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Driver Response Time of Queuing Vehicles at Urban Signalized Intersections

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Abstract

Driver response (reaction) time (t_r) of the second queuing vehicle is generally longer than other vehicles at signalized intersections. Though this phenomenon was revealed in 1972, the above factor is still ignored in conventional departure models. This paper highlights the need for quantitative measurements and analysis of queuing vehicle performance in spontaneous discharge pattern because it can improve microsimulation. Video recording from major cities in Australia plus twenty two sets of vehicle trajectories extracted from the Next Generation Simulation (NGSIM) Peachtree Street Dataset have been analyzed to better understand queuing vehicle performance in the discharge process. Findings from this research will alleviate driver response time and also can be used for the calibration of the microscopic traffic simulation model.

Keywords: departure model; driver response (reaction) time; ngsim; hcm2000; enlarged stopping distance; signalized intersections

1. Introduction

There are different descriptions of driver response time in various vehicle departure models. In 1972, Medelska stated that a second driver needed more time to react following the movement of the first vehicle; after the fifth vehicle the vehicle in a row kept equal intervals during the green signal phase (Jan et al., 2009). This means the second driver response time is longer than other drivers. However, the HCM2000 departure model assumes that the first four queuing vehicles headway appear in a steady decline; and then the headway remains constant after the fifth vehicle at signalized intersections (TRB, 2000a). As a result, there is a start-up loss. In comparison, Akcelik (2002) summarized previous departure

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models and expressed the queue discharge headway as a function of time since the green signal onset. The equation is:

$$h_s = h_n / \left[1 - e^{-m_q(t-t_r)}\right] \quad (1)$$

where, h_s is queue discharge headway at time t (seconds), h_n is minimum queue discharge headway (seconds), m_q is a parameter in the queue discharge flow rate model, t is time since the start of the displayed green period (seconds), t_r is start response time (a constant value) related to an average driver reaction time for the first vehicle to start moving at the start of the displayed green period (seconds).

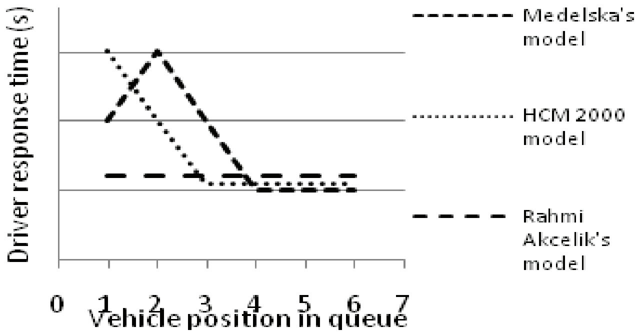


Fig. 1. Concept of driver response time with queue position

Figure 1 highlights the necessity of quantifying the driver response time because the concept of variations of driver response time is not clear. This paper aims to offer quantitative measurements and analysis of queuing vehicle dynamic performance in the discharge process at urban signalized intersections. Video recording was conducted in three major cities in Australia. Also, twenty two sets of the first five queuing vehicle discharge examples are extracted from the Next Generation Simulation Peachtree Street Data. An 'Enlarged Stopping Distance' (ESD) method is proposed and simulated to reduce the second driver response time. Findings from this research will provide a better understanding of the queuing vehicles discharge process and also will calibrate the microscopic traffic simulation model.

2. Video record survey of the second vehicle departure

The gap between the above descriptions of driver response time led to video recording queuing vehicle departures at urban signalized intersections in Brisbane, Melbourne and Sydney, Australia. To ensure the accuracy of this survey, the video recording is based on the following three criteria: different time and different location, different time but same location, in the same city and same day but different location. To avoid effecting the driver, this survey used a mobile phone to record the video clips which only capture the vehicle discharge process during one signal phase when the researcher arrived at the intersection.

