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STOPPING DISTANCE ANALYSIS FOR THROUGH VEHICLES IN A THREE-LANE ROAD AT SIGNALIZED INTERSECTIONS

Jiazhen Li[1], Wenhao Yuan[2], Liyong Yao[3] & Yongqing Guo[*4]
[1,2,3&*4]School of Transportation and Vehicle Engineering, Shandong University of Technology, Zibo, China

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ABSTRACT

Signalized intersections are the common bottlenecks in road networks, which significantly affect road safety and traffic efficiency. With the increasing number of vehicles, driving behaviors tend to be more differential and diverse. The differentiation and diversity might increase accident risk and traffic congestion. Therefore, it is essential to identify drivers' behavior characteristics for improving the efficiency and safety of signalized intersections. This study focuses on investigating the stopping distance distribution for through vehicles at signalized intersections during peak hours. The differences of stopping distance in the three lanes, and the relationship between stopping distance and upstream speed were examined. The results show that for vehicles waiting in the first row of a three-lane road, the stopping distance is shorter for the first vehicle to pass the stop-line than for the two other vehicles. And else, there is a negative non-linear relationship between stopping distance and upstream velocity, for the 1st vehicle passing the line. It was found that most drivers might have made the decision to pass first before they entering the surrounding zone to the intersection. The findings of this study can provide supporting evidence for developing traffic micro-simulation models, and also can be used for improving road safety and traffic efficiency at signalized intersections.

KEYWORDS: Signalized intersection; stopping distance; three-lane; upstream velocity.

1. INTRODUCTION

With the increasing number of vehicles, road accidents and traffic fatalities are on the rise in urban road network in China, especially at signalized intersections. Research shows that most traffic accidents are due to human factors, such as impropriate driving behavioral habit. Therefore, it is of significant to explore drivers' behavior characteristics, to enhance the safety and efficiency of signalized intersections.

Zhao [1] analyzed the time and speed distributions of vehicles passing the stop-line, using regression model and correlation analysis. Jiang [2] identified the influences of traffic indicates and drivers' personality types on drivers' decision-making behavior at signalized intersections, based on the random- effect Logistic model. Li [3] used the images processing technology to analyze drivers' reaction time to green signals at signalized intersections. Zhu [4] explored the speed characteristics of through vehicles at signalized intersections, and found that drivers' steering intention can be predicted based on their speed fluctuation characteristics at the straight section through the intersection. Li [5] applied the cellular automata model to analyze the speed characteristics of through vehicles during green countdown signals. Wu [6-7] examined the effects of vehicles' stopping position and distance headway on delay at signalized intersections. Pan [8] proposed a minimum safety distance between stop-line and crosswalk, based on the vehicle acceleration model. Tang [9] developed a multinomial log it model and a multiple linear regression model to predict the stop-line crossing patterns and speeds. In summary, only a few research related to stopping distance for through movement at signalized intersection have been conducted. This study will analyze the stopping distance characteristics of through vehicles in different through lanes, and the relation between stopping distance and upstream velocity at signalized intersections. All content should be written in English and should be in 1 column.

