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Modelling follow up time at a single-lane roundabout

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Abstract: The follow up time is an important parameter for estimating the entry capacity of roundabouts. However, its variability and contributing factors have long been ignored in the literatures. In this study, 171 follow up samples and contributing factors (traffic volume, vehicle position, waiting vehicles behind, vehicle type, and drivers' gender) are collected at a roundabout in Pacific Pines, Australia. It is found that the follow up time is indeed significantly affected by traffic volume, waiting vehicles behind, vehicle type, and drivers' gender. In order to establish the relationship between the follow up time and its contributing factors, an inverse Gaussian regression model is further developed. This relationship could be applied to estimate the entry capacities by taking into account the variability of follow up samples. According to the model, the traffic volume and vehicle types are the most important contributing factors.

Key words: roundabout capacity; critical gap; follow up time

1 Introduction

Urban roads are becoming more and more congested due to the increase of car ownership. A number of management tools, such as pricing, signal control, dedicated lanes have been applied to alleviate road congestion (Liu and Meng 2014; Liu et al. 2013a; Liu et al. 2014; Meng and Liu 2011; Meng et al. 2012; Wang et al. 2013). At the same time, there are some roads that are less controlled such as unsignalized intersections. A roundabout is a type of circular intersection or junction in which road traffic is slowed and flows almost continuously in one direction around a central island to several exits onto the various intersecting roads (Tenekeci et al. 2010; Xu and Tian 2008; Qu et al. 2014). As pointed out by Bie et al. (2008), unlike a signalized intersection, wherein traffic streams are controlled by the traffic signal, vehicles must follow the give way rules to enter a roundabout. The direction of traffic flow is either clockwise for left-side driving or anticlockwise for right-side driving. Since all vehicles are regulated to travel

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along with the same direction, number of conflicting points is significantly reduced (Wong et al. 2012). Further, the drivers usually slow down the vehicles' speed thanks to the impact of "give way" rules and the roundabout curves (Al-Masaeid 1999). The roundabout is therefore considered as a safer intersection type compared to signalized intersections, in terms of both frequency and severity of accidents (Vasconcelos et al. 2012). A roundabout can also reduce the delay (for low traffic conditions) and thus decrease pollutant emissions (Hoglund 1994). Accordingly, the roundabout becomes an increasingly popular intersection type, especially for suburbia with relatively low traffic volume.

The entry capacity of a roundabout is usually estimated on the basis of gap acceptance theory. The fundamental parameters for this theory are the critical gap and follow up time. The critical gap is the minimum time gap between successive circulating conflicting traffics that allow vehicles queued in an approach to enter the roundabout. The follow up time is defined as the time difference between two vehicles queued in an approach entering the roundabout during the same gap in the circulating traffic (Özuysal et al. 2009). It has been well recognized that both parameters are highly affected by drivers' behaviours, traffic conditions, geometric parameters, and vehicle types. The variability of critical gap and its affecting factors have been well analyzed in the literatures (e. g. Bottom and Ashworth 1978; Polus et al. 2003; Tian et al. 1999). By contrast, the other important contributing factor, follow up time, has been unfortunately out of the focus in the literatures. Akcelik (2005) mentioned that the follow-up time was reduced with increasing circulating traffic. Dahl and Lee (2012) pointed out that the follow up time varies with the vehicle types of the two entering vehicles in a queue. The above-mentioned two articles are, to the best of our knowledge, the only references that analyze the contributing factors of follow up time. In reality, according to the Highway Capacity Manual (HCM) models (TRB 2000; 2010), the variability of follow up time might have higher impact on entry capacities than that of critical gap, especially during the light traffic conditions. Therefore, it is of great importance to analyze the variability of follow up time and its contributing factors.

In this study, traffic videos are recorded during distinct time periods (8×30 minutes each) at a roundabout in Pacific Pines of Queensland, Australia. 171 samples of follow up times and the contributing factors (including vehicle type, waiting position in a queue, queuing vehicles behind, traffic volume, and driver's gender) are measured and/or identified from the videos. Then, one way analysis of variance (ANOVA) is applied to examine whether a contributing factor has a statistically significant impact on follow up time. Finally, a generalized linear regression model is developed to establish the relationship between follow up time and its contributing factors.

The contributions of this study are two-fold. On one hand, this paper analyses the impact of various contributing factors (including vehicle position in a queue, number of waiting vehicles behind, and driver's gender) on follow up time using real data. More importantly, this is the first attempt to establish the relationship between follow up time and its contributing factors using a generalized linear nature. This result could be applied to estimate the roundabout capacity by incorporating the impact of these contributing factors.