Table 1 indicates that the second vehicle in the queue generally starts to accelerate a few seconds after the first vehicle while the third vehicle accelerates at the same time as the second. Therefore, it is clear that the second driver response time is longer than other drivers. For the Brisbane case, a similar problem still exists even two years passed. The video in the Sydney case indicates that the second taxi driver, a professional driver, starts to accelerate only when the first vehicle has crossed the stop line. However, the above survey only offers visual evidence, so it was necessary to conduct quantitative measurements and analysis to support this research.

Table 1. Video record survey

Video clips	Record date & place	Aim
	21 August 2008, Vulture Street and Grey Street, Southbank, Brisbane. Recorded by Shuai Yang	Different time but same location
	16 November 2010, Vulture Street and Grey Street, Southbank, Brisbane. Recorded by Shuai Yang	Different time but same location
	20 September 2008, Nicholson Street and Victoria Street, Melbourne. Recorded by Shuai Yang	In the same city and same day but different location
	20 September 2008, Brunswick Street and Victoria Parade, Fitzroy, Melbourne. Recorded by Shuai Yang	In the same city and same day but at different location
	26 July 2010, Broadway and Abercrombie Street, Ultimo, Sydney. Recorded by Haoyao Zhang	Different time and different location

3. Evaluate the research of second driver response time

The Kobari data from Tang and Nakamura (Tang et al., 2007) in Aichi Prefecture, Japan, highlights the value of this research. Since the study of reducing first vehicle reaction time has become successful by using of countdown clocks and other methods, this research mainly focuses on quantitative measurements and analysis of queuing vehicle performance in spontaneous vehicle discharge at signalized intersections. The following diagram, drawn from the Kobari data, shows that the first two vehicles cannot reach average flow rate (Fig. 2(a)). If it could save the response time for the second vehicle, the headway time between the first and the second vehicles in queue will decrease. Consequently, the time for the first four to five vehicles to cross the stop line is shorter and will generate an observable impact on the saturation flow rate. This means the slope of the cumulative plot shown in Fig. 2(a) will be steeper and will potentially benefit to increase the discharge rate at signalized intersections. The above phenomenon that the second driver response time is relatively longer is also identified in Japan through the Kobari field data analysis.

3. Characterize queuing vehicle dynamic performance in discharge process

Traditional methods use headway to measure queuing vehicle dynamic performance at signalized intersections (Bonneson, 1992; Fairclough et al., 1997; Jin et al., 2009; Lee et al., 1986). In HCM 2000, headway is defined as, “The time, in seconds, between two successive vehicles as they pass a point on the

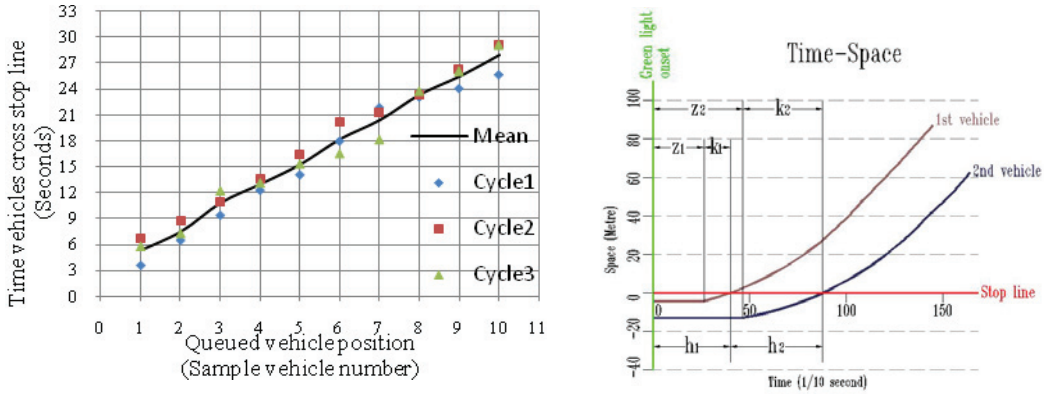


Fig. 2. (a) Crossing stop line headway analysis (Kobari Intersection) drawn by Shuai Yang;
(b) Relationship z_i & k_i with h_i