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2. RESEARCH METHOD

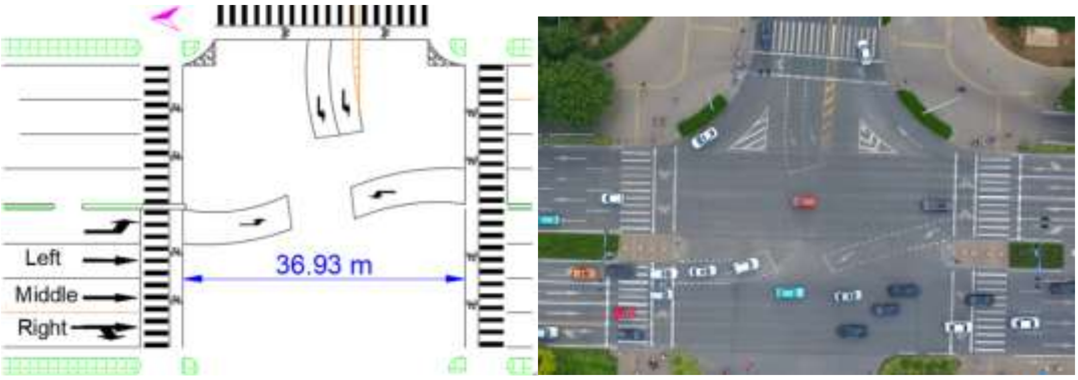

Figure 1 The selected signalized intersection (Nanjing Rd. &Gongqingtuanxi Rd.)

In this study, the intersection of Nanjing Rd and Gongqingtuan West Rd. was selected for analysis. A school gate is located in the west side of the intersection, so the intersection is with very unbalanced traffic flows. There are high traffic volumes in the south-north direction and light traffic in the east-west direction. The south-north direction has a three-lane road for through movement, in which the right lane is a shared one used by straight-through and right-turn vehicles. An unmanned aircraft system was used to gather vehicle information at the signalized intersection. The software Kinovea was used to extract traffic parameters such as velocity, acceleration, position, and stopping distance.

3. RESULTS AND DISCUSSION

Stopping Distance

This study analyzed the distance distribution of stopping behind a stop line for through vehicles. The stopping distance refers to the distance from the location the 1st vehicle wait to the stop line. The three scenarios were presented based on the vehicle proceeding through the line first, in the left, middle and right lanes. The stopping distance distributions for the three scenarios are shown in Figures 2, 3 and 4, respectively. There are a total of 55 data groups for the scenario of left vehicle moving forward first, 50 data groups for the scenario of middle vehicle moving forward first, and 40 data groups for the scenario of right vehicle moving forward first.

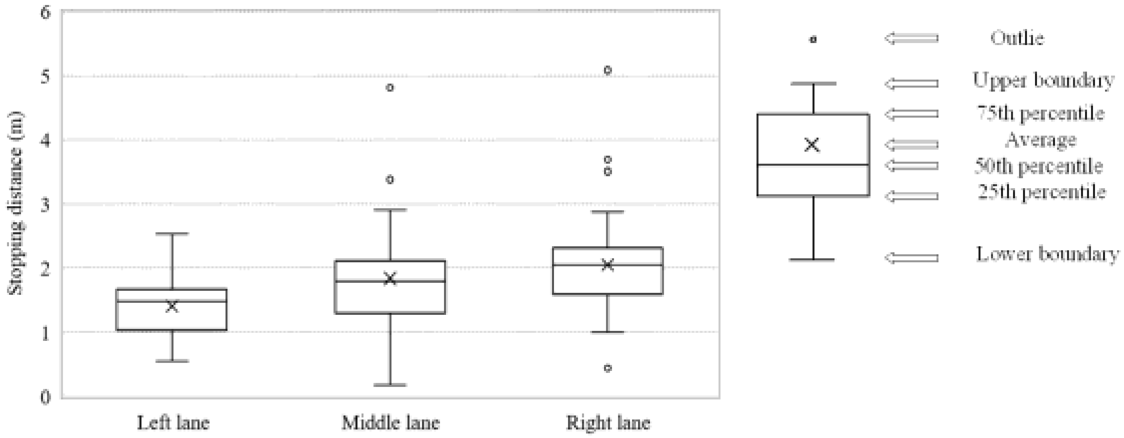

Figure 2 The stopping-distance distribution for the scenario of left vehicle moving forward first

In Figure 2, it was observed that the stopping distances for the left vehicle (crossing the stop-line first) are distributed in 0.5~2.5m, and the average is about 1.5m. Compared to the middle and right vehicles, the stopping distances for the left vehicle are closer together. It indicates that the vehicle crossing the stop-line first is more likely to stop closer to the line.

