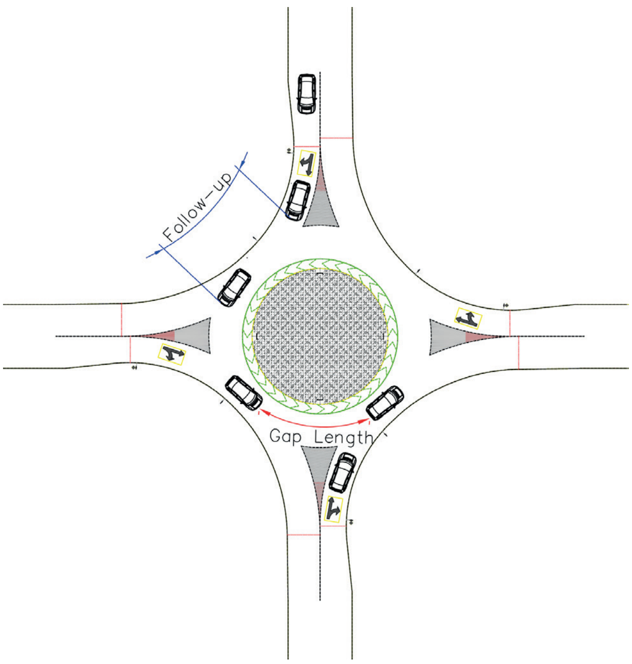

Fig. 1 Gap and Headway (Source: Author)

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local conditions like geometric layout, driver behavior, and traffic conditions [2]. There are different methods available for estimating the critical gap [3-6]. In this paper, authors decided to use Raff's (also known as the graphical method) for estimating critical gap for its straightforward approach and robust results as investigated in [7], in addition to that Raff's method is prevalent among researchers and traffic engineers in many countries because of its simplicity. The cumulative probability function is calculated for accepted gaps Fa(t) and rejected gaps Fr(t) based on the field calculations, then the critical gap tc is obtained graphically by finding the interception point between the two functions 1-Fr(t) and Fa(t) as shown in (Fig. 2)

In this paper, only single-lane roundabouts were examined. and seven roundabout design parameters analyzed to investigate the influence of these parameters on the critical gap (entry width, Width of circulating carriageway, central island diameter, the distance between neighboring legs, entry angle, splitter island width, and Approach entry width) (Fig. 3).

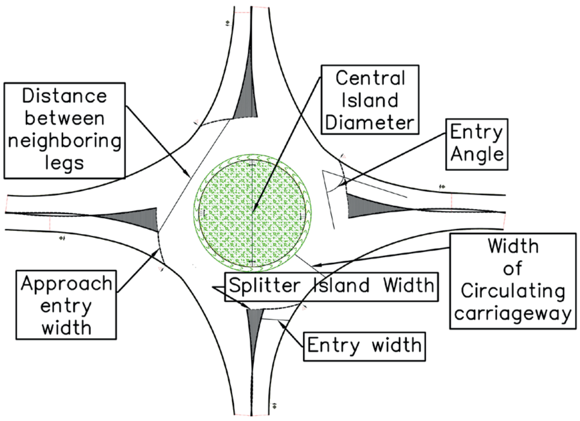

Fig. 3 Single Lane roundabout studied parameters (Source: Author)

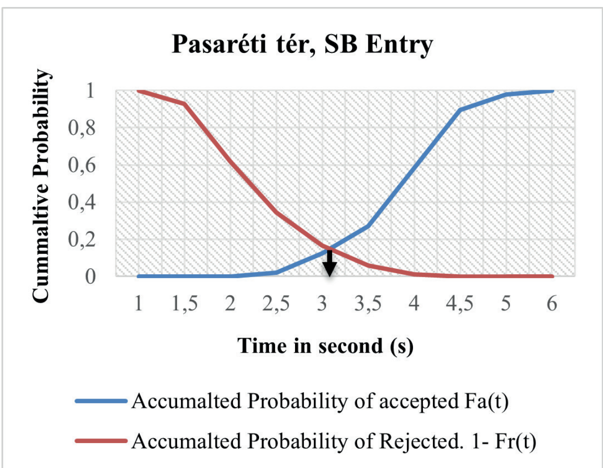

Fig. 2 Pasaréti tér SB entry Critical gap estimation using Raff's method. (Source: Author)

2 Methodology

Ten Single-lane roundabouts of the same traffic situation were selected in Budapest, and its surrounding as shown in Table 1.

