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THE MOVEMENT MODEL FOR SMALL ROUNDABOUTS WITH MINOR ROADS CAPACITY ESTIMATING

Summary. Base on measurements and movement analysis, movement model for small roundabouts has been built. Model can be useful for minor roads capacity estimating. The gap acceptance problem for small roundabouts has been presented in this article. This is one of the burning issue in modelling traffic flow on small roundabouts. At roundabout, vehicle circle counterclockwise. Approaching flow give priority to circulating flows. This ensures an uninterrupted flow in the circulating roadway. Circulating and approaching flows merge immediately at the entrance to the circulating roadway. Each vehicle must make two right turns. All other movements are eliminated. As a subordinate vehicle enters the circulating roadway it became a priority vehicle. The value of critical gap is very important in merging process.

MODEL RUCHU NA MAŁYCH RONDACH DLA POTRZEB OBLICZANIA PRZEPUSTOWOŚCI

Streszczenie. Na podstawie badań i analiz ruchu na małych rondach zbudowano model, który służy do wyznaczania przepustowości wlotów podporządkowanych małych rond. Artykuł zawiera opracowanie jednego z podstawowych zagadnień dotyczących budowy wspomnianego modelu, a mianowicie problemu akceptacji odstępów czasu przez pojazdy z wlotów podporządkowanych małych rond. Wyznaczanie wartości odstępu granicznego na podstawie badań empirycznych jest jednym z najtrudniejszych zadań dla inżyniera ruchu. W artykule przedstawiono wyniki pomiarów odstępów czasu pomiędzy pojazdami na jezdni małego ronda, na podstawie których szacowano wartość granicznego odstępu czasowego. Pomiary wykonywano na trzech małych rondach zlokalizowanych, na terenach zabudowanych Górnego Śląska.

1. INTRODUCTION - GAP ACCEPTANCE PROCESS

The estimation of critical gaps from observed traffic flow patterns is one of the most difficult tasks in empirical traffic engineering science. Miller in 1972 in his classic paper, could refer to nine different estimation methods, which did not cover the whole range of possible procedures to be obtained from international literature at that time. Today it would be easy to find more than 35 methods published around the world for the estimation of critical gaps [1]. Many different methods for the estimation of critical gaps (lag) at unsignalized intersections have been published in Poland [2, 3] and in the international literature [1, 5, 10, 13].

Siegloch in 1973 proposed a consistent framework for the theory of capacities at unsignalized intersections [12]:

$$C = q_p \cdot \int_{t=0}^{\infty} f(t) \cdot \alpha(t) dt \qquad (1)$$

where: C - minor approaches capacities, $\alpha(t)$ - the number of minor street vehicles that can enter the conflict area during one minor stream gap size t, $f(t)$ - statistical density function of all gaps (or hadways) in the major stream, q - the expected number of gaps of size t within the major stream (or volume of major stream).

This equation for the capacity of unsignalized intersections forms the foundation of the whole gap-acceptance theory. Almost all of the different analytical capacity estimation formulae found in the international literature are based on this concept, even in cases where the original authors were not aware of this method. In Siegloch estimation $f(t)$ was exponential distribution. The drawback for practical application is the fact that this method can only be applied for saturated conditions, which are difficult to find in many practical cases. There are other so popular gap-acceptance estimation methods above Siegloch method like: Raff's method, Ashworth's method, Harders' method, Hewitt's method [8], logit procedures, probit procedures, maximum likelihood procedures and another. Every one was described in publication [1].

Tracz [11 pp. 12] gave definition of critical gap for minor road vehicles on small roundabouts. According to traffic rules, each major stream vehicle can pass the intersection without any delay. A minor street vehicle, however, can only enter the conflict area if the next major vehicle is far enough away to allow the minor vehicle safe passage to the whole conflict area. Far enough is defined as: The next major street vehicle will arrive at the intersection at an instant that will happen t_g seconds after the previous major stream vehicle or t_g seconds after the minor vehicle's arrival. This value t_g is called the critical gap, which is the minimum time gap in the priority stream that a minor street driver is ready to accept for crossing on entering the major stream conflict zone.

These are needed: kind of roundabout (small, medium-size, big), exterior diameter, number of lanes on minor roads in choosing value of critical gap. Tracz suggested values of critical gaps which was presented in table 1.

Table 1

Values of critical gaps for small roundabouts
with one-lane minor roads and different value of exterior diameter

Exterior diameter [m]	below 24	from 24 to 30	above 30 to 36	above 36
Critical gap [s]	5.0	4.8	4.6	4.5

Source: [11 pp. 24].