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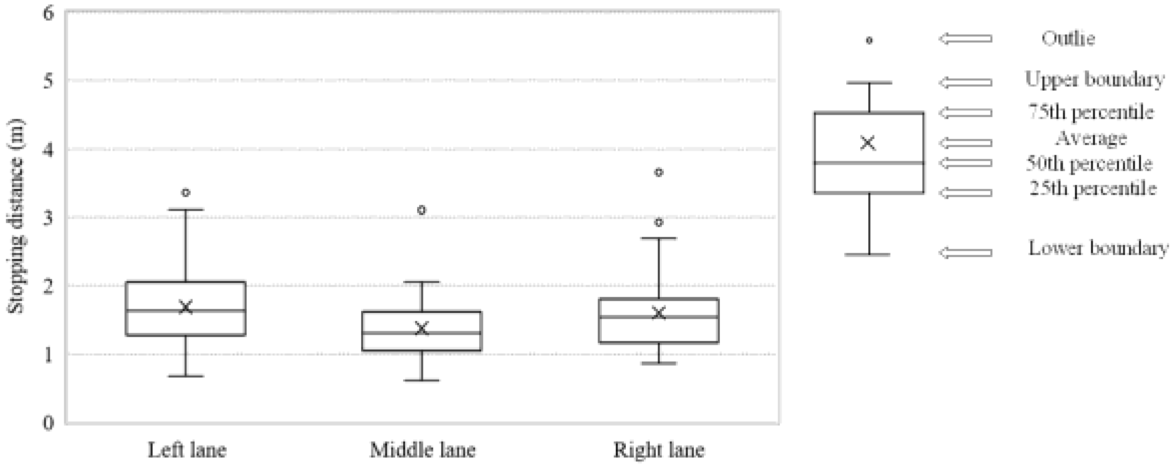

Figure 3 The stopping-distance distribution for the scenario of middle vehicle moving forward first

In Figure 3, it was noticed that the stopping distances for the middle vehicle (crossing the stop-line first) are distributed in 0.5~2m, and the average is approximate 1.2m. Compared to the left and right vehicles, the stopping distance distribution for the middle vehicle has lower variability. It indicates that the vehicle crossing the stop-line first is more likely to stop closer to the line.

Moreover, compared to the vehicles moving forward the stop-line first in Figures 2 and 3, it was noticed that the distances for the middle vehicle are closer together.

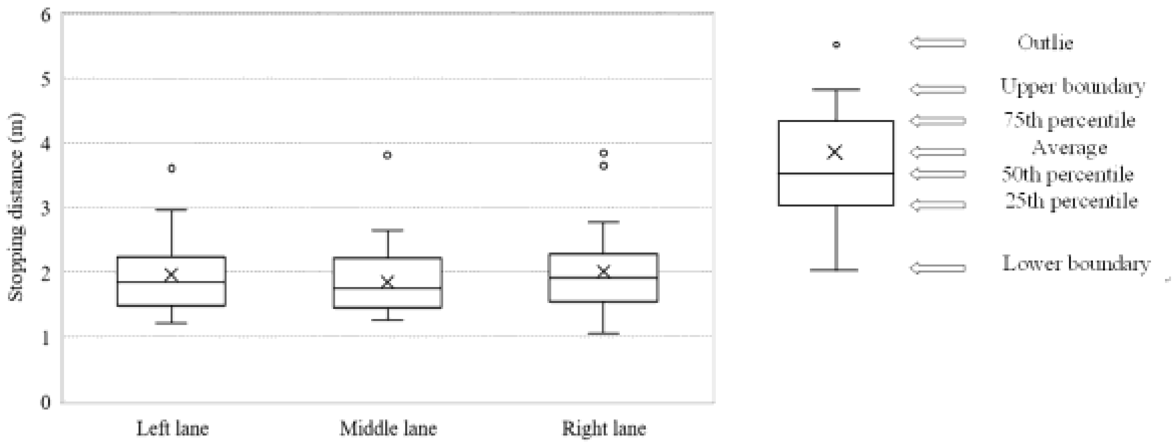

Figure 4 The stopping-distance distribution for the scenario of right vehicle moving forward first

In Figure 4, it was noticed that the stopping distances for the right vehicle (crossing the stop-line first) are distributed in 1~3m, and the average is approximate 2m. There is no obvious difference in stopping distance between the right vehicle and the other two corresponding vehicles.