Field data was collected using a video camera recorder mounted on a 4 m long pole placed at a specific location in each roundabout to have a picture of the whole roundabout and all entry legs are clearly visible (Fig. 4).and the specification of the used camera described in Table 2.

Table 1 The locations of the roundabouts, date of recording, and the duration of recording. (Source: Author)

City	Roundabout location	Inscribed Diameter, m	# Of lanes	Date	Length of video
Budapest	Pusztaszeri köröndl	22	1	9-Oct-20 16-Mar-21	4 h
	Pasaréti tér	24	1	19-Oct-20 2-Nov-20	4h: 15m
	Szabadság út-Baross utca	24	1	22-Mar-21	2h:07m
Budaörs	Budaörs Townhall	23	1	22-Mar-21	2h:16m
	Budaörs Gimnázium	23.5	1	23-Mar-21	2h:30m
	Budaörs Ifjúság	26.5	1	23-Mar-21	2h:20m
Érd	Érd-alsó	26.5	1	17-Nov-20	2h
	Érd felső	26.5	1	9-Mar-21	1h:30m
	Nagytétény	68	1	27-Jan-21	2h
Törökbálint	Törökbálint	46.5	1	16-Mar-21	2h:40m

Fig. 4 The installation of the Camera at one of the studied roundabouts (Source: Author)

Table 2 Camera specification

	Specifications
Manufacture	SJCAM
Model	SJ4000 WIFI ACTION CAMERA
Sensor	12.0MP CMOS sensor
Lens	170 Degree HD wide-angle Lens
Resolution of videos recorded	1080P (1920*1080) 30FPS 720P (1280*720) 60FPS 720P (1280*720) 30FPS WVGA (640*480) 60FPS

The video recording was carried out on two different occasions, the morning peak hour, evening peak hour and during the day for a specific time for each roundabout, as shown in Table 1. The distribution of the locations is presented in Fig. 5.

Main features of different properties (mean, standard deviation, number of data entries, quantiles, etc) see (Table 3) AVS video converter Software was used to add a timestamp in milliseconds on each video for analysis purposes. In addition to, VLC Player software for video playing because it is flexible and easy to use (Fig. 6).

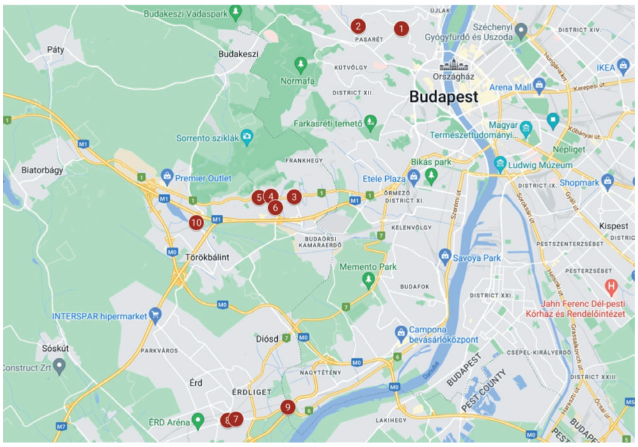

Fig. 5 The locations of the studied roundabouts (Source: Google maps)

Headway data were analyzed manually by analyzing each leg of each roundabout separately and recording each rejected or accepted gaps into an excel sheet then Raff's method is adopted to find the critical gap by finding the probability of rejected and accepted gaps separately, afterwards the accumulated Fa(t) and 1-Fr(t) is calculated see (Table 4) and the graphical presentation of the results generated by using excel as shown in Fig. 2.

Table 3 Main features of different properties (mean, standard deviation, number of data entries, quantiles. (Source: Author)

	Distance between neighboring legs	Approach entry width	Entry Width	Width of circulating carriageway	Splitter island width	Critical Gap s	Entry angle	Central island diameter
count	32	32	32	32	32	32	32	32
mean	30.6365	5.4775	4.52	7.3593	7.0566	3.0376	57.406	25.969
std	11.7914	1.0424	0.46	1.0643	3.1998	0.248	7.3259	16.028
min	13.3	4.2	3.7	6	2.7	2.41	41	13.5
25%	24.15	4.5	4.15	6.5	5.1375	2.925	52.75	16
50%	26.65	5.215	4.5	7	5.85	3.0815	58.5	19
75%	33	6.125	5	8.5	8.25	3.185	62.25	25
max	64	7.9	5.5	9	14.8	3.46	73	59

