

The Comparison of Models for Follow-up Headway at Roundabouts

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Abstract. One of the basic parameter used for roundabout entry capacity calculation is follow-up headway. This parameter beyond critical headway and traffic volume on roundabout roadway major for vehicle drivers from entry determines roundabout entry capacity. The comparative analysis of models and studies on follow-up headway estimation have been presented in this article. The analysis were made for single lane, two lane and turbo roundabouts. The largest number of models and studies of follow-up headway parameter refers to single lane roundabouts. The least studies were devoted to values of follow-up headway parameter at turbo roundabouts due to the fact that this is still relatively a new type of roundabout in compare with single lane or two lane roundabouts.

Keywords: Roundabouts · Follow-up headway · Gap acceptance theory · Road traffic engineering

1 Introduction

In recent years roundabouts are very popular kind of intersection. They are subject of multifaceted scientific research concerning both considerations on microscopic level f.ex. like their performance, capacity, safety (f.ex.: [1–10]) and also considerations on macroscopic level as element of the transport systems [11–19]. Due to the high level of traffic safety roundabouts are willingly used as a part of transport networks in urban area and outside urban area. The roundabouts popularity resulted in the development of models and methods for mapping behavior of traffic streams (vehicle driver, pedestrians, cyclists) on roundabouts (f.ex: [20–29]).

In models intended to roundabout entry capacity calculations based on gap acceptance theory the critical headway and follow-up headway are the basic parameters in vehicle drivers decision-making process at roundabout entry. These parameters usually represent the average behaviors in vehicle drivers population and together with the headway distribution between vehicles on main roadway of roundabout decides about the degree of accuracy of roundabout entry capacity determination.

According to literature [30] the follow-up headway (t_f) is defined as the time between the departure of first (previous) vehicle from the roundabout entry and the departure of the next vehicle using the same major-street headway under a condition of queuing on the roundabout entry. If the distance between vehicles in traffic stream on main roadway of roundabout allows for entry of further vehicles from the queue, they are passing through the edge of the roundabout roadway at follow-up headway one

after another. At very low traffic volume on main roadway of roundabout the value of follow-up headway mainly decides about the entry capacity. According to Polish recommendations [30] setting for the roundabout capacity calculation the follow-up headway values the type of roundabout, roundabout external diameter and number of entry lanes are taking account.

In case of assumption that on roundabout entry is queue of vehicles and vehicle drivers from this queue use the same gap between vehicles moving on main roadway of roundabout the follow-up headway value can be calculated from equation:

$$t_f = t_f^{next} - t_f^{previous} [s] \quad (1)$$

where:

- t_f - follow-up headway [s],
- t_f^{next} - crossing time the edge of the roundabout roadway by next vehicle driver [s],
- $t_f^{previous}$ - crossing time the edge of the roundabout roadway by previous vehicle driver [s].

Many scientific studies provide results from measurements of follow-up headway from real data at roundabouts. In practice, the value of parameter t_f is frequently represented as the average value (specifying also with value of the standard deviation) or as a median. In different scientific papers the minimum and maximum values are also presented. In case of two lane roundabouts the follow-up headway values are stated separately for the right and left entry lane as well as for the inner and outer lane on roundabout roadway. Whereas in case of turbo roundabouts further decomposition of t_f values occurs because of different types of traffic control on entry and on roundabout main roadway area, i.e. one or two entry lanes and one or two circulating lanes.

The analysis in the regards of scientific papers related to determination of follow-up headway values for vehicle drivers on single lane, two lane and turbo roundabouts have been presented in this article. In view of a very large collection of published studies connected with this issue, the analysis in this article is focused on the most important, most popular models and the latest studies in this area.

2 The Comparison of Models for Follow-up Headway at Roundabouts

In scientific literature can be found a lot of synthetic reviews on gap acceptance parameters for roundabouts, f.ex. [31–35]. According to research the values of follow-up headways may depends on roundabout geometry, number of traffic lanes on entry and on main road of roundabout, vehicle type, the presence of bunched vehicles on main roadway and many other factors. The follow-up headway value also depend on combination of vehicle types in the queue at the entry (i.e. passenger cars and heavy vehicles). In many scientific papers the follow-up headway value is defined for

passenger cars, less frequently for another type of vehicle like heavy vehicles, bikes, buses etc. The selected studies characterizing the follow-up headway for drivers at single lane roundabouts entries are presented in Table 1.

Table 1. Comparison of follow-up headway models for single lane roundabouts.