Statistical analysis was performed using SPSS Statistics 23.0 where the confidence interval was set at 95%. The ANOVA test was used to determine whether there are differences in stopping distance, between the vehicle to cross the line first and the other two corresponding vehicles. The stoppingdistance differences of the three vehicles in the scenarios are shown in Table 1.

- For the left vehicle crossing first, the results show that there are statistically significant differences in stopping distance among the three vehicles (p=0.003). The post hoc tests present that there is a difference between the left and right vehicles (p=0.001), no differences between the left and middle vehicles (p=0.055) and between the middle and right vehicles. It should be noted that p value of 0.055 (between the left and the middle vehicles) is slightly larger than 0.05, so it is close to being statistically significant.

- For the middle vehicle going across first, the results show that there are statistically significant differences in stopping distance among the three vehicles (p=0.045). The post hoc tests present that there is a difference between the middle and left vehicles (p=0.020), no differences between the middle and right vehicles (p=0.053) and between the left and right vehicles. It should be noted that p value of 0.053 (between the middle and the right vehicles) is slightly larger than 0.05, so it is close to being statistically significant.
- For the right vehicle going across first, the results show that there are no differences in stopping distance among the three vehicles (p>0.05).

In summary, the differences in stopping distance between the vehicle passing the line first and the two corresponding vehicles exist. This indicates that there is a relation between moving forward the line first and stopping distance. Specifically, the 1st vehicle to cross the line tends to wait closer to the stop-line than others. This phenomenon appears in the left and middle lanes, not in the right lane. This might be due to the effects of distractions on the right vehicles, such as pedestrians or bicycles on the roadside.

Table 1. The stopping distance differences of the three vehicles in the three scenarios

		Mean Diff.	Std. Error	95% Confidence Interval		Sig.
				Lower Bound	Upper Bound	
L vehcrossing first(*P*=0.003)	Left-Middle	-0.309	0.160	-0.625	0.007	0.055
	Left-Right	-0.550	0.160	-0.866	-0.234	0.001
	Middle-Right	-0.241	0.160	-0.557	0.075	0.134
M veh crossing first(*P*=0.045)	Middle-Left	-0.277	0.118	-0.511	-0.045	0.020
	Middle-Right	-0.230	0.118	-0.463	0.003	0.053
	Left-Right	0.048	0.118	-0.185	0.281	0.685
R veh crossing first(*P*=0.866)	Right-Left	-0.062	0.117	-0.293	0.170	0.597
	Right-Middle	-0.024	0.117	-0.255	0.208	0.840
	Left-Middle	0.038	0.117	-0.193	0.270	0.743

The relationship between stopping distance and upstream velocity

The relationship between the stopping distance and upstream velocity was analyzed, for the 1st vehicle crossing the stop-line. In the south-north direction, it was observed that the 1st vehicles usually start decelerating approximate 30m behind the stop-line. Therefore, vehicle's upstream velocity was defined with the velocity in this location. Figures 5, 6 and 7 illustrate the link between stopping distance and upstream velocity for the vehicle passing the stop-line first, in the left lane, in the middle lane, and in the right lane.

In Figure 5, it was noticed that a negative non-linear relationship exists between stopping distance and upstream velocity, for the vehicle passing the stop-line first in the left lane. That is, the faster the upstream speed, the shorter the stopping distance. For the velocity-distance data, the R^2 value of 62.2% presents that the regression model fits the data pretty well. Meanwhile, the data can be roughly divided into two parts: the first one with distance of 0.5~2.5m, and the second one with distance of 2.5~3.5m. In the first part, most drivers might consciously make the decision to proceed through the stop-line first, at a distance more than 30m behind the stop-line. This can be called as a type of active choice. In the second part, drivers might make the decision to move forward first during waiting, or pass first to be unintentional. This belongs to passive selection. For vehicles passing the line first in the left lane, most drivers might be involved in active choice.