Several critical values have been discussed in the literature. Greenshields defined the acceptable average-minimum time gap as a gap accepted by half the drivers. Raff [4] defined a critical lag. The critical lag is the size of lag whose number of accepted lags shorter than it is equal to the number of rejected lags longer than it. The Raff parameter is median values (median critical lag). Drew in [4] have assigned value of critical gap in the same way as Raff.

According to Hagring [6] a minor stream driver attempts to maximize her or his utility by accepting a major stream headway having a safety risk lower than the value of the expected delay resulting from headway rejection. Therefore critical gap can be regarded as a compromise between the demand for safe entry to an intersection and for minimizing delay.

The availability of gaps is described by a probability distribution function of headways in higher priority stream. A gap acceptance function describes the usefulness of headways as well as queue discharge.

The gap acceptance distributions most frequently applied in the literature are:

a) Binomial distribution. Lag bigger than critical gap t_g will be accepted and lag smaller than critical gap t_g will be rejected.

$$\alpha_1(t) = \begin{cases} 1 & t \geq t_g \\ 0 & t < t_g \end{cases} \qquad t_g > 0 \tag{2}$$

where: $\alpha_i(t)$ - probability of accepting lag $t_g\left(t < t_g \leq t + \delta t\right)$, t - value of headway, t_g - critical gap. The minimum major-stream headway during which a typical minor-stream vehicle can make a maneuver.

b) Negative exponential distribution:

$$\alpha_2(t) = 1 - e^{-\lambda t} \qquad t > 0, \lambda > 0 \tag{3}$$

where: $\alpha_i(t)$ - probability of accepting lag $t_g\left(t < t_g \leq t + \delta t\right)$, t - value of headway, λ - the scale parameter.

c) Shifted exponential distribution:

$$\alpha_3(t) = \begin{cases} 1 - e^{-\theta(t - t_g)} & t > t_g \\ 0 & t \leq t_g \end{cases} \qquad \theta > 0 \tag{4}$$

where: $\alpha_i(t)$ - probability of accepting lag $t_g\left(t < t_g \leq t + \delta t\right)$, t - value of headway, θ - the scale parameter, t_g - critical gap. The minimum major-stream headway during which a typical minor-stream vehicle can make a maneuver.

d) Uniform distribution:

$$\alpha_4(t) = \begin{cases} 0 & , \quad t < T_1 \\ \dfrac{t - T_1}{T_2 - T_1} & , \quad T_1 \leq t < T_2\,, \quad T_1 < T_2 \\ 1 & , \quad t \geq T_2 \end{cases} \tag{5}$$

where:

$\alpha_i(t)$ - probability of accepting lag $t_g\left(t < t_g \leq t + \delta t\right)$, t - value of headway, T_1, T_2 - value of lags.

e) Stepwise gap acceptance function:

$$\alpha_5(t) = \left\lfloor \frac{t - t_g + t_f}{t_f} \right\rfloor_+ = \begin{cases} 0, & \text{jeżeli} \quad t < t_g \\ \left\lfloor \dfrac{t - t_g + t_f}{t_f} \right\rfloor & \text{jeżeli} \quad t \geq t_g \end{cases} \tag{6}$$

where: $\alpha_i(t)$ - probability of accepting lag $t_g\left(t < t_g \le t + \delta t\right)$, t - value of headway, t_f - follow-up time. Time between the departure of one minor-stream vehicle and the departure of the next vehicle using the same gap under a condition of continuous queuing, t_g - critical gap. The minimum major-stream headway during which a typical minor-stream vehicle can make a maneuver, $\lfloor X \rfloor$ - the floor function i.e., greatest integer not larger than X.

f) Linear gap acceptance function: Linear gap acceptance function is continuous for headways larger than the shortest acceptable headway t_g. A linear gap acceptance function has been suggested by Siegloch [12] as:

$$\alpha_6(t) = \left(\frac{t - t_o}{t_f}\right)_+ = \left(\frac{t - t_g + \frac{t_f}{2}}{t_f}\right)_+ \tag{7}$$

where: $\alpha_i(t)$ - probability of accepting lag $t_g\left(t < t_g \le t + \delta t\right)$, t - value of headway, $t_o = t_g - \frac{t_f}{2}$ - the shortest acceptable headway, t - follow-up time. Time between the departure of one minor-stream vehicle and the departure of the next vehicle using the same gap under a condition of continuous queuing, t - critical gap. The minimum major-stream headway during which a typical minor-stream vehicle can make a maneuver.