Country	Author	The model/value of follow-up headway parameter [s]
Germany	W. Brilon [36]	For small roundabouts ($13 \leq D_z \leq 26$ m) and single roundabouts ($26 \leq D_z \leq 40$): $t_f = 2.84 + \frac{2.07}{D_z}$, $t_f \in \langle 2.89; 3.00 \rangle$, (Average value = 2.94)
	N. Wu [37]	Average value = 2.88
USA	HCM 2010 [38]	Average value = 3.20
	NCHRP Report 572 [39]	$t_f \in \langle 2.6; 4.3 \rangle$, (Average value = 3.20)
	HCM 2016 [40]	Average value = 2.60
	Y. Mereszczak et al. [41]	$t_f \in \langle 2.6; 3.0 \rangle$, (Average value = 2.80)
	F. Xu, Z. Tian [42]	$t_f = 2.38 - 0.000071 \cdot Q_{nwl}$, (Average value = 2.50)
Canada	J. Dahl, Ch. Lee [43]	$t_f \in \langle 2.10; 4.20 \rangle$, (Average value = 3.15)
The Netherlands	L. Fortuijn [44]	Average value = 2.10
Australia	L. Ren, Q. Xiaobo [45]	$t_f \in \langle 2.35; 2.75 \rangle$, (Average value = 2.55)
	X. Qu [46]	Average value = 2.76
Portugal	L. Vasconcelos, A. Seco, A. Silva [47]	$t_f \in \langle 2.10; 2.30 \rangle$, (Average value = 2.20)
Spain	M. Romana [48]	$t_f \in \langle 1.65; 1.75 \rangle$, (Average value = 1.70)
Denmark	P. Greibe [49]	Average value = 3.00
Italy	A. Gazzarri et al. [50, 51]	$t_f \in \langle 2.52; 2.76 \rangle$, (Average value = 2.63)
Slovenia	T. Tollazi [52]	Average value = 2.90
Poland	J. Chodur [53]	$t_f = 0.31 \cdot D_z - 0.0044 \cdot D_z^2 + 0.00052 \cdot wm - 2.59$ (Average value = 2.85)
	E. Macioszek [54]	For $22 \text{ m} \leq D_z \leq 45 \text{ m}$, $4 \text{ m} \leq l_{jr} \leq 8 \text{ m}$: $t_f = 3.64 - 0.02 \cdot D_z - 0.03 \cdot l_{jr}$ (Average value = 2.79)

where:

D_z - roundabout external diameter [m],

Q_{nwl} - circulating flow [pcu/h],

wm - city size determined by the number of inhabitants (19.60-740.00 thousands of inhabitants),

\bar{V} - the average vehicle speed [km/h],

l_{jr} - the width of the roundabout roadway [m],

t_g - critical headway [s].

On the basis of data included in Table 1 can be concluded the differences between the proposed follow-up headways values. These differences are the results of various vehicle driver behavior in different countries in the world as well as result from the different techniques and methods of follow-up time headway parameter measurements. The comparison of average values of follow-up headways for single lane roundabouts proposed by different authors in different countries of the world have been presented on the Fig. 1.

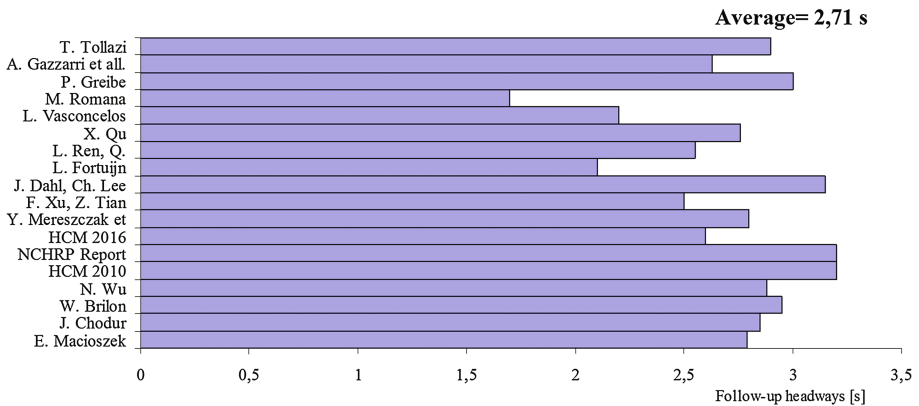


Fig. 1. The average values of follow-up headways for single lane roundabouts

On the basis of Fig. 1 can be concluded that the average value of follow-up headway for all models is equal 2.71 s. Values below the average can be observed f.ex. in such countries as Italy, Spain, Portugal, USA (according HCM 2016), Netherlands, Australia. Whereas values higher than the average value can be observed f.ex. in Germany, Canada, Denmark, Slovenia and Poland. It should be noted that according most recent research published in HCM 2016 average value of follow-up headway is equal 2,60 s, while previous USA studies (f.ex. HCM 2010, NCHRP Report 572, F. Xu, Z. Tian) indicate for a slightly higher average values of follow-up headway for single lane roundabouts. The decrease in average value of follow-up headway confirms that vehicle drivers in USA have become accustomed with roundabouts and they drive firmly on this type of intersections.