It should be noted that, the active choice can be considered to make the decision to cross the stop-line first at a distance longer than 30m behind the stop-line. This can provide enough time for drivers to consciously choose an appropriate stopping distance, which allows drivers to reach the intersection as quick as possible. The active choice should belong to a clearly purposive action. The passive choice can be considered to make the decision to move forward first during waiting, or move first to be unconscious.

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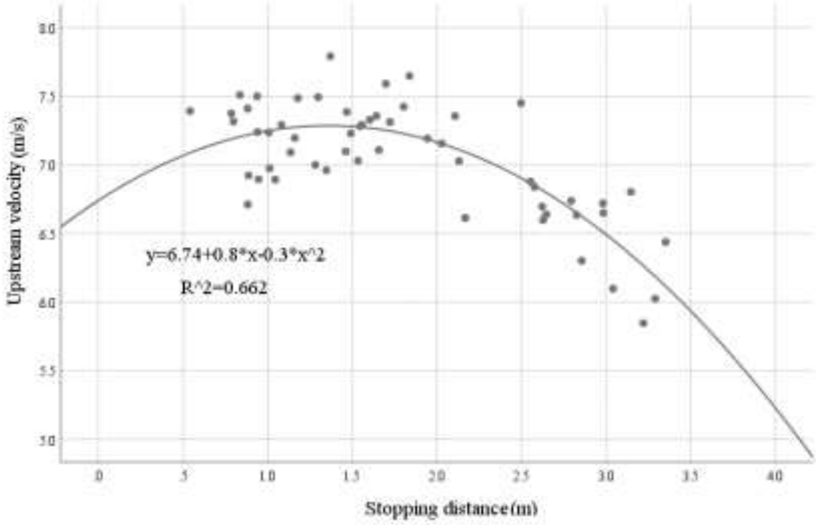

Figure 5 The relation between stopping distance and upstream velocity for the vehicle crossing the line first in the left lane

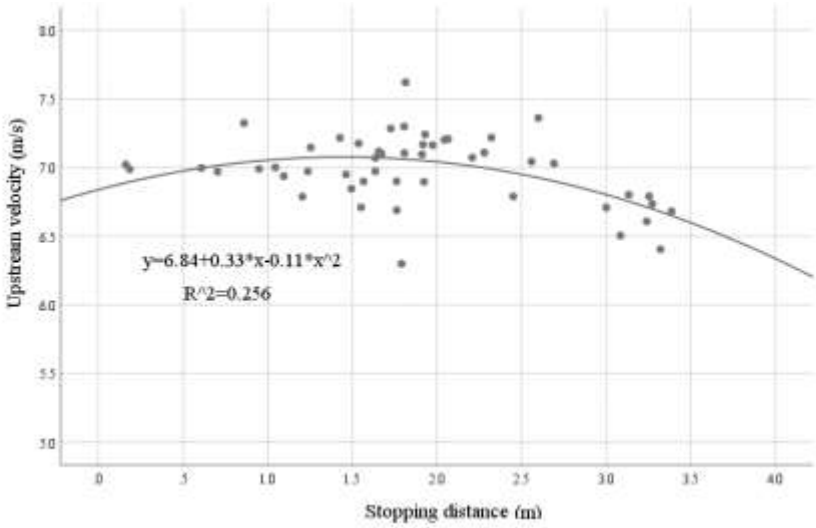

Figure 6 The relation between stopping distance and upstream velocity for the vehicle crossing the line first in the middle lane

In Figure 6, it was noticed that a negative non-linear relationship exists between stopping distance and upstream velocity, for the vehicle passing the stop-line first in the middle lane. The R^2 value of 25.6% reveals that the regression model seems to provide an inadequate fit to the data. While, the data can also be roughly divided into two parts: the first one with distance less than 3.0m, and the second one with distance longer than 3m. In the first part, most drivers might be involved in active choice. In the second part, most drivers might get involved in passive choice.

In Figures 5 and 6, it was noticed that the percentage of passive choice is higher in the left lane than in the middle lane. This result indicates that more drivers make the decision to move forward first during waiting, in the middle lane than in the left lane.

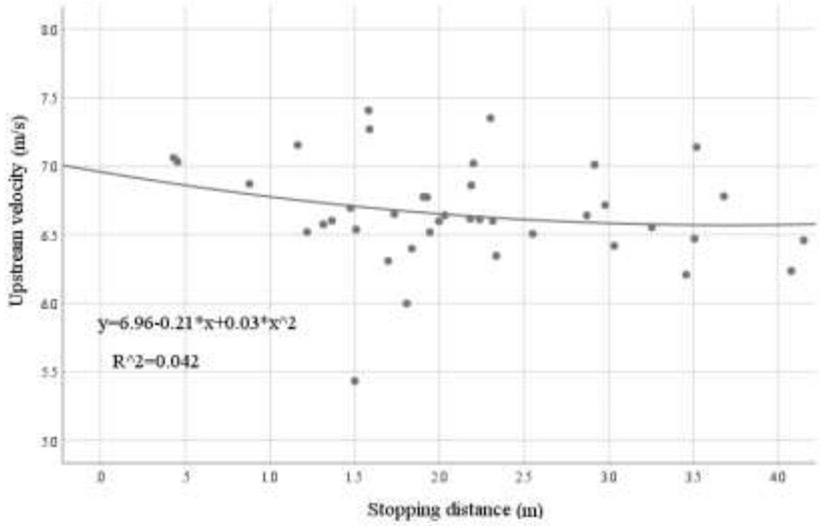

Figure 7The relation between stopping distance and upstream velocity for the vehicle crossing the line first in the right lane

In Figure 7, it was noticed that a correlation between stopping distance and upstream velocity seems not to exist, for the vehicle passing the stop-line first in the right lane. This might be because drivers in the right lane are more easily to be distracted by pedestrians or bicycles on the roadside.

4. CONCLUSION

This study identified the stopping distance distribution of through vehicles in a three-lane road at signalized intersections. By analyzing the differences in stopping distance in the three lanes, and the relationship between stopping distance and upstream velocity, the following conclusion can be drawn:
In the left and middle lanes, the stopping distance is shorter for the vehicle crossing the line first than for the two corresponding vehicles. This phenomenon does not show in the right lane.

In the left and middle lanes, there is a negative non-linear relationship between stopping distance and upstream velocity, for the vehicle moving forward the line first. The relationship does not appear in the right lane.
In the left and middle lanes, most drivers might make the decision to cross first at a distance longer than 30m behind the stop-line. There is a higher percentage in the middle lane than in the left lane.

The findings of this study can provide supporting evidence for developing traffic micro-simulation models, and can also be used for improving road safety and traffic efficiency at signalized intersections. Further study will focus on analyzing the speed characteristics of the vehicle reaching the intersection first.

This study identified the stopping distance distribution of through vehicles in a three-lane road at signalized intersections. By analyzing the differences in stopping distance in the three lanes, and the relationship between stopping distance and upstream velocity, the following conclusion can be drawn:

a) In the left and middle lanes, the stopping distance is shorter for the vehicle crossing the line first than for the two corresponding vehicles. This phenomenon does not show in the right lane.
b) In the left and middle lanes, there is a negative non-linear relationship between stopping distance and upstream velocity, for the vehicle moving forward the line first. The relationship does not appear in the right lane.
c) In the left and middle lanes, most drivers might make the decision to cross first at a distance longer than 30m behind the stop-line. There is a higher percentage in the middle lane than in the left lane.

The findings of this study can provide supporting evidence for developing traffic micro-simulation models, and can also be used for improving road safety and traffic efficiency at signalized intersections. Further study will focus on analyzing the speed characteristics of the vehicle reaching the intersection first.

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