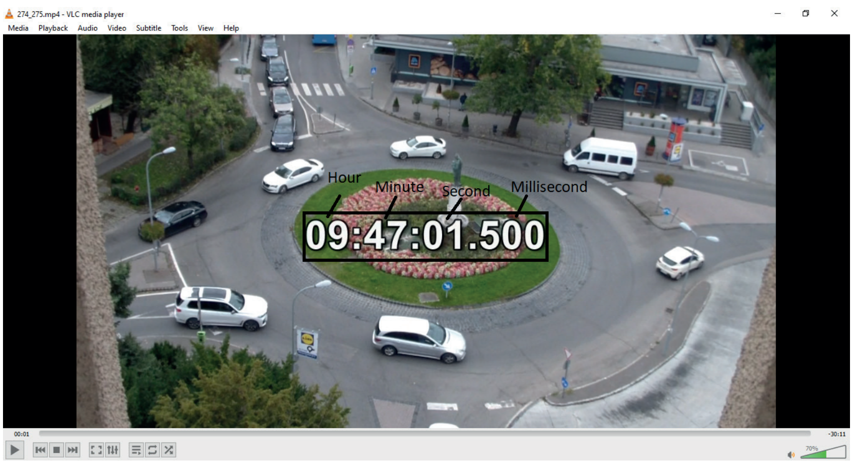

Fig. 6 AVS video converter added timestamp and VLC player. (Source:Author)

Table 4 Calculation process of critical gap using Raff's method. (Source: Author)

Interval	Accepted	Rejected	Probability of Accepted	Probability of Rejected	Accumulated Fa(t)	Accumulated 1-Fr(t)
0.00–1.00		4	0	0.031496063	0	1
1.01–1.50		37	0	0.291338583	0	0.968503937
1.51–2.00		38	0	0.299212598	0	0.677165354
2.01–2.50	2	30	0.039215686	0.236220472	0.039215686	0.377952756
2.51–3.00	10	13	0.196078431	0.102362205	0.235294118	0.141732283
3.01–3.50	10	2	0.196078431	0.015748031	0.431372549	0.039370079
3.51–4.00	15	2	0.294117647	0.015748031	0.725490196	0.023622047
4.01–4.50	7		0.137254902	0	0.862745098	0.007874016
4.51–5.00	4	1	0.078431373	0.007874016	0.941176471	0.007874016
5.51–6.00	2		0.039215686	0	0.980392157	0
6.51–7.00	1		0.019607843	0	1	0
Total	51	127				

Furthermore, throughout the analysis, gaps greater than six seconds were neglected because the entering vehicles behave and enter the roundabout freely as if it is entering an empty roundabout. Hence, after filtering out all the gaps greater than six seconds, the remaining collected data consisted of accepted and one, two, or more rejected gaps. Design parameters investigated of all 10 roundabouts consisting of 32 legs (see Table 5).

- Central island diameter,
- Width of circulating carriageway,
- Entry width,
- Approach entry width,
- Entry angle, and
- Splitter island width.

These were collected from vector images provided by road operators Budapest Közút ZRt and Magyar Közút ZRt or satellite images of Google Earth (Fig. 7).

3 Analysis and results

Evaluation of the extracted data was carried out by a python code using pandas [8], seaborn [9] and sklearn [10] packages.

The correlation coefficient between the different measured properties is visualized with the help of seaborn's heatmap (see Fig. 8).

When analyzing which parameter the critical gap is mainly correlated with, the most important parameters are entry width, distance between neighboring legs, and approach entry width.

For a sensitivity analysis, a metamodel was generated representing a linear map from the set of the measured parameters to the value of the critical gap. As a first step before the meta modelling, the different parameters were shifted and scaled with a MinMax scaler, such way that all scaled parameters are in the range from 0 to 1, because each parameter measured with different scale than critical gap and that cause unequal contribution in model fitting and generating bias. The model was computed by regression using the Linear Regression model of sklearn [10]. The distance between neighboring legs, the entry width and the approach entry width, whereas approach entry width has a negative correlation, meaning that, the smaller the entry width the larger the critical gap gets.

The sensitivity of the critical gap on the different parameters are evaluated with the help of the coefficient that is directional gradients of the model according to this analysis (see Fig. 9 and Table 6).

The above sensitivities give only a rough estimation of dependencies (see Fig. 10). The partial dependences graphs gave an insight of how the geometric parameters have an effect on the critical gap. In case of entry angle entry width, distance between neighboring legs have an increasing behavior dependence indicating that with the increase in the value of these parameter the critical gap tends to increase. On the other hand, in case of central island diameter, approach entry width and splitter island width have a decreasing behavior dependence meaning that with the increase of the values of theses parameters the critical gap value tends to decrease.