roadway, measured from the same common feature of both vehicles" (TRB, 2000b). Greenshield et al. (1947) stated that driver response time to signal change and reaction time between successive vehicles should be calculated independently in the discharge process research. Therefore, this research explored each queuing vehicle dynamic performance in the discharge process by following two aspects: time for the driver to perceive a signal change (or get safety distance to accelerate) and react and time for the vehicle to start to move till it crosses the stop line. These two components are separately symbolised as z_i and k_i. Also, this research uses h_i to present the time for the i^{th} vehicle to cross the stop line from the queuing position from the onset of the green signal. Consequently, the time of z_i add to k_i will equal the time h_i. The headway at the stop line will be h_i minus h_{i-1}.

Figure 2(b) presents the relationship between z_i, k_i and h_i. The *X* axis shows the time (1/10s) compared with the vehicle trajectory curve; the *X* axis presents the stop line location. The *Y* axis shows the distance of each vehicle to the stop line as they correspond to time. Moreover, the *Y* axis also presents the time of the onset of the green signal. For example, the signal changes to green when the value of the *X* axis is zero; and then, the second driver spends time z_2 to react (driver response time) and the second vehicle uses the time k_2 to cross the stop line from when it moves. The second vehicle then spends the time of (z_2+k_2) to cross the stop line after the onset of the green signal. This research uses the NGSIM Peachtree Street Data to extract some vehicle trajectory examples and analyze these group trajectories to get the time z_i and k_i for each queuing vehicle to calculate the headway. This research, therefore, characterizes the i^{th} queuing vehicle headway from $(z_i+k_i)-(z_{i-1}+k_{i-1})$.

3.1. NGSIM Peachtree Street Data analysis

Cambridge Systematics Inc. developed the Peachtree Street Data as part of the Federal Highway Administration's Next Generation Simulation project. However, many authors reported the shortcomings of this data set since it was published. For example, Dixon et al. (2010) reported that this data set lacked the information to get the location of the stop bar. Vincenzo et al. (2009) also stated that some data items of this data set included many errors, such as the vehicle velocity value appeared as zero while the raw video showed that the corresponding vehicle accelerated. Therefore, this study calculates the real distance between the successive vehicles, using the Global *X* and Global *Y* data of the Peachtree Street Data, and then extracts the trajectory of each vehicle. The above steps are different with Dixon's method that only used the successive vehicles Local *Y* data variation as the vehicle distance to generate the vehicle trajectory.

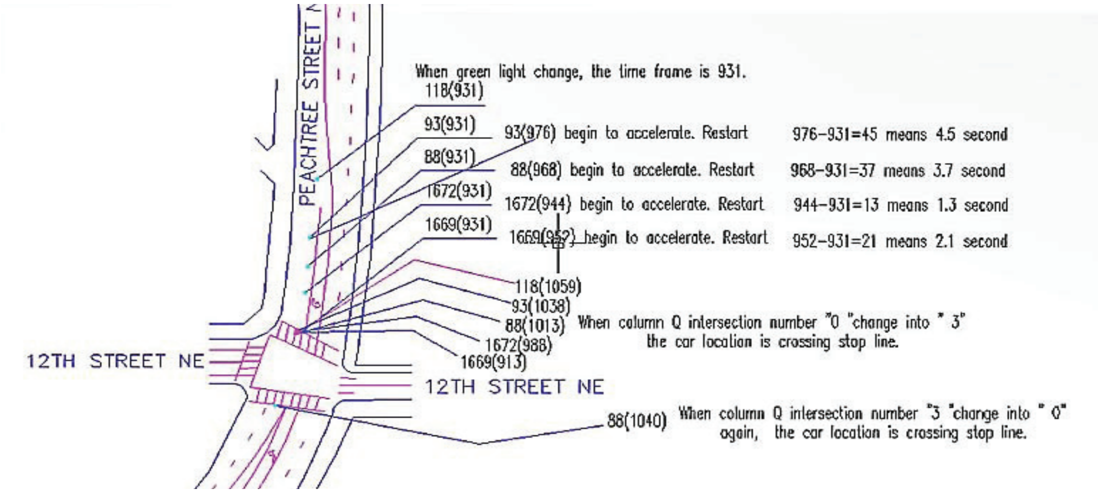
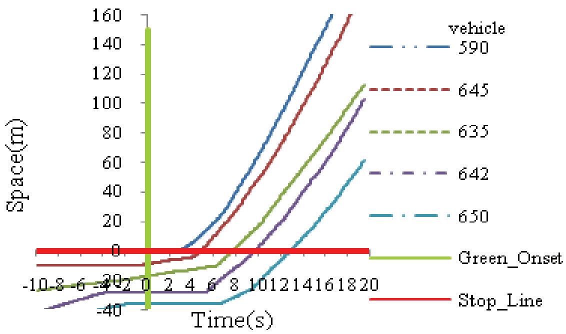


