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Research Article

Impact of Guideline Markings on Saturation Flow Rate at Signalized Intersections

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Many intersections around the world are irregular crossings where the approach and exit lanes are offset or the two roads cross at oblique angles. These irregular intersections often confuse drivers and greatly affect operational efficiency. Although guideline markings are recommended in many design manuals and codes on traffic signs and markings to address these problems, the effectiveness and application conditions are ambiguous. The research goal was to analyze the impact of guideline markings on the saturation flow rate at signalized intersections. An adjustment estimation model was established based on field data collected at 33 intersections in Shanghai, China. The proposed model was validated using a before–after case study. The underlying reasons for the impact of intersection guideline markings on the saturation flow rate are discussed. The results reveal that the improvement in the saturation flow rate obtained from painting guide line markings is positively correlated with the number of traffic lanes, offset of through movement, and turning angle of left-turns. On average, improvements of 7.0% and 10.3% can be obtained for through and left-turn movements, respectively.

1. Introduction

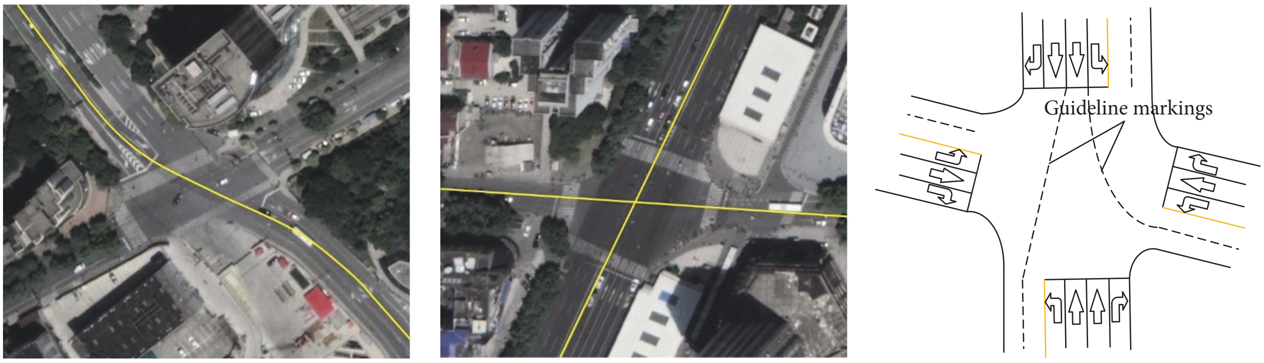
An intersection is a key point in addressing traffic problems in an urban road network [1]. Owing to several factors, such as limitations on land use, many intersections are irregular crossings where the approach and exit lanes are offset or the two roads cross at oblique angles, as shown in Figures 1(a) and 1(b), respectively. These irregular intersections can sometimes confuse drivers and lead to drivers hesitating. Thus, traffic efficiency can be adversely affected.

There are two common methods to solve these problems: intersection design and standardization of cross-road intersections and traffic channelization measures such as the traffic signs and markings shown in Figure 1(c) [2–4]. Many studies have shown that traffic signs and markings can be effectively used to regulate, warn, and guide road users [5–11]. At intersections, the MUTCD (Manual on Uniform Traffic Control Devices for Streets and Highways) describes the utilization of various traffic channelization measures such as intersection guideline markings [12]. In China, the application conditions and methods for intersection guideline markings are also set in the Chinese road traffic signs and marking codes [13, 14].

Although intersection guideline markings are recommended in many design manuals and codes on traffic signs and markings [12–14], the effectiveness and application conditions are ambiguous. This often causes traffic designers to subjectively rely on their own experience when deciding whether to utilize guideline markings.

The saturation flow rate is the basic metric used to determine the efficacy of intersection traffic design. It is an important input parameter, particularly with regard to signal timing and the evaluation of the operational efficiency of signalized intersections. In addition, saturation flow rate reflects the operational efficiency of vehicles and is the basis for calculating the capacity of signalized intersections.

To calculate the saturation flow rate more accurately, factors such as intersection geometry, traffic conditions, and signal control are taken into account to modify the basic saturation flow rate. Many countries formulate their Highway Capacity Manuals according to their particular circumstances, which result in different saturation flow rate



(a) Offset crossing (b) Oblique angled crossing (c) Guide line markings

Figure 1: Irregular intersections and guidelines.

adjustment factors. For example, the HCM2010 (Highway Capacity Manual 2010) [15] states that the following factors affect the saturation flow rate: lane width, heavy vehicles in traffic stream, approach grade, parking lane and parking activity adjacent to lane group, bus stop within intersection area, lane utilization in lane group, turning traffic in lane group, pedestrians crossing turning traffic, and area type, e.g., business district. Researchers have analyzed the impact of these factors on the saturation flow rate in detail.