Weiss and Maradudin [7] presented method of determination accepted lag and method of calculation vehicle delays. Those methods cover impatience of drivers. They proved that accepted lag is smaller when vehicle delay is growing. They also showed that drivers accept small and small lag when they waiting for their lag long time. In this cases probability of accepting lag grow and inequalities are true:

$$\alpha_0(t) \le \alpha_1(t) \le \ldots \le \alpha_n(t) \tag{8}$$

2. MEASUREMENTS OF HEADWAYS ON SMALL ROUNDABOUTS

The measurements of headways between major stream vehicles on small roundabouts were done in april 2006. The measurements were done on three small roundabouts:

- in Siemianowice Śl. (exterior diameter = 36 m) localized in centre of the city,
- in Radzionków (exterior diameter = 25 m) localized in centre of the city,
- in Tarnowskie Góry (exterior diameter = 30 m) lokalized on suburbia of the city.

In evaluating any critical gap it is apparent that a given gap must be either accepted or rejected by a given driver. Each driver can accept only one gap, but he can reject several of them. This means that if all rejected gaps are given the same weight as accepted gaps, then the percentage of intervals accepted for a particular size will not be a true measure of the percentage of drivers who find such an interval acceptable. If the percentage of intervals accepted is to be used to determine the percentage of drivers who are willing to accept them, then the same number of intervals must be counted for each driver. Raff [4] accomplished this by counting only lags and ignoring the gaps.

According to Drew [4] for every of stopped vehicles only two gaps were considered for each vehicle – the largest rejected gap and the gap finally accepted. In evaluating gap acceptance characteristics for moving vehicles only the first available gap for minor road vehicles was considered. The same procedure like Drew procedure for recording gaps was used in recording gaps on three mentioned small roundabouts. The critical gaps for minor roads vehicles on small roundabouts are: in Siemianowice - t_g = 4.40 s, in Radzionków - t_g = 6.10 s, in Tarnowskie Góry - t_g = 4.51 s.

At the mentioned small roundabouts the number of gaps accepted and rejected have been tabulated in cumulative form. Measurements were done on three roundabouts.Here are presented data for the small roundabout in Radzionkow city in this article (in table 2 and on figure 1).

The critical gap may be determined algebrically from equation given by Drew [4, str. 178]:

$$t_g = t + \frac{(c-a)\Delta t}{(b+c)-(a+d)} \quad [s] \tag{9}$$

The critical gap determined algebrically is shown in table 2. The critical gap may also be determined graphically, as illustrated in figure 1. Two cumulative distribution curves are shown which depict the number of accepted gaps shorter than *t* and the number of rejected gaps longer than *t*. The value of *t* which these two curves intersect is the critical gap.

The value of critical gap depend on vehicle speed on main road at small roundabout too. According to many international publications vehicle speed during driving on main road at small roundabout is about 38 km/h, but speed cannot be higher than 40-45 km/h.

According [14] to geometrical elements of small roundabouts permitting driving on main roads with speed 20-30 km/h (with the exception of bigger vehicles such as lorries or buses). The author of this article gathered data of vehicle speeds on main road at small roundabouts. The speeds were measured using a tested vehicle. Vehicles which are travelling on main roads at small roundabouts are either free or following. There were distinguishing characteristic in measurements vehicle speeds. Average free vehicle speed was 37.75 km/h and average following vehicle speed was 29.27 km/h. The results of this data collection and detailed description regarding this problem have been presented in article [9].

Table 2

Estimating critical gap for small roundabout in Radzionków city

Lenght of gap *t* [s]	measurement 1		measurement 2		All vehicles		Accepted gaps as percentage [%]
	Accepted gaps < t	Rejected gaps > t	Accepted gaps < t	Rejected gaps > t	Accepted gaps < t	Rejected gaps > t	
0-0.9	0	1693	0	1570	0	3263	0.00
1-1.9	0	1321	0	1241	0	2562	0.00
2-2.9	3	1007	16	941	19	1948	3.48
3-3.9	25	731	64	690	89	1421	15.09
4-4.9	55	530	126	497	181	1027	22.83
5-5.9	a=113	c=365	a=209	c=351	a=322	c=716	33.81
6-6.9	b=224	d=222	b=376	d=218	b=600	d=440	55.27
7-7.9	403	109	562	106	965	215	72.56
8-8.9	546	39	716	38	1262	77	82.27
9-9.9	637	7	808	6	1445	13	93.85
10-10.9	706	1	879	0	1585	1	99.29
11-11.9	753	0	927	0	1680	0	100.00
12-12.9	788	0	964	0	1752	0	100.00
13-13.9	812	0	989	0	1801	0	100.00
14-15	824	0	1001	0	1823	0	100.00
Critical gap [s]	t_g = 6.3 [s]		t_g = 5.8 [s]		t_g = 6.1 [s]		