Besides, the potential impact of follow-up headway value on single lane roundabout entry capacity was examined by varying the parameter t_f from minimum to maximum values under different circulating traffic flows (Q_{nwl}). The follow-up headway value change between 1.70–3.20 s. This t_f values were adopted on the basis of various authors research presented in Table 1 (see Fig. 2). Critical headway was assumed to be constant. As can be seen from Fig. 2 single lane roundabout entry capacity is higher when vehicle drivers from queue at roundabout entry moving on main roadway of roundabout with smaller follow-up headway values. Consequently, accurate determination of follow-up headway value is very important because can improves the accuracy of roundabout entry capacity calculation.

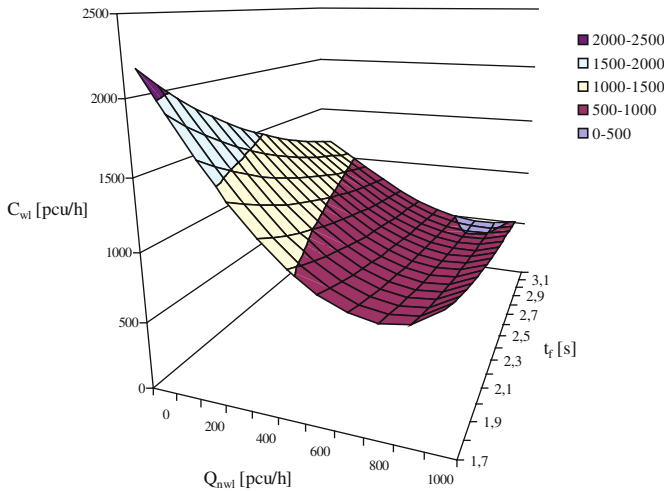


Fig. 2. The change in single lane roundabout entry capacity calculated with different values of follow-up headways

In scientific studies can be found slightly less number of follow-up headways models and results for two lane roundabouts then in case of single lane roundabouts. The comparison of selected follow-up headway results for two lane roundabout have been presented in Table 2. Base on the Table 2 can be concluded that part of these results were defined with accuracy of roundabout entry lane and other part applies only to value of follow-up headway for entire roundabout entry.

The comparison of average values of follow-up headways for two lane roundabouts proposed by different authors in different countries of the world have been presented on the Fig. 3. Based on the Fig. 3 can be concluded that average values of follow-up headway for vehicle drivers from right and left entry lane are respectively 2.68 s and 2.72 s. It means that vehicle drivers from the right entry lane moving on main roadway of roundabout faster, with shorter follow-up headways then vehicle drivers from the left entry lane.

One of new types of roundabouts like turbo roundabouts were already development and implemented in many countries in the world. In case of turbo roundabouts the follow-up headway value depend on traffic control in entry and roundabout main roadway area. In practice at turbo roundabouts can be distinguish few different type of traffic control in entry and roundabout main roadway area i.e. one or two entry lane and one or two circulating lane. The comparison of follow-up headway values for turbo roundabouts have been presented in Table 3. Due to the fact that turbo roundabouts are relatively new type of intersection, there are little research results and models for follow-up headways. There is a definite need for further research on follow-up headways values at turbo roundabouts at different variants of traffic control.

Table 2. Comparison of follow-up headway results for two lane roundabouts.

Country	Author	The value of follow-up headway parameter [s]
Germany	W. Brilon [36]	$t_f \in \langle 2.20; 2.90 \rangle$, (Average value = 2.55),
	N. Wu [37]	Average value = 2.88
USA	HCM 2010 [38]	Left lane average = 3.20, Right lane average = 3.20
	HCM 2016 [40]	Left lane average = 2.66, Right lane average = 2.53
	F. Xu, Z. Tian [42]	Left lane average = 2.30, Right lane average = 2.20
	NCHRP Report 572 [39]	Left lane = 3.1-4.7, (Average value = 3.4), Right lane = 2.7-4.4, (Average value = 3.1)
Canada	J. Dahl, Ch. Lee [43]	$t_f \in \langle 1.60; 5.00 \rangle$, (Average value = 3.30)
Portugal	L. Vasconcelos, A. Seco, A. Silva [47]	$t_f \in \langle 1.94; 2.78 \rangle$, (Average value = 2.36)
Switzerland	N. Leemann, G. Santel [55]	$t_f \in \langle 2.27; 2.63 \rangle$, (Average value = 2.45)
Denmark	P. Greibe [49]	Average value = 2.60
	O. Hagrings, N. Rouphail, H. Sorensen [56]	Average value = 2.79
Italy	A. Gazzarri, M. Martello, A. Pratelli, R. Souleyrette [50]	Left lane average = 2.65, Right lane average = 2.64, Minimum value = 2.16, Maximum value = 3.10
The Netherlands	L. Fortuijn [44]	$t_f \in \langle 2.24; 2.26 \rangle$, (Average value = 2.25)
Poland	Polish Quidelines [30]	$t_f \in \langle 2.90; 3.30 \rangle$, (Average value = 3.10)
	E. Macioszek [54]	Left lane average = 3.20, Right lane average = 3.20

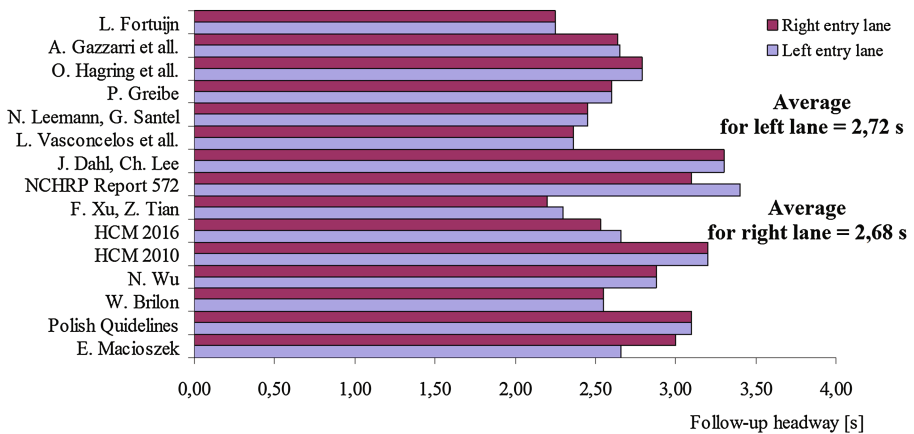
**Fig. 3.** The average values of follow-up headways for two lane roundabouts

Table 3. Comparison of follow-up headway results for turbo roundabouts.

Country	Author	The value of follow-up headway parameter [s]
The Netherlands	L. Fortuijn [44]	Right entry lane at major entry: average 2.13 Left entry lane at major entry: average 2.25 Depending on traffic control
Germany	W. Brilon, L. Bondzio, F. Weiser [57]	$t_f \in \langle 2.50; 2.80 \rangle$ Depending on traffic control
Poland	E. Macioszek [54]	Right lane: 1.48-4.76 (average 2.21) Left lane: 1.24-5.08 (average 2.35) Depending on traffic control

3 Summary

The synthesis from scientific studies about follow-up headway values for single lane, two-lane and turbo roundabouts have been presented in this article. The largest number of models and studies of t_f parameter refers to single lane roundabouts. This is connected with a large number of such type of roundabouts developed in different countries of the world. Because of their great advantages in the context of road traffic safety in many countries single lane roundabouts are the most numerous group among roundabouts. By far the least studies were devoted to values of t_f parameter at turbo roundabouts due to the fact that this is still relatively a new type of roundabout in compare with single lane or two lane roundabouts. There is a definite need for further research on follow-up headways values at turbo roundabouts at different variants of traffic control.

The values of follow-up headway for particular types of roundabouts are different depending on country and individual studies. These differences have an influence on calculated roundabout entry capacity. In addition, in many studies in calculations the constants values of follow-up headway are recommended (which represent an average value from all observed vehicle drivers) instead functions which enable adjustment the value of follow-up headway to traffic and geometric features f.ex. like roundabout external diameter, number of traffic lanes, lanes width, entry radius etc. In turn, assuming in roundabout entry capacity calculations average value of follow-up headway (and average value of critical headway) causes inaccuracy in calculations and averaging the results.

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