The accuracy of the metamodel is limited to a linear one, which is mirrored in the not too high value of the coefficient of determination (R2) of the prediction, which score was 0.627 (~63% of the variance of the critical gap can be explained by the parameters according to the model).

Table 5 Roundabout's locations and the parameter of each leg (Source: Author)

City	Roundabout	Central Island Diameter, (m)	Leg	Critical Gap, Sec	Width of Circulating Carriageway (m)	Entry Width, (m)	Approach Entry width, (m)	Distance between neighboring legs, (m)	Entry angle, (˚)	Splitter Island Width, (m)
Budapest	Pusztaszeri köröndq	13.5	NWB	3.073	8.5	4.5	5.9	25.8	57	5.15
			WB	2.41	8.5	4.5	7.5	15.53	61	4.8
			SEB	3.16	8.5	4	4.6	30.13	67	4.15
			EB	2.5	8.5	4.5	7.2	13.3	60	4.7
	Pasaréti tér	18	NWB	3	6	3.7	5.3	23.8	55	3.5
			SWB	3.09	6	4.5	5.9	23.7	60	5.8
			SEB	2.63	6	3.75	4.8	15.8	73	2.7
			NEB	2.69	6	3.85	5.13	30.7	51	8
Budaörs	Szabadság út- Baross utca	16	NB	3.2	8	5.1	6.5	24.2	55	6.16
			WB	3.37	8	5.1	5.6	24	63	5.5
			EB	3.46	8	5	5.5	34.6	63	5.9
	Budaros Town Hall	16	NB	3.16	7	4	4.5	25.3	59	5.5
			WB	3.23	7	4.5	4.5	25.81	53	6.7
			EB	3	7	4.2	4.5	26.7	61	5.6
	Budaros Gimnazium	16	NB	3.03	7.5	4.2	6.5	25	62	5
	Budaros Ifjúság	20	WB	2.91	6.5	4	4.5	22.6	65	6
			SB	3.18	6.5	5.5	5.4	24.5	63	6.25
			EB	2.88	6.5	4.5	4.5	21	63	5.75
Érd	Érd-alsó	19	WB	3.43	7.5	4.5	4.5	30	71	5.1
			EB	3.26	7.5	4	4.5	33	52	5
	Érd felső	20	NB	2.89	6.5	4.5	6	28.3	46	5.6
			WB	2.93	6.5	4.75	4.2	25	50	5.25
			SB	3.07	6.5	4.75	4.75	26.6	53	6
			EB	3.09	6.5	4	4.85	32	58	5.9
	Nagytétény	59	NWB	3.15	9	5	7.9	64	60	13.25
			WB	3	9	4.5	7	32	61	10
			SWB	2.65	9	4.5	6.75	33	47	12
			SEB	3.07	9	5.25	6.5	58	55	13.25
			NEB	3.14	9	5	6	43.2	52	14
Törökbálint	Törökbálint	40	SB	3.2	6.5	4.75	4.5	55	41	14.8
			EB	3.23	6.5	5	5	46.5	55	9
			NWB	3.12	6.5	5	4.5	41.3	45	9.5

The second problem is the number of available data, which limits the accuracy of the analysis. Maybe executing a gradient boosted decision tree code could have more favorable results from the existing design parameters data, and the mean squared error could be lower.

While the coefficient of determination (R2) became 0.976 (97.6%) after finding the mean squared error of the data, and the main results in case of linear regression for each separate design parameter with critical gap are (see Fig. 11):

4 Conclusions and next steps

Firstly, the sensitivity of critical gap (Fig. 9) gives a general view of the regression coefficient of each parameter separately with critical gap. It was noticed that distance between neighboring legs has the highest sensitivity value of all other parameter then approach entry width, splitter island width, and entry width shows favorable results.