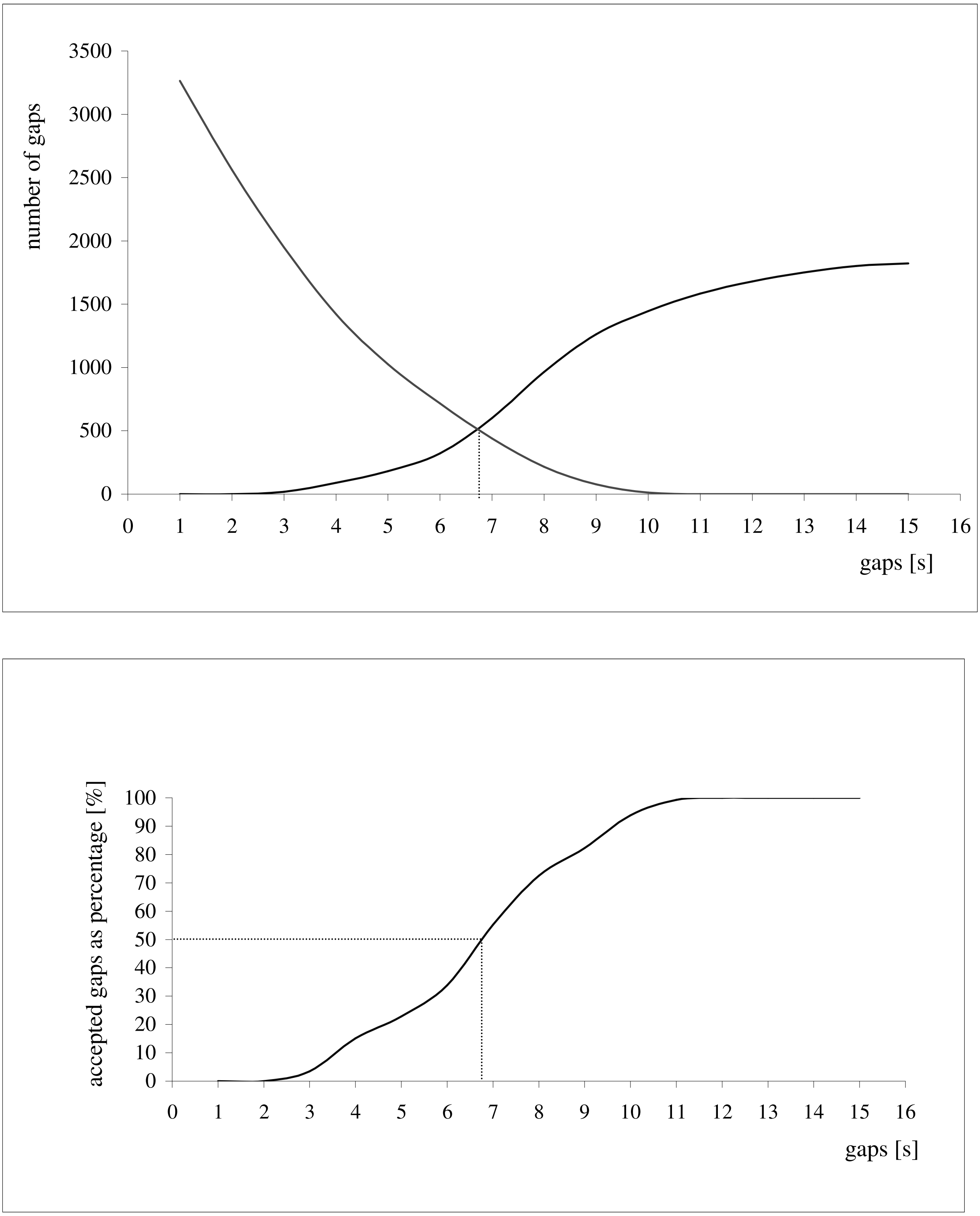

Fig. 1. Estimating critical gap for small roundabout in Radzionków city
Rys. 1. Ustalenie wartości granicznego odstępu czasowego dla małego ronda w Radzionkowie

3. CONCLUSIONS

The investigation of critical gaps on three small roundabouts has been presented in this article. Determination critical gap is complicated because this value cannot be measured directly. It is necessary to measure the number of accepted and rejected gaps.

The measurements shown that driver's behaviour are different. Even under similar conditions a driver may behave differently at different times. A driver may accept a gap that is shorter than a gap rejected by the same driver earlier. Most of the observed inconsistent behavior can be explained by situation-specific factors, such as waiting time and variation in speed and type of major stream vehicles. Typically the acceptable headway decreases as the number of rejected gaps increases. This is caused by impatience of drivers. If critical gap increases as the number of rejected gaps increases, the behavior is not inconsistent. Accordingly, inconsistency increases capacity of small roundabouts.

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