With respect to geometric factors, Susilo et al. derived a modification of the saturation flow formula by taking into account different widths of approach lanes [16]. Shao et al. discovered that lane width, approach grade, and turning radius have a significant effect on the saturation flow rate of the left-turn lane. Adjustment factors for lane width and turn radius were developed accordingly [17]. Bargegol et al. established a relationship between the lane width and the saturation flow rate at far-side legs and near-side legs of signalized intersections [18]. Zhao et al. established a model to estimate the lane group capacity at signalized intersections with the consideration of the effects of access points. Two scenarios of access point locations, upstream or downstream of the signalized intersection, and impacts of six types of access traffic flow were taken into account [19]. Recently, with the application of unconventional intersections [20, 21], the saturation flow rate adjustment model for unconventional intersections was established based on field data [22–24].

With respect to traffic factors, Washburn et al. focused on the effects of trucks on queue discharge characteristics and established passenger car equivalency values for different truck sizes [25]. Chand et al. developed a dynamic Passenger Car Unit (PCU) equivalent for signalized intersections with heterogeneous traffic [26]. Preethi et al. proposed an adjustment factor to account for the influence of right turn traffic under homogeneous traffic conditions [27]. The impact of saturation flow rates on heterogeneous lanes with shared traffic movements (through movement and turning) was also analyzed [28, 29].

With respect to signal control factors, Radhakrishnan et al. highlighted the effect of vehicle type, lateral position on the roadway, and green time on the discharge headway. They proposed a discharge headway model which could be used to acquire saturation flow rates and capacity at signalized intersections [30]. Sharma et al. analyzed queue discharge characteristics at signalized intersections under heterogeneous traffic conditions and on the effect of a countdown timer on the headway distribution based on the data collected from two intersections in Chennai, India [31]. Tang et al. investigated the impact of green signal countdown devices and long cycle lengths on queue discharge patterns and discussed their implications for capacity estimation in the context of China's traffic [32].

Numerous studies have been performed with the primary objective of determining the factors that influence saturation flow rates at signalized intersections. However, few previously published reports have addressed the impact of guide line markings.

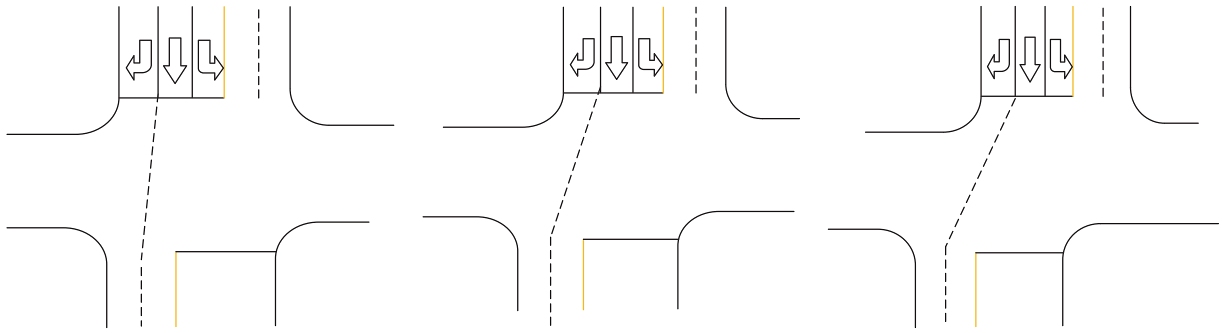
The research goal was to analyze the impact of guide line markings on the saturation flow rate at signalized intersections. An adjustment estimation model was established based on field data collected at 33 intersections in Shanghai, China. The model considered the traffic flow direction, number of traffic lanes, offset of through movement, and the turning angle of the left-turns. The proposed model was validated based on a before–after case study. The reasons for the impact of intersection guideline markings on the saturation flow rate are also discussed.

2. Data Collection

To analyze the impact of intersection guideline markings on saturation flow rate, control groups were established considering traffic flow direction, number of lanes, offset for through movement, and turning angle for left-turns. Based on these control groups, 33 intersections in downtown Shanghai were surveyed.

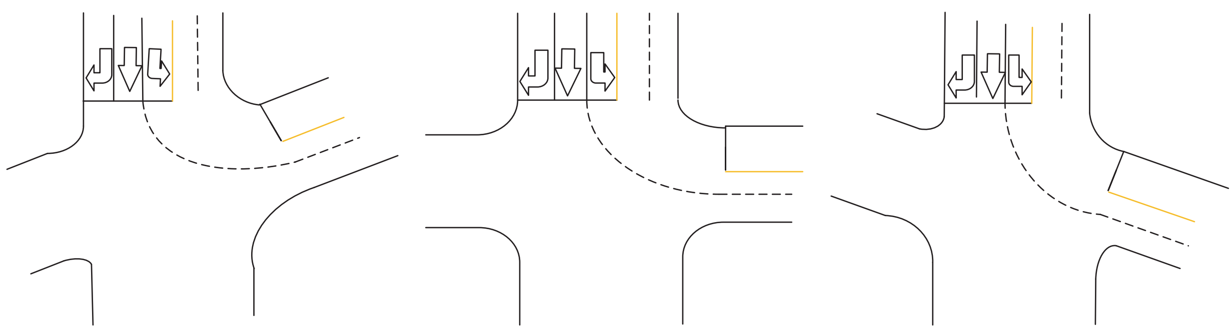
2.1. Potential Influencing Factors. The impact of intersection guideline markings on saturation flow rate could be affected by many factors. The following factors were considered:

(1) Traffic Flow Direction. At a signalized intersection, traffic flows in different directions have different saturation flow rates. Through movement and left-turn flows were taken into account.



(a) Small offset (b) Medium offset (c) Large offset

Figure 2: Through movement offset categories.



(a) Acute angle (b) Right angle (c) Obtuse angle

Figure 3: Left-turn angle categories.

(2) Number of Traffic Lanes. This study focused on three categories, namely, one, two, and three traffic lanes for through movement and left-turns.

(3) Through Movement Offset. Approach and exit lanes that are offset for through movement can make it difficult for drivers to judge the position of exit lanes. Comparing the difference in saturation flow rate between intersections with and without guideline markings under the same through movement offset is beneficial for determining the application conditions of intersection guide line markings. As shown in Figure 2, the offset of approach and exit lanes in through movement was classified into three classes: an offset of less than one lane width is a small offset, between one lane and two-lane widths is a medium offset, and more than two-lane widths is a large offset.

(4) Left-Turn Angle. The left-turn angle size greatly affects the driver's judgment, the vehicle's speed, and its moving trajectory. Painting intersection guideline markings in the left-turn lane can assist drivers in quickly identifying the exit lanes and thereby eliminate hesitation time. As shown in Figure 3, the left-turn angle was classified into three classes: acute angle, right angle, and obtuse angle.

2.2. Selection of Survey Locations. Considering traffic flow direction (2 types), number of lanes (3 types), offset for through movement (3 types), and turning angle for left-turns (3 types), eighteen control groups (9 for through movement and 9 for left-turns) were established. Alternative intersections were selected to identify the most appropriate lanes for data collection. The conditions which defined an appropriate intersection are as follows. Table 1 shows the 33 intersections that were surveyed in downtown Shanghai, China.

(1) The volume of traffic is large enough to ensure sufficient surveyed data.

(2) The grade of approach and exit lanes is less than 2%.

(3) Near the intersection, there are no access points, such as entrances or exits of schools, parking lots, supermarkets, etc.

(4) There are no work zones near the intersection that can potentially affect the judgment of drivers.

(5) For the same control group, only one of the influence factors should be different at a time for the candidate intersection.

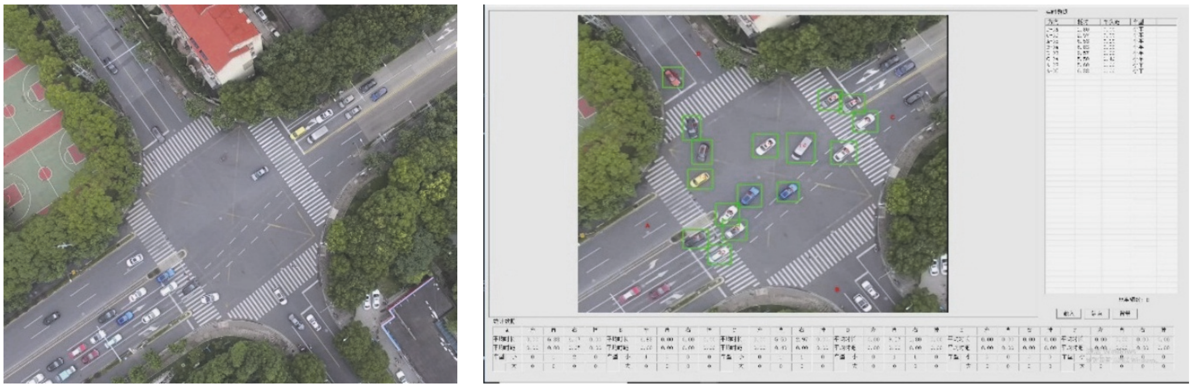
2.3. Survey Content and Method. The saturation flow rate can be calculated by (1). Headway data were collected under saturated conditions in three steps. First, traffic flow in the intersection was recorded using a UAV (unmanned aerial vehicle) during the morning or evening peak of the workday, as illustrated in Figure 4(a). Second, the trajectory of each vehicle was captured, and the time taken to pass through the stop line was recorded, as illustrated in Figure 4(b). Finally, the headways were calculated. The measurement method

Table 1: Survey locations with and without guideline markings.

Through movement						
	Offset					
Number of lanes	Small		Medium		Large	
	Without guidelines	With guidelines	Without guidelines	With guidelines	Without guidelines	With guidelines
One	Zhoujiazui Rd - Longchang Rd	Linshan Rd - Nanyangjing Rd	Guoshun Rd - Yingkou Rd	Jinke Rd - Zuchongzhi Rd	Jungong Rd - Changyang Rd	Jiangpu Rd - Kunming Rd
Two	Songhuajiang Rd - Yingkou Rd	Henan Rd - Beijing Rd	Changyang Rd - Linqing Rd	Jungong Rd - Changyang Rd	Zhoujiazui Rd - Huangxing Rd	Zhongshandong Rd - Yanan Rd
Three	Guoshun Rd - Huangxing Rd	Zhoujiazui Rd - Dalian Rd	Jungong Rd - Xiangying Rd	Haining Rd - Zhoujiazui Rd	Jinhai Rd - Jinke Rd	Henan Rd - Yanan Rd

Left-turn						
	Turning angle					
Number of lanes	Acute angle		Right angle		Obtuse angle	
	Without guidelines	With guidelines	Without guidelines	With guidelines	Without guidelines	With guidelines
One	Songhuajiang Rd - Yingkou Rd	Dongfang Rd - Lancun Rd	Jiangpu Rd - Kongjiang Rd	Huangpi Rd - Yanan Rd	Zhoujiazui Rd - Longchang Rd	Xizang Rd -Yanan Rd
Two	Dalian Rd - Zhoujiazui Rd	Henan Rd - Fuxing Rd	Siping Rd- Zhongshanbeier Rd	Haining Rd - Wusong Rd	Wenshui Rd - Quyang Rd	Dalian Rd - Kongjiang Rd
Three	Zhoujiazui Rd - Huangxing Rd	/	/	/	Songhu Rd - Zhayin Rd	Xujiahui Rd - Luban Rd

/ means that this kind of intersection is not found in Shanghai, China.



(a) Aerial view of intersection using UAV

(b) Image capturing of vehicle trajectory

FIGURE 4: Data collection.

recommended in HCM [15] is used. The headways can be measured directly, and then the saturation flow rate can be calculated. The headways of the first four cars at the start of the green phase were deleted. Only queued vehicles are recorded as useful data. Moreover, all the data related with the heavy vehicles were deleted, which includes the headways of the heavy vehicles and all the headways of the vehicles following the heavy vehicles. The relevant statements have been added in the revised paper. The number of the surveyed hours, useful cycles, and useful vehicles in each case are listed in Table 2:

$$S = 3600/h_s \quad (1)$$

where S is the saturation flow rate of an entrance lane, veh/h/ln; and h_s is the saturation headway, s.

3. Saturation Flow Rate Analysis

In this section, the saturation flow rate of through movement and left-turns is studied based on the collected data and control groups. Firstly, the distribution of saturation headways is investigated. Subsequently, the adjustment factor model is established for quantitative analysis of the effect of guideline markings.

3.1. Calculation of the Headway. By separating through movement and left-turns, the headway of each cycle under different conditions is calculated, and the distribution histogram of the headways is obtained. The corresponding trend line is then fitted for a comparison between the intersections in the control groups. In the comparison graphs, the further the curve is to the left, the smaller the saturation headway and the higher the saturation flow rate are.

3.1.1. Through Movement. The results of the comparison of through movement saturation headways are shown in Figure 5. By controlling the offset or the number of traffic lanes, the trend of the difference in the saturation flow rate offset is investigated, and qualitative analysis is performed on the impact of intersection guideline markings on the saturation flow rate. One can observe the following.

(1) In every control group, the saturation headway of an intersection with guideline markings is smaller compared to intersections without guide line markings.

(2) Apart from the control group with a single lane and small offset, there is a noticeable difference in saturation headways between intersections with and without guideline markings.

(3) The greater the offset, the more pronounced the effect of the guide line markings on the saturation flow rate.

(4) The larger the number of lanes, the more pronounced the effect of the guide line markings on the saturation flow rate.

3.1.2. Left Turn. The method of analysis for left-turn traffic is the same as that for through movement. However, for left-turns, the trend of the difference in the saturation flow rate is investigated by controlling the left-turn angle or number of traffic lanes. The results of the comparison are shown in Figure 6. The following can be seen.

(1) Setting guideline markings can improve the saturation flow rate irrespective of the turning angle.

(2) The greater the number of left-turn traffic lanes, the more pronounced the effect of the guide line markings on the saturation flow rate.

(3) The smaller the left-turn angle, the more pronounced the effect of the guideline markings on the saturation flow rate.

3.2. Calculation of the Adjustment Factor. Referring to the adjusted saturation flow rate model of HCM 2010 [15], the ratio of the saturation flow rate at an intersection with guideline markings to an intersection without guide line markings can be defined as the adjustment factor for guide line markings, as shown in (2). By studying the relationship between the adjustment factor and other factors, including the traffic flow direction, number of lanes, offset for through movement, and turning angle for left-turns, the model can be adapted to determine the adjustment factor for guide line markings under different conditions:

$$f_{gl} = \frac{S_0}{S} \quad (2)$$

Table 2: Surveyed data.

Movement	Number of lanes	Offset/Turning angle	Guidelines	Surveyed hours	Useful cycles	Useful vehicles
Through	One	Small offset	Without	1	11	214
Through	One	Small offset	With	1	11	214
Through	One	Medium offset	Without	1	11	282
Through	One	Medium offset	With	1	18	177
Through	One	Large offset	Without	1	11	114
Through	One	Large offset	With	1	18	177
Through	Two	Small offset	Without	1	24	633
Through	Two	Small offset	With	1	9	161
Through	Two	Medium offset	Without	1	9	232
Through	Two	Medium offset	With	1	10	91
Through	Two	Large offset	Without	1	13	364
Through	Two	Large offset	With	1	8	217
Through	Three	Small offset	Without	1	8	659
Through	Three	Small offset	With	1	7	378
Through	Three	Medium offset	Without	1	11	296
Through	Three	Medium offset	With	1	8	458
Through	Three	Large offset	Without	1	7	195
Through	Three	Large offset	With	1	8	400
Left-turn	One	Acute angle	Without	1	19	133
Left-turn	One	Acute angle	With	1	16	83
Left-turn	One	Right angle	Without	1	13	252
Left-turn	One	Right angle	With	1	7	94
Left-turn	One	Obtuse angle	Without	1	8	76
Left-turn	One	Obtuse angle	With	1	16	180
Left-turn	Two	Acute angle	Without	1	13	240
Left-turn	Two	Acute angle	With	1	8	158
Left-turn	Two	Right angle	Without	1	10	206
Left-turn	Two	Right angle	With	1	7	251
Left-turn	Two	Obtuse angle	Without	1	15	163
Left-turn	Two	Obtuse angle	With	1	12	569
Left-turn	Three	Acute angle	Without	1	10	479
Left-turn	Three	Obtuse angle	Without	1	15	671
Left-turn	Three	Obtuse angle	With	1	7	233
Sum				33	378	9050

where S is the saturation flow rate per lane at a signalized intersection with guideline markings, veh/h/ln; S_0 is the saturation flow rate per lane at a signalized intersection without guideline markings, veh/h/ln; and f_{gl} is the adjustment factor for the guideline markings.

3.2.1. Through Movement. Small, medium, and large offsets are defined as offset 1, 2, and 3, respectively. As shown in Figure 7, the saturation headway of an intersection with guideline markings is always less than the saturation headway of an intersection without guideline markings. On average, improvements of 7.0% can be obtained for through movement.

Multifactor analysis of variance was performed to investigate whether the guideline markings, number of traffic lanes, offset and the interaction of these factors have a significant influence on the saturation flow rate. The results are shown in Table 3 and reveal that guideline markings, number of traffic lanes, offset, and these factors combined have a significant influence on the saturation flow rate (p-value < 0.001).

Calculated values of the adjustment factor for guideline markings under different conditions are listed in Table 4. It was determined that with an increase in offset and number of traffic lanes, the adjustment factor value also increases. To estimate the adjustment factor value for guideline markings under different conditions for a given offset and number of traffic lanes, an adjustment factor model for through movement is established by surface fitting according to the measured adjustment factor values, as given by (3). The goodness of fit (R^2) is 0.970:

$$f_{gl}^{T} = 0.9818 + 0.01918d - 0.004593n - 0.002431d^2 + 0.001233dn + 0.01399n^2 \quad (3)$$

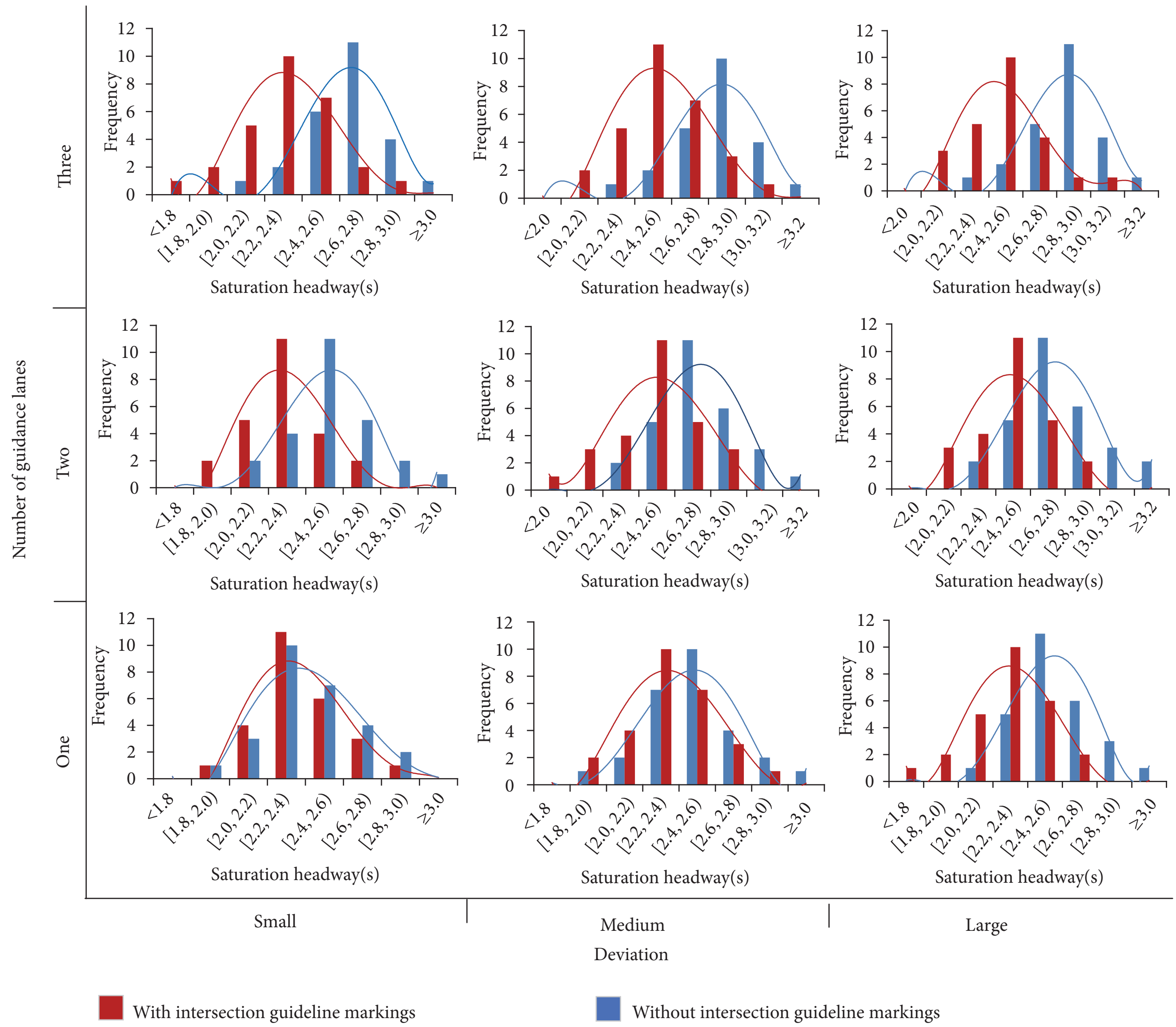


Figure 5: Comparison of through movement headways with and without guideline markings.

Table 3: Multifactor analysis of variance for through movement.

Source	Sum of Squares	df	Mean Square	F	Sig.
Offset	0.394	2	0.197	87.166	0.000
Number of traffic lanes	0.582	2	0.291	128.841	0.000
Intersection guideline markings	0.387	1	0.387	171.280	0.000
Offset ∗ Number of traffic lanes ∗ Intersection guideline markings	0.170	12	0.014	6.275	0.000

where f_{gl}^{T} is the adjustment factor for guide line markings; d is the offset, (d = 1, 2, and 3 for small, medium, and large offsets, respectively); and n is the number of traffic lanes.

3.2.2. Left Turn. The effect of guideline markings on the saturation flow rate for left-turns is quantitatively analyzed in the same manner as for through movement. The acute, right, and obtuse angles are defined as angle 1, 2, and 3,

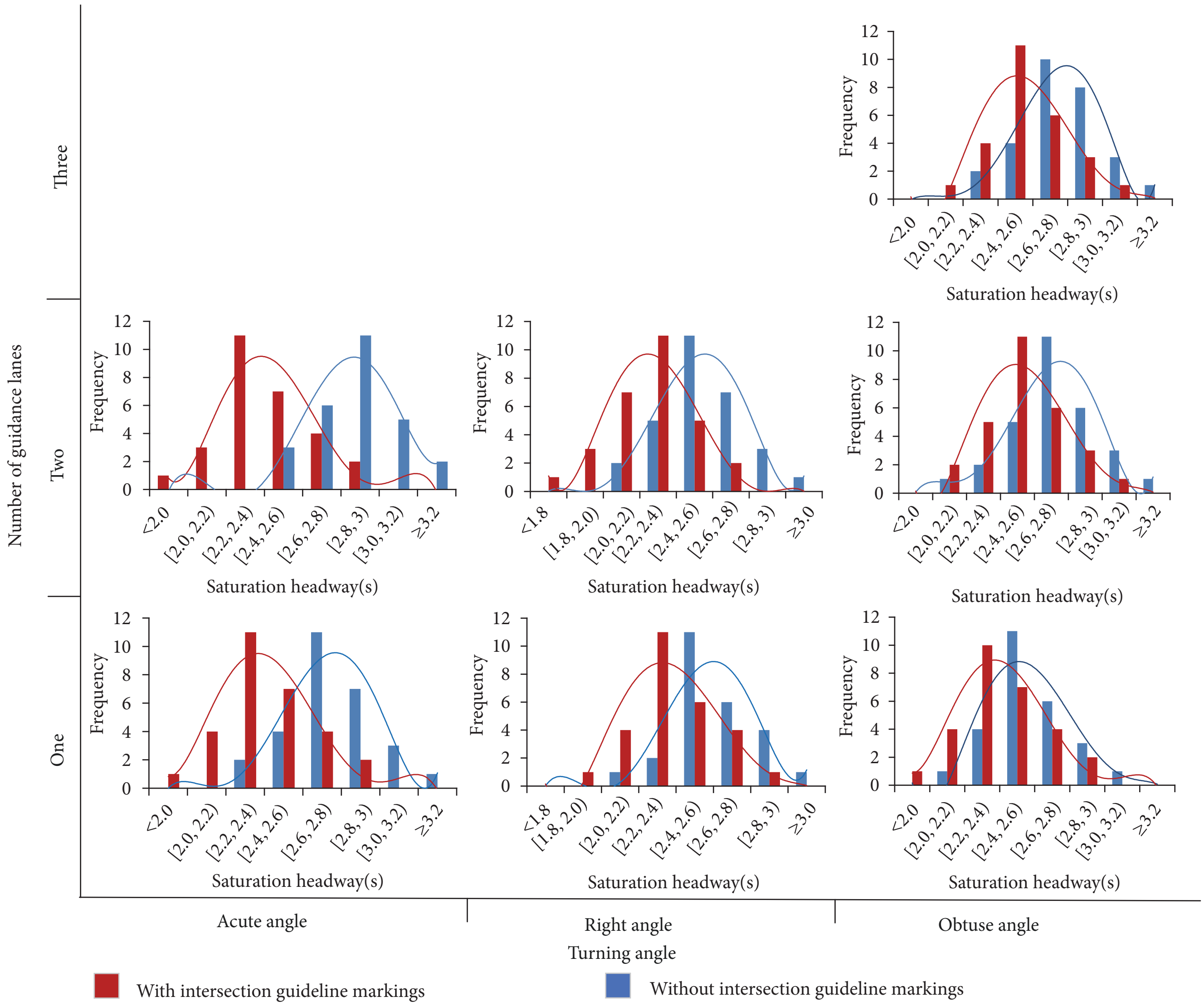


Figure 6: Comparison of left-turn headways with and without guideline markings.

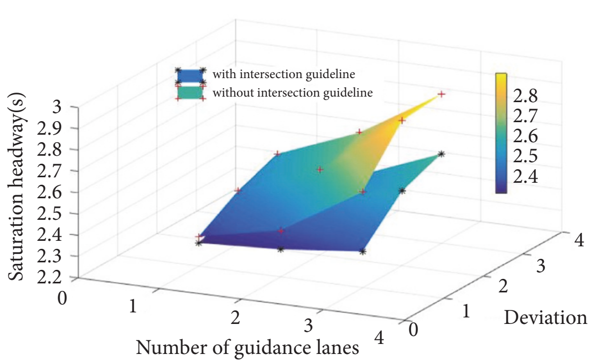


Figure 7: Comparison of saturation headways for through movement.

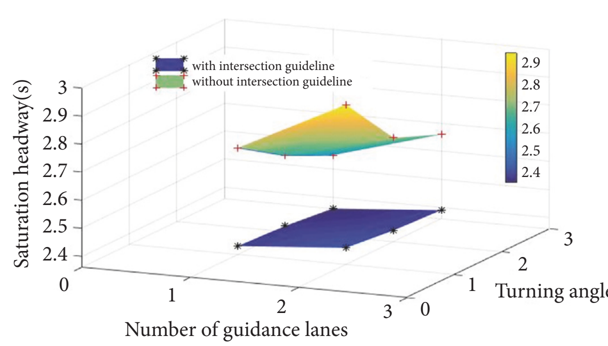
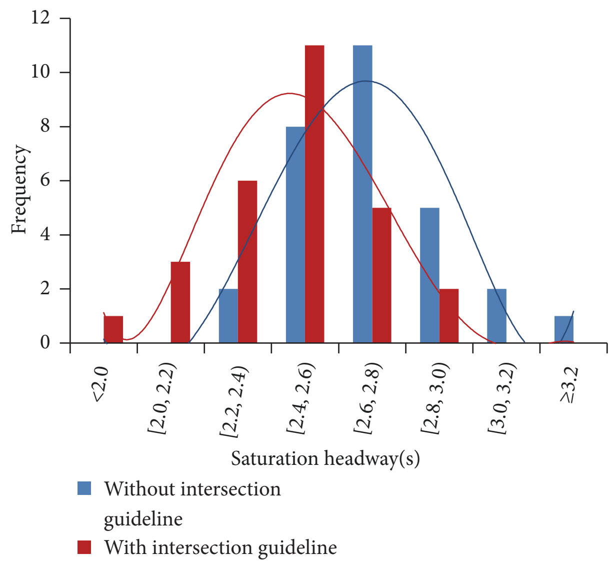


Figure 8: Comparison of saturation headways for left-turns.

respectively. As shown in Figure 8, the saturation headway of an intersection with guideline markings is always less than the saturation headway of an intersection without guide line markings. On average, improvements of 10.3% can be obtained for left-turns. The results of the multifactor analysis

(a) Before (no guideline markings)

(b) After (with guideline markings)



(c) Comparison of saturation headways with and without guideline markings

Figure 9: Mingsheng Rd. and Lingshan Rd. intersection.

Table 4: Adjustment factor values of guideline markings for through movement.

Number of traffic lanes	Offset		
	Small	Medium	Large
1	1.014292	1.020304	1.027451
2	1.038911	1.063478	1.079167
3	1.118143	1.130612	1.136235

of variance in Table 5 show that guideline markings, number of traffic lanes, turning angle, and the interaction of these factors have a significant influence on the saturation flow rate of left-turns.

Calculated values of the adjustment factor for guideline markings under different condition are listed in Table 6. It was determined that with an increase in the number of traffic lanes, the adjustment factor value also increases. However, with the increase in turning angle, the adjustment factor value decreases. The adjustment factor model for left-turns is then established by surface fitting according to the measured adjustment factor for guideline markings, as given by (4). The goodness of fit (R2) is 0.9674.

$$f_{gl}^{L} = 1.148 - 0.07433t + 0.07672n + 0.0151t^2 - 0.01842tn + 0.001169n^2 \quad (4)$$

where f_{gl}^{L} is the adjustment factor for guide line markings; t is the turning angle (t = 1, 2, and 3 for acute, right, and obtuse angles, respectively); and n is the number of traffic lanes.

4. Model Validation

The proposed model was further validated based on a before–after comparative analysis. The intersection of Mingsheng Rd. and Lingshan Rd. in Shanghai, China, was used, as shown in Figures 9(a) and 9(b). Through movement in the south-north direction has medium offset. The saturation headways of southbound and northbound through movement under before (without guideline markings) and after conditions (with guideline markings) were compared, as shown in Figure 9(c). Based on the number of traffic lanes (2

Table 5: Multifactor analysis of variance for left-turns.

Source	Sum of Squares	df	Mean Square	F	sig
Turning angle	0.098	2	0.049	391.781	0.000
Number of traffic lanes	0.225	2	0.112	902.585	0.000
Intersection guideline markings	1.054	1	1.054	8467.279	0.000
Offset ∗ Number of traffic lanes ∗ Intersection guideline markings	0.093	9	0.010	83.036	0.000

Table 6: Adjustment factor values of guideline markings for left-turns.

Number of traffic lanes	Turning angle		
	Acute angle	Right angle	Obtuse angle
1	1.145957	1.105042	1.081278
2	1.212121	1.139738	1.110612
3	/	/	1.135758

/ means that the value is unavailable owing to lack of surveyed data.

Table 7: Result of significant difference (Mann-Whitney test).

Indicator	Value
Mann-Whitney U	7.000
Wilcoxon W	8.000
Z	-0.498
Asymptotic significance (2-sided)	0.619
Precision significance (2-sided)	0.762

lanes) and offset (medium), the adjustment factor value for guideline markings of through movement was calculated as 1.062.

To verify the accuracy of the adjustment factor model, the difference between the calculated and measured saturation flow rates of each cycle was analyzed using the Mann-Whitney nonparametric test for two independent samples. As shown in Table 7, there is no statistically significant difference between the calculated and measured saturation flow rates of each cycle (p-value = 0.762 > 0.05). Therefore, the accuracy of the adjustment factor model is acceptable.

5. Discussion

An irregular intersection could cause difficulty for a driver to identify appropriate exit lanes. Therefore, a vehicle may interfere with other lanes, leading to a decrease in saturation flow rate. The relationship between the adjustment factor for guide line markings and the ratio of the degree of interference at intersections with guideline markings to those without guideline markings is analyzed in this section.

The degree of interference is defined as the ratio of the number of vehicles which do not enter the corresponding exit lanes to the number of all vehicles in that direction. As shown in Figure 10, the cars that move along the red tracks are the interference cars that do not enter the corresponding exit lanes.

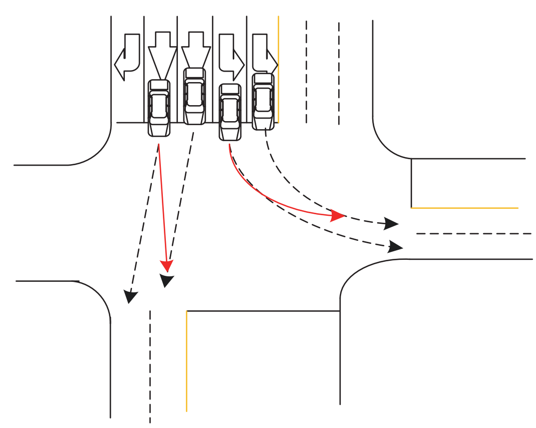


Figure 10: Interference vehicles.

Calculated values for the degree of interference at different intersections for through movement and left-turns are listed in Tables 8 and 9, respectively. On average, 45.4% and 49.6% interference can be eliminated for through and left-turn movements, respectively.

The correlation between the adjustment factor for guideline markings and the ratio of the degree of interference at intersections with and without guideline markings was analyzed using the Pearson correlation test (see Table 10). The results prove that there is a statistically significant correlation between the adjustment factor for guