TRANSPORT PROBLEMS 2008
PROBLEMY TRANSPORTU Tom 3 Zeszyt 3

Elżbieta MACIOSZEK*, Janusz WOCH
Silesian University of Technology, Faculty of Transport, Department of Traffic Engineering
Krasińskiego St. 8, 40-019 Katowice, Poland
**Corresponding author*. E-mail: elzbieta.macioszek@polsl.pl

THE FOLLOW-UP TIME ISSUE ON SMALL ROUNDABOUTS

Summary. The follow-up time was investigated. The aim of this analysis was to create a formula that allows the follow-up time calculated using the most important external parameters. The studies were based on empirical data collected at small roundabouts localized on Upper Silesia. The follow-up time is the average time gap between two cars of the minor stream being queued and entered the same major stream gap one behind the other. Follow-up times were measured directly by observing traffic flow. Resulting follow-up times were analyzed to determine their dependence on parameters such as intersection layout, roundabouts diameter and left visibility. These parameters were tested using the conventional calculation method (regression analysis). The dependence of follow-up time was then integrated into the own capacity estimation method for small roundabouts localized on urban areas. One of the biggest advantages this dependence is that capacity and traffic flow on small roundabouts can be determined reliably and appropriately for actual situations. The new follow-up time values for all range of external diameters of small roundabout 26 (22) – 40 m have been presented in this article.

MINIMALNE ODSTĘPY CZASU POMIĘDZY POJAZDAMI WJEŻDŻAJĄCYMI Z KOLEJKI NA WLOTACH MAŁYCH ROND JEDNOPASOWYCH

Streszczenie. Wartości minimalnych odstępów czasu analizowane są głównie podczas obliczeń przepustowości skrzyżowań regulowanych znakami drogowymi, czyli skrzyżowań bez sygnalizacji świetlnej oraz rond. W przypadku rond, decydujący wpływ na przepustowość podporządkowanego wlotu jednopasowego lub dwupasowego mają wielkości natężeń nadrzędnych w obszarze kolizyjnym na jezdni ronda przy danym wlocie (Q_{nwl}), graniczny odstęp czasowy (t_g) i odstęp czasu pomiędzy pojazdami wjeżdżającymi z kolejki na wlocie podporządkowanym (t_f). Przy dużych wartościach natężeń ruchu na wlotach odstępy t_f w głównej mierze decydują o przepustowości wlotów podporządkowanych. W artykule przedstawiono wyniki pomiarów odstępów czasu pomiędzy pojazdami wjeżdżającymi z kolejki na wlocie wraz z ich analizą statystyczną. Pomiary wykonano na małych rondach zlokalizowanych na terenach zabudowanych zlokalizowanych na Górnym Śląsku. Wykorzystując analizę regresji i korelacji wielorakiej uzyskano zależność funkcyjną do wyznaczania minimalnych wartości odstępów czasu, która może posłużyć w obliczeniach przepustowości wlotów na skrzyżowaniach regulowanych znakami drogowymi. Typowe wartości minimalnych odstępów czasu pomiędzy pojazdami wjeżdżającymi z kolejki na wlocie obliczone za pomocą oszacowanej funkcji przedstawiono w artykule. Wartości t_f podano dla pełnego zakresu możliwych średnic zewnętrznych małych rond, czyli dla 26 (22) - 40 (45) m.

1. INTRODUCTION

Usually capacity calculations for unsignalized intersections controlled by Yield or Stop signs are based on gap acceptance theory. The fundamental parameters in this theory are critical gaps and follow-up times. Considering small roundabout with two streams-one major and one minor, the vehicles in the minor stream can only pass the conflict area when the time gap between the cars in the major stream is long enough (fig. 1). That means they can only enter the conflict area when the time gap between the major vehicles is larger than their critical gap – t_g. Therefore the critical gap t_g is defined as follows:

The critical gap (t_g) - is the minimum time gap between the vehicles of the major stream that is necessary for the vehicles in the minor stream to enter the conflict area.

In addition, several cars of minor stream can only follow one behind the other within a certain time space, which is called their follow-up time - t_f.

The follow-up time (t_f) - is the average time gap between two cars of the minor stream being queued and entered the same major stream gap one behind the other.

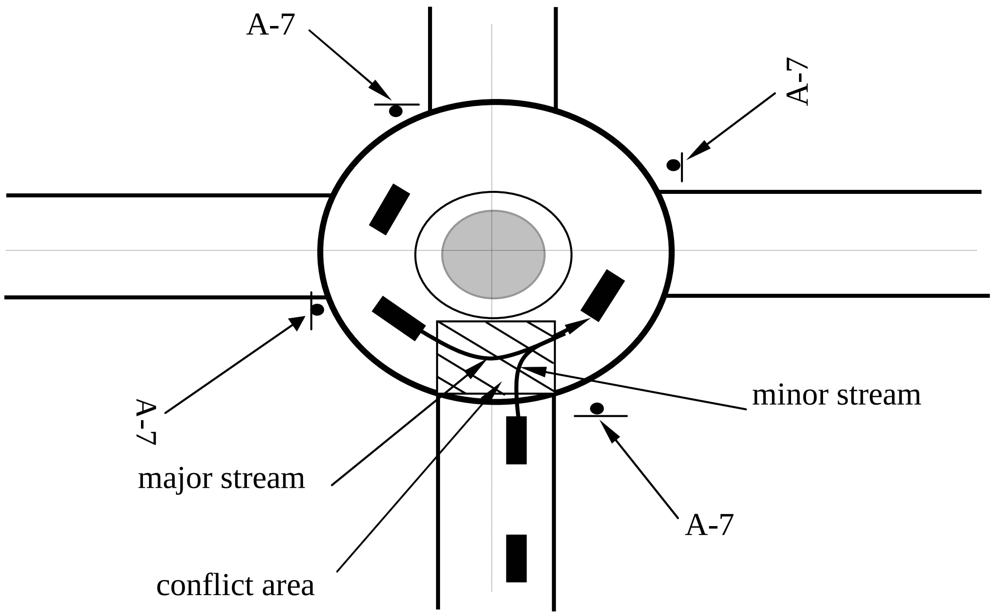
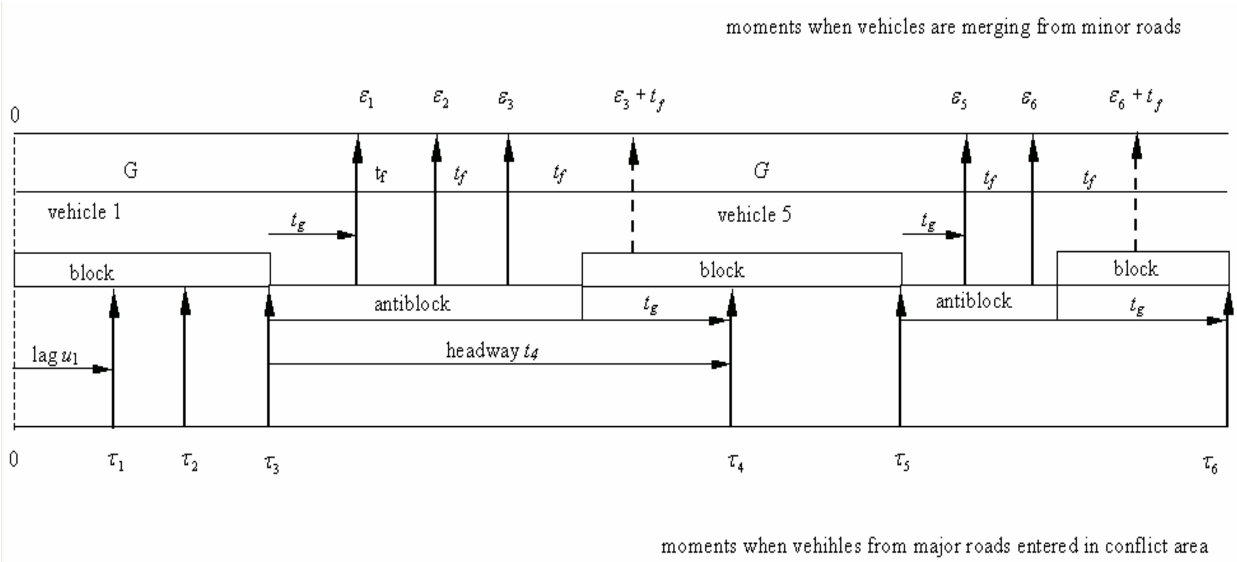


Fig. 1 Small roundabout with two conflicting streams
Rys. 1 Kolizyjne potoki ruchu na małym rondzie

Typical situation at high traffic volume in conflicting area during merge manoeuvre was illustrated on fig. 2.

Parameters like t_g and t_f indicate the dependence of traffic conditions at intersections without traffic signals on drivers' behavior. Each driver waiting in a minor stream has to decide when it is safe to merge into the conflicting traffic streams. The critical gaps and follow-up times take into account the influence of external parameters, for example the geometric design of the intersection or decision-making process.

Capacity formulas based on gap acceptance theory have been improved continuously. Different methods were developed by many scientists like: Siegloch, Harders, Brilon and Grossman in Germany. Kyte, Tian, Mir, Hameedmansoor, Kittelson, Vandehey, Robinson and many other all over the world [1], [2], [4], [6].



where: G - waiting time at Yield line, ε_i - moment, when i – vehicle is entering from minor road to main road of small roundabout, τ_i - vehicles' arrival moments at conflicting areas, t_g - critical gap, t_f - follow-up time, block - time interval, which starts t_g seconds before the major stream vehicle arrives and lasts until the beginning of the next major stream headway $t_i \geq t_g$, antiblock - the time interval between two blocks. An antiblock starts when a headway $t_i \geq t_g$ starts and ends t_g before the arrival of the next major stream vehicle. Minor stream vehicles can enter the intersection during antiblock.

Fig.2 Gap acceptance and queue discharge at small roundabouts
Rys.2. Proces wjazdów pojazdów z wlotu podporządkowanego na jezdnię małego ronda

2. THE EMPIRICAL STUDY

Measurements were taken at 12 urban intersections. Traffic flow at these intersections was videotaped with a time signal recorded. The time code helped identify each vehicle's arrival time at a specific point along the road within 0.04 second. Each vehicle of a minor stream was recorded in a database using vehicle type, time of arrival in front position and time of departure. These data were then used to record drivers' follow-up times could be derived. Example of location places for follow-up times measurement has been presented in fig. 3.

Defining arrival and departure times turned out to be difficult. Many minor stream cars approached the yield line easily and stopped right in front of the yield line. Other vehicles approached hesitantly and rolled to stop slowly. To address these questions, generalizations had to be made. Thus, after a series of experiments, the definitions were made according to the best knowledge of the researcher. Once defined however, the definitions were applied to all intersections consistently.

Fig. 3. Example of location places for follow-up times measurement
Rys. 3. Przykładowe lokalizacje stanowisk do pomiaru odstępów czasu pomiędzy pojazdami wjeżdżającymi z kolejki na wlocie

4. DETERMINING FOLLOW-UP TIMES

The first results were used to verify the assumptions made for estimating the critical values. The resulting follow-up times varied within relatively wide margins as illustrated on fig. 4. These variations were investigated to determine whether they are natural characteristics of the follow-up times or if there are any systematic influences responsible for the variations.

The follow-up times were tested for their dependence on several external parameters listed in table 2. The critical values were tested using a t-student test. The regression coefficient was tested using a t-student test to determine whether it was different from zero which means that correlations exist. The results of these tests were shown also in table 1. When a parameter turned out to have a significant influence on the follow-up time it is indicated by „yes”. In those cases, the coefficient of correlation is given. From the coefficient of correlation one can see how significant the influence of the external parameter is on the follow-up time. The bigger the coefficient of correlation is the stronger the correlation between variables is. The other geometric effects were not relevant because all measured intersections were designed according to the quadelines and there were no extreme conditions such as acute angles between intersections arms or uncharacteristic approach gradient etc.

Tab.1

Results from the determination of follow-up times

	Small roundabout in	The range of follow-up times
1.	Świerklaniec	2.60 – 4.88
2.	Tarnowskie Góry II	1.64 – 3.00
3.	Tarnowskie Góry I	1.16 – 4.04
4.	Bytom-Radzionków	1.52 – 4.32
5.	Katowice	2.50 – 4.84
6.	Mysłowice	2.76 – 3.92
7.	Tychy I	1.16 – 4.04
8.	Tychy II	1.92 – 3.96
9.	Tychy III	1.20 – 3.32
10.	Tychy IV	1.44 – 3.60
11.	Piekary Śląskie	2.00 – 3.84
12.	Siemianowice	1.56 – 3.76

0 1 2 3 4 5 6 7 8 9 10

follow-up times [s]

The follow-up time values obtained from new formula was given in table 3. The follow-up times was given for main road lane width equal 4.0 m. According to polish guideline, small roundabouts are intersections with external diameter from range of 26 (22) - 40 (45) m. Values is brackets are permissible in exceptional situations. In table 3 the typical values of external diameter are highlighted in bold.

Tab. 2

Dependence of follow-up times on external parameters

	External parameter	Dependence
1	Three or four armed small roundabouts	no
2	Existence of island on minor road	no
3	Sight distance	no
4	Minor road width	no
5	External diameter of small roundabout	yes R = -0.99
6	Major road width	yes R = -0.72

Tab. 3

Follow-up time values recommended for one-lanes small roundabouts localized in urban areas

***D*_z [m]**	22	23	24	25	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
***t*_f [s]**	3.32	3.30	3.28	3.26	3.24	3.22	3.20	3.18	3.16	3.14	3.12	3.10
***D*_z [m]**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	41	42	43	44	45
***t*_f [s]**	3.08	3.06	3.04	3.02	3.00	2.98	2.96	2.94	2.92	2.90	2.88	2.86

4. CONCLUSIONS

The paper provides detailed investigations on the various factors that affect on follow-up time. The investigation was based on the database established during the traffic flow parameters measurements on few small roundabouts localized on urban area. The step-wise regression analysis was conducted to investigate the potential factors affecting the follow-up time. General observations of the various factors can be summarized below:

- It was found that the major factors affecting follow-up time include intersection geometry like small roundabout external diameter and major lane width.
- With the increase of major stream volume drivers tend to seek smaller gaps.
- With the increase of small roundabouts external diameter, the follow-up time value tends to decrease.
- With the increase of major lane width the follow-up time value tends to decrease. It was due to the increase of the easiness of the movement manoeuvre.
- Follow-up time of heavy vehicles is found to be consistently higher than for passing cars.
- It was proved after control measurements that the follow-up time values proposed in the article can be used in small roundabouts capacity calculation.

Although the regression analysis provided insights on the relationships among various factors, practical engineering judgment still played an important role while recommending the final set of follow-up time values. For example the other few factors appeared to be significant in the regression analyses were not included in the final recommendations. These factors were dealt with specifically in other parts of the capacity analysis procedure.

The newly recommended follow-up time values have been adopted in the own method for small roundabouts capacity calculations.

Bibliography

1. Brilon W., Troutbeck R., Tracz M.: *Review of International Practices Used to Evaluate Unsignalized Intersections*. Transportation Research Circular 468. Transportation Research Board, Washington, 1997.
2. Brilon W., Wu N., Bondzio L.: *Unsignalized Intersections in Germany – a State of the Art 1997*. Third International Symposium on Intersections without Traffic Signals. Portland, Oregon, July, 1997, p.61-70.
3. Hagring O.: *Roundabout entry capacity*. Bulletin 135. Department of Traffic Planning and Engineering, Lund, 1996.
4. Kyte M., Tian Z., Mir Z., Hameedmansoor Z., Kittelson W., Vandehey M., Robinson B., Brilon W., Bondzio L., Wu N., Troutbeck R.: *Capacity and Level of Service at Unsignalized Intersections*. National Cooperative Highway Research Program (NCHRP), Washington, 1996, p. 3-46.
5. *Metoda obliczania przepustowości rond. Instrukcja obliczania*. Generalna Dyrekcja Dróg Krajowych i Autostrad, Warszawa, 2004.
6. Tian Z., Troutbeck R., Kyte M., Brilon W., Vandehey M., Kittelson W., Robinson B.: *A Further Investigation on Critical Gap and Follow-Up Time*. Transportation Research Circular E-C018: 4th International Symposium on Highway Capacity. Bochum, Germany, 2000, p. 397-408.
7. Transportation Research Board. *Special Report 209: Highway Capacity Manual*. National Research Council, Washington, 1997.
8. Troutbeck R.: *Estimating the Critical Acceptance Gap from Traffic Movements*. Research Report 92-5. Queensland University of Technology, Brisbane, 1992.
9. Weinert A.: *Estimation of Critical Gaps and Follow-Up Times at Rural Unsignalized Intersections in Germany*. Transportation Research Circular E-C018: 4th International Symposium on Highway Capacity. Bochum, Germany, 2000, p. 409-421.
10. Woch J.: *Nowe ujęcie przepustowości drogi z porównaniem modeli*. Zeszyty Naukowe Politechniki Śląskiej, s. Transport, Gliwice, z. 47, 2003, s. 43-72.

Received 24.01.2008; accepted in revised form 22.09.2008