Fig. 3. Using AutoCAD to test the data accuracy

This study inputs the variation of the Global Location data with the corresponding Intersection and Section data, the green signal timing data, and the Stop Line Location data to the offered AutoCAD file (the NGSIM data offered stop line location to user using Peachtree-Main-Data/ cad-diagram/ Atlanta-Peachtree.dwg) and the results confirm that inter-relationships between the above Peachtree Street Data items are accurate (Fig. 3). This study uses the data sets collected on the Peachtree Street and 11th, 12th, and 14th Street from 4.00pm to 4.15pm. The data was extracted from signal phase when there are at least five leading queuing vehicles. As a result, only twenty two sets of discharge trajectories can be extracted. Fig. 4(a) presents one example of discharge trajectories collected on the Peachtree Street Data.

This study gets five mean queuing vehicle trajectories from the above twenty two sets of the vehicle trajectories and generates a Time-Space diagram to illustrate the five queuing vehicles discharge process (Fig. 4(b)). In the diagram, it assumes that the first vehicle stops at the stop line when the time z_1 is zero. Thus, the *X* axis can be used as the stop line location and the *Y* axis can present the onset of the green signal. The *Y* axis values indicate the stopping distance between the successive queuing vehicles at the start of green. The *X* axis values present the time of the vehicle crosses the stop line when corresponding vehicle trajectory is at that the *Y* axis value is zero.



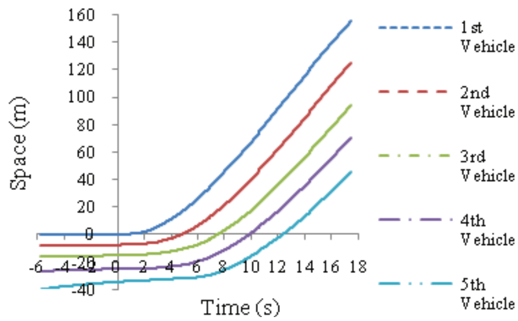


Fig. 4. (a) Time-Space graph Example 04 (b) Mean Time-Space graph

3.2. Characterize the time z_i and k_i

Though the accuracy of the above Peachtree Street Data items has been confirmed, outside factor still has negative effects on some data items; for instance, the wind make the camcorder vibrate and thus the value of the velocity alternatively appears positive and negative. The number of zero does not appear in the velocity data because most queuing vehicles keep sliding forward too. Therefore, it is necessary to define the term of "Stop" and this study defines stop as speed below 3 meter/second. This criterion is used to extract the driver response time z_i. Table 2 presents each driver response time z_i that is extracted from the twenty two departure examples.

Table 2. Driver response time z_i

	Queue position	1st	2nd	3rd	4th	5th
Examples driver response time (second)	1	2.1	5.5	4.2	6.8	7.7
	2	4	4.2	7.4	7	7.8
	3	2.1	4	5.9	2.6	7
	4	2.5	4.1	6.3	5.2	6.9
	5	4.2	3.7	5.7	9.9	7.4
	6	2.2	3.5	5.3	6.8	7.2
	7	8	1.9	4.2	3.8	5.6
	8	1.6	3	5.8	5.9	7.5
	9	1.1	4.2	6	5.3	8.5
	10	1.2	2.9	4.2	6.2	4.2
	11	8	3.9	3	6.8	6.9
	12	2.6	3	6.5	8.8	9
	13	3.9	5.3	7.3	9.7	11.9
	14	2	3.1	5.1	7.2	9.1
	15	9.6	17.3	13.7	12.3	11.3
	16	4.8	5.8	7.2	11	10.2
	17	2.2	5.1	5.4	11.8	10.5
	18	3.1	3.2	4.2	6.9	8.5
	19	2.2	5.1	7.6	7.8	8.4
	20	2.5	2.4	4.4	5.7	7.2
	21	1.7	4.3	7.4	8.2	7.4
	22	2.3	2.8	3.6	5.3	6
Median reaction time (second)		2.2	3.95	5.75	6.85	7.95

Normally, most departure models use average method to get driver response time, mainly because the varying of driver response time is presumed to be small. On the contrary, findings of this research reveal that the response time varies widely. For example, the second driver response time varies from 1.9 to 17.3 seconds. Thus, it is more reasonable to use median time rather than average time to measure the driver response time in this paper. The five leading queuing vehicles median response time z_i are: z_1= 2.2 seconds, z_2= 3.95 seconds, z_3= 5.75 seconds, z_4= 6.85 seconds, and z_5= 7.95 seconds. The headway of the first five driver response time is: 2.2 seconds, 1.75 seconds, 1.8 seconds, 1.1 seconds, and 1.1 seconds, and the time are on a decreasing trend.

On the other hand, this study uses average time to measure the time that the vehicle spends to move from queuing position to the stop line (the time k_i). Using average time can cover most of common samples because successive vehicles need to have a safety distance before it can accelerate except the first vehicle and the situation is not much different in vehicle acceleration process. The first five queuing vehicles average time k_i are directly yield from the NGSIM Peachtree Street Data: k_1= 0 second, k_2= 4.9 seconds, k_3= 7.7 seconds, k_4= 10.3 seconds, and k_5= 12.9 seconds.

3.3 *Calibration of the leading vehicle discharge process*

The above study procedure has generated two essential components for this research (see Table 3 and Fig. 5). In this section, the median time z_i and the average time k_i will be regressed to generate the headway time. The decreasing trend of driver response time (z_i) in the above analyses reveals that the most significant headway clearly exists between the first and the second vehicle. This fits the observed visual display in Table 1 and demonstrates that the driver response time is not a constant parameter.

Table 3. Peachtree Street data set yield the time z_i & k_i

Vehicle position	Response time z_i (Second)	Time to cross the stop line k_i (Second)	Total time (Second)	Headway (Second)
The first five queued vehicles at signalized intersections	The time of the vehicle starts to move from green onset	The time of the vehicle takes to move till cross the stop line from queue position	The total time of the vehicle takes to cross the stop line from green onset	The headway between each vehicle
1st vehicle	2.2	0	2.2	2.2
2nd vehicle	3.95	4.9	8.85	6.65
3rd vehicle	5.75	7.7	13.45	4.6
4th vehicle	6.85	10.3	17.15	3.7
5th vehicle	7.95	12.9	20.85	3.7

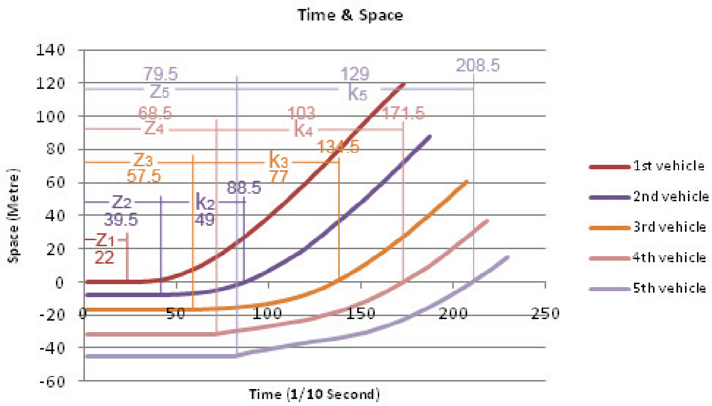


Fig. 5. Analysis of the time-space graph

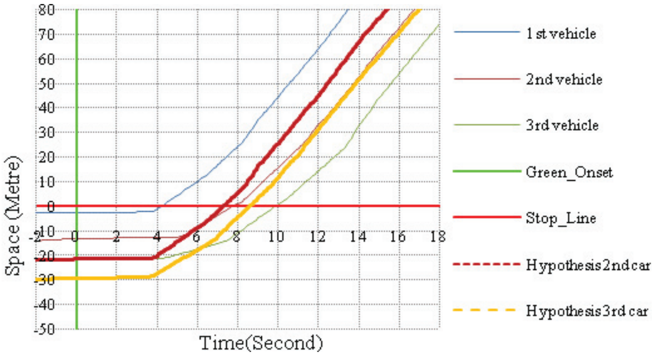


Fig. 6. Hypothesis Time & Space graph

4. Proposed 'Enlarged Stopping Distance' (ESD) concept

There is longer headway between the first and the second vehicles, because the second driver needs to get enough distance before it can accelerate, while the time z_i is on a decreasing trend. Thus, this paper proposes a method named as 'Enlarged Stopping Distance' (ESD) to reduce the above significant headway. The proposed ESD assumes that enlarging the stopping distance between the first two queuing vehicles could reduce the second driver response time and therefore it could alleviate the second vehicle effect on the start-up loss. For a better understanding, Fig. 6 illustrates the above proposed ESD concept using a real departure example of Peachtree Street Data.

This research hypothesizes that the stopping distance between the first and the second vehicle is enlarged, the second vehicle will start at the equivalent position of the third vehicle. With the extract spacing, the second vehicle can now has the same response time as the first vehicle. Based on the above assumptions, the trajectory of the second vehicle can be the same as the first vehicle but starting further back as shown in Figure 6. When comparing these simulated curves with the second and the third vehicle trajectories, this change can shorten the time for the corresponding vehicles to cross the stop line. These curves can be used to confirm the value of the 'Enlarged Stopping Distance' concept. If the space between the first two vehicles were increased, it would contribute to saving time for better traffic flow crossing the intersection. However, this approach needs further research to confirm its effect.

5. Conclusions

The conventional departure models assume that the headway presents a decrease trend in terms of side effects of start-up lost time. However, based on the NGSIM Peachtree Street Dataset study, the simulations reveal that the significant headway exists between the first and the second vehicle; even though there is a decreasing trend of time that the vehicle starts to move from the onset of the green signal. The reason for this is that the second vehicle uses more time than the other four leading vehicles in the queue, from start till crossing the stop line. Consequently, driver response time is not a constant parameter in a departure model. This research is crucial to gaining a better understanding of the driver response time of queuing vehicles at signalized intersections and this is also useful for calibration of microscopic traffic simulation model. Furthermore, this paper proposed an 'Enlarged Stopping Distance' (ESD) approach to better the vehicle discharge. Further research is needed to collect real vehicle trajectory data to examine the above ESD concept because it is generated from the NGSIM Peachtree Street Dataset collected in 2006.

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