2 Data description

The field data analyzed in this paper was collected from a roundabout at the junction of Smith Street and Pitcairn Way, Pacific Pines, Queensland (Fig. 1). Traffic videos were recorded during distinct time period (8×30 minutes each; a combination of peak and off-peak hours during day time). The speed limit for Smith Street and Pitcairn Way are 70 and 60 km/hour, respectively. As the Smith Street is the most important corridor connecting Pacific Pines to Gold Coast, the traffic volume of this roundabout during peak hours is relatively high. The radius of the central island is 24 meters. In sum, 171 follow up samples and the contributing factors are measured and/or identified from the videos. The mean and standard deviation of the samples are 2.76 seconds and 0.62 seconds, respectively. The contributing factors to follow up times are vehicle type, waiting position in a queue, queuing vehicles behind, traffic volume, and driver's gender. According to the field survey, the utes are usually associated with a shorter follow up times, while the follow up times of vans and trucks are generally longer. In this study, we categorize the vehicles into three types: utes, cars (sedan, coupe, hatchback, and wagon), and heavy vehicles (van, bus, and trucks). It is also found that the follow up times of first queuing vehicles (i. e. 2nd vehicle in the approaching queue) are usually shorter. This is perhaps because these drivers are better prepared to follow up. Further, the vehicles with waiting ones behind might have a shorter follow up time. We use the binary variable to represent the vehicle positions in a queue ('0', first queuing vehicle; '1', others). Similarly, the binary variables are used to represent the drivers' gender ('0', female; '1', male) and whether there are waiting vehicles behind ('0', no; '1', yes). Drivers' age could also be a contributing factor. However, as this study is an observational one, it is thus difficult to assess the age of participants. Therefore, the impact of age is not considered in this research.

Fig. 1 Roundabout

3 Significance analysis

One way analysis of variance (ANOVA) is a well-recognized method in transportation data analysis (Qu et al. 2012; 2014; Jin et al. 2011; Liu et al. 2013b). We apply this method to evaluate whether the contributing factors have significant impact on follow up times at the level of 0.05. Tabs. 1-5 show the results of significance analysis. As can be seen in the tables, vehicle type, waiting vehicles, traffic volume, and gender do have significant effects on the follow up times. It is found that the heavy vehicles have significantly longer (p-value = 0.000) follow up times because their start-ups need more time and accelerations are relatively smaller. Interestingly, the drivers with waiting vehicles behind have the tendency to hurry up perhaps because of the moral pressure imposed from the queuing ones (p-value = 0.046). Under low to mid traffic conditions, the traffic volume has a positive relationship with the follow up time (p-value = 0.000). This might be because the drivers are more cautious under relatively high volumes. This result shows there are significant differences between female drivers and male drivers. It seems that female drivers are more conservative (p-value = 0.022). According to the observation, the first queuing vehicles (the 2nd vehicle in the queue) are usually associated with a shorter follow up time. This might be because this type of vehicles pre-examine the circulating flows before following up the lead vehicle. According to the data analysis, there is a difference between the means of the two groups (first queuing vehicle or not): 2.741 seconds vs. 2.775 seconds. However, based on the ANOVA, this difference is not significant (p-value = 0.736).

Tab. 1 Results of significance analysis (vehicle types)

	Sum of squares	Dgeree of freedom	Mean square	F	Significance
Between groups	13.048	2	6.524	20.806	0.000
Within groups	52.678	168	0.314		
Total	65.726	170			

Tab. 2 Results of significance analysis (vehicle positions)

	Sum of squares	Dgeree of freedom	Mean square	F	Significance
Between groups	0.044	1	0.044	0.114	0.736
Within groups	65.682	169	0.389		
Total	65.726	170			

Tab. 3 Results of significance analysis (waiting vehicles)

	Sum of squares	Dgeree of freedom	Mean square	F	Significance
Between groups	1.530	1	1.530	4.029	0.046
Within groups	64.196	169	0.380		
Total	65.726	170			

Tab. 4 Results of significance analysis (traffic volume)

	Sum of squares	Dgeree of freedom	Mean square	F	Significance
Between groups	26.446	7	3.778	15.678	0.000
Within groups	39.279	163	0.241		
Total	65.726	170			

Tab. 5 Results of significance analysis (gender)

	Sum of squares	Dgeree of freedom	Mean square	F	Significance
Between groups	2.003	1	2.003	5.311	0.022
Within groups	63.723	169	0.377		
Total	65.726	170			

4 Calibration of follow up times

4.1 Statistical analysis for follow up samples

A data analysis procedure is proposed in order to obtain the best-fitted follow up distributions. Seven commonly used continuous distributions are examined in this study: Inverse Gaussian, Exponential, Normal, Lognormal, Gamma, Weibull, and Erlang. Kolmogorov-Smirnov (K-S) test, a nonparametric test, has been widely applied to compare a sample with a reference probability distribution in transportation studies (Meng and Qu 2012; 2013; Qu et al. 2013; 2014; Qu and Meng 2014). The K-S statistic quantifies a distance between the empirical distribution function of the sample and the cumulative distribution function of the reference distribution. In this study, a distribution with the lowest K-S test statistic is regarded as the best-fitted distribution. According to the K-S test, the Inverse Gaussian distribution is the best fitted one. Fig. 2 presents the empirical cumulative distribution functions (CDF) with the best fitted distributions. As can be seen in the figure, the Inverse Gaussian distribution fits the data very well.