That lead the authors to find the partial dependences to have a broader idea of the correlation between the design

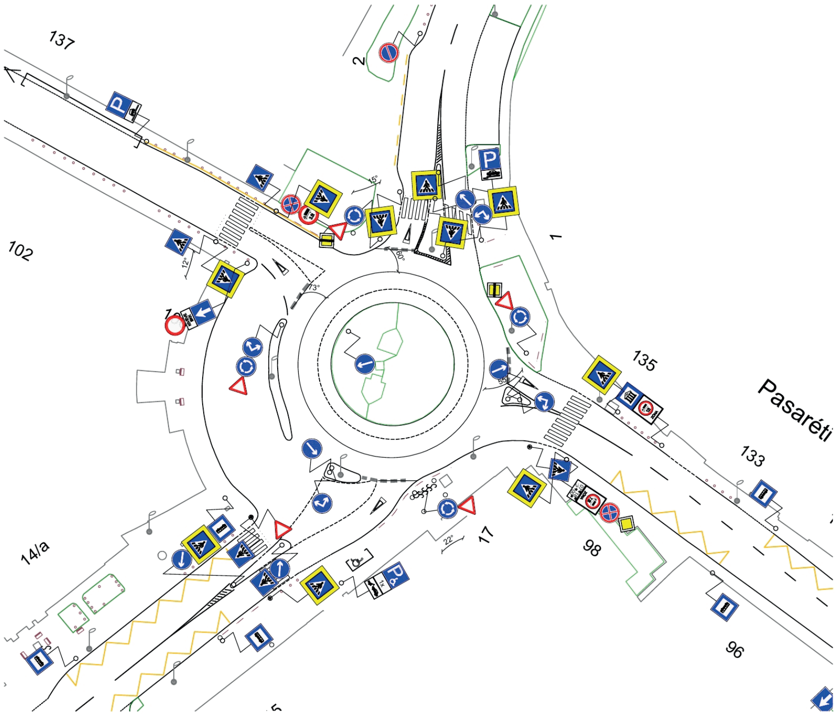

Fig. 7 AutoCAD drawing of Pasaréti tér. (Source: Budapest Közút ZRt)

Fig. 8 The correlation coefficient between different parameters measured by Seaborn's heatmap. (Source: Author)

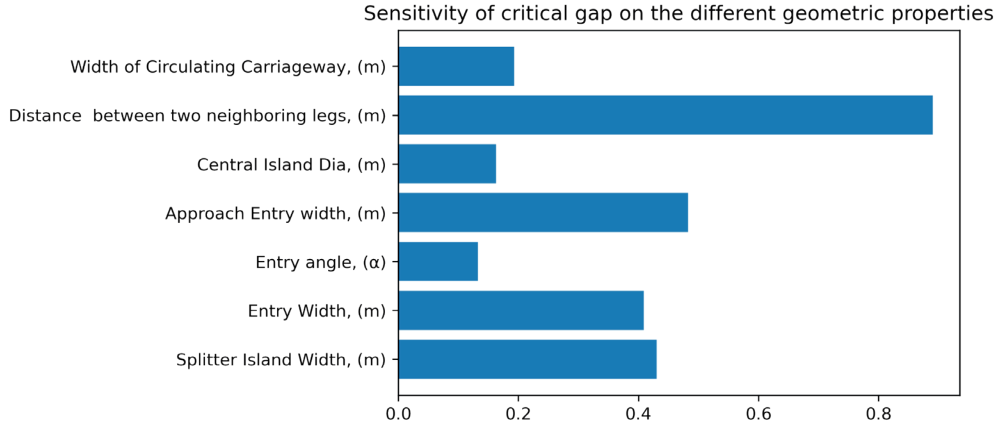

Fig. 9 The sensitivity of the critical gap on the different parameters (Source: Author)

Table 6 Coefficients of the regression model of each parameter (Source: Author)

Parameter	Coefficients of the regression model (slopes = sensitivities)
Width of circulating carriageway	0.19288768
Entry width	0.40892137
Entry angle	0.13259364
Distance between neighboring legs	0.89050936
Central island diameter	-0.16310108
Approach entry width	-0.48298439
Splitter Island Width	-0.43016598

parameters and critical gap. According to the partial dependencies (Fig. 10), it's noticed that width of circulating path, entry angle as well as central island diameter. have slight influence on the value of critical gap, where the critical gap slightly increases with the increase of width of circulating path and entry angle, in the same time critical gap decreases with the increase of central island increases. On the other hand, entry width, distance between neighboring legs, approach entry width as well as splitter island width have a great impact on critical gap value. In case of entry width, and distance between neighboring legs the value of critical gap increases greatly with the increase of both values and decreases greatly with the increase of splitter island width.

Based on the results in Section 3 (Fig. 11), further research must be conducted. There are further recordings of other roundabouts to analyze, so we can

- Increase the size of the database concentrating on parameters showing the highest sensitivity with more accurate measurements.
- Research certain pairs of parameters that may show even higher correlation with critical gap together.

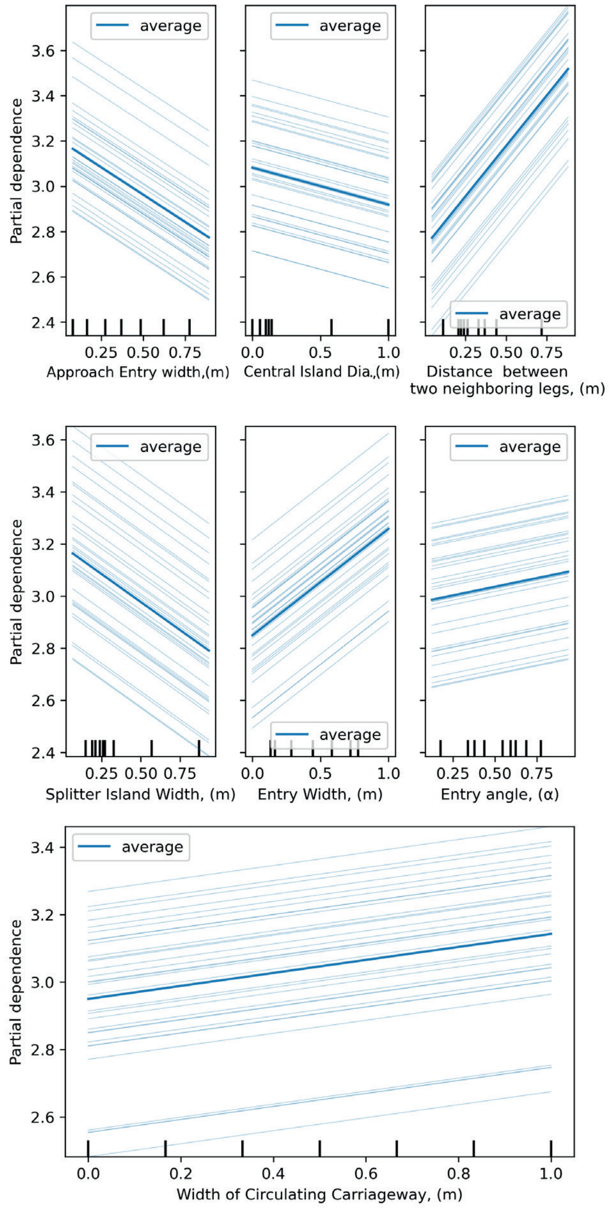

Fig. 10 Partial dependencies of the parameters with respect to critical gap. (Source: Author)

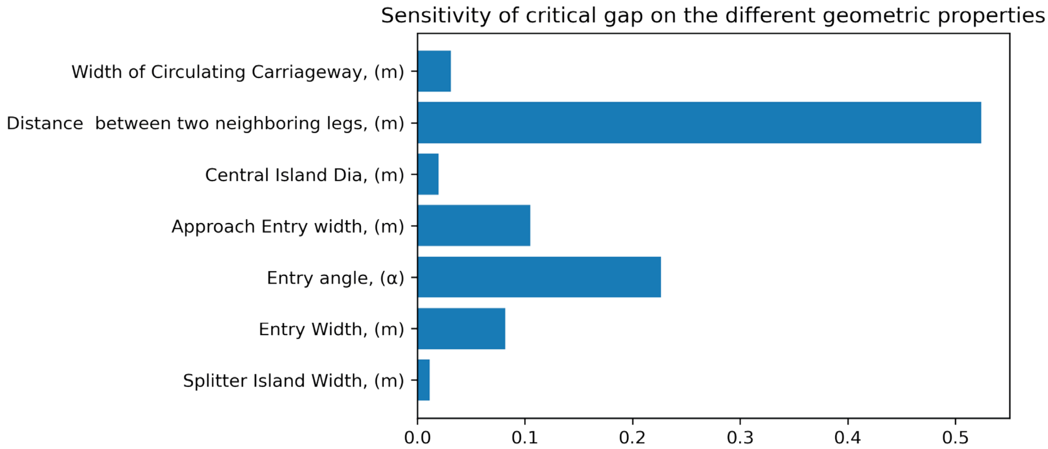

Fig. 11 The sensitivity of the critical gap on the different parameters after finding the mean squared error (Source: Author)

- Include traffic (number of approaches of all types except with gaps over 6s) into the investigation: are there significant differences between the types and where are the boundaries?
- What is the difference in gap acceptance in different vehicle classes?
- Is there a difference between urban and rural roundabouts?

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