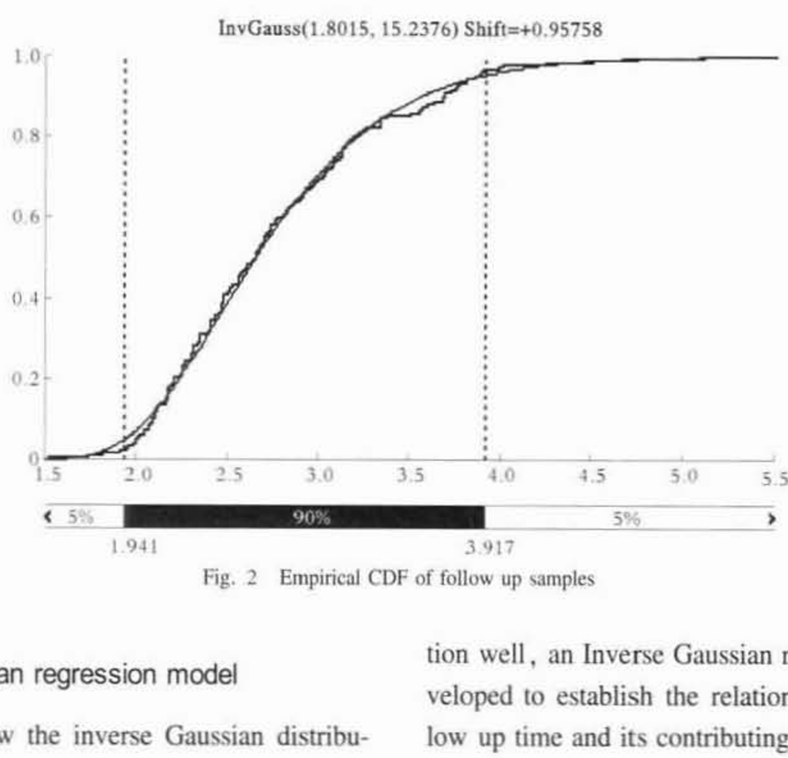

Fig. 2 Empirical CDF of follow up samples

4.2 Inverse Gaussian regression model

As the samples follow the inverse Gaussian distribution well, an Inverse Gaussian regression model is developed to establish the relationship between the follow up time and its contributing factors. To formulate an Inverse Gaussian regression model, set y_i, $i = 1, 2, \cdots, n$, be n independent observations (follow up samples) distributed as $IG(\mu_i, \lambda)$, in which sample mean (μ_i) has a linear relationship with these contributing factors, namely:

$$\mu_i = \beta_0 + \beta_1 x_1 + \cdots + \beta_j x_j + \cdots + \beta_n x_n \quad (1)$$

where x_j denotes the contributing factor j; and β_j is the regression coefficient. This model could be solved by IBM SPSS 20.0. The results are presented in Tab. 6.

Tab. 6 Parameter estimates of inverse Gaussian model

			95% Wald confidence interval		Hypothesis test		
Parameter	β	Std. error	Lower	Upper	Wald chi-square	Degree of freedom	Sig.
(Intercept)	1.411	0.2459	0.929	1.893	32.953	1	0.000
Traffic volume	0.005	0.0005	0.004	0.006	92.350	1	0.000
Vehicle type =0	−0.569	0.1525	−0.868	−0.270	13.924	1	0.000
Vehicle type =1	−0.982	0.1773	−1.330	−0.635	30.707	1	0.000
Vehicle type =2	0[a]						
No waiting vehicles	0.089	0.0628	−0.034	0.212	2.015	1	0.156
Waiting vehicles	0[a]						
Female	0.150	0.0680	0.016	0.283	4.851	1	0.028
Male	0[a]						
(Scale)	0.009[b]	0.0009	0.007	0.011			

Note: dependent variable: follow up time; model: (intercept), volume, vehicle type, waiting vehicles behind, and gender; [a]set to zero because this parameter is redundant; [b]maximum likelihood estimate.

The follow up time with respect to distinct traffic volume, vehicle type, waiting vehicles, and drivers' gender could be represented by an Inverse Gaussian distributed random variable with parameter μ and λ, where μ is a function of these contributing factors, and λ is 0.009 according to Tab. 6.

4 Conclusions

The follow up time is an important parameter for estimating the entry capacity of roundabouts. However, its variability and contributing factors have long been ignored in the literatures. In this study, 171 follow up samples and contributing factors (traffic volume, vehicle position, waiting vehicles behind, vehicle type, and drivers' gender) are collected at a roundabout in Pacific Pines, Australia. According to ANOVA, the follow up time is indeed significantly affected by traffic volume, waiting vehicles behind, vehicle type, and drivers' gender. In order to establish the relationship between follow up time and its contributing factors, an Inverse Gaussian regression model is further developed. This relationship could be applied to estimate the entry capacities by taking into account the variability of follow up samples. According to the model, traffic volume and vehicle types are the most significant contributing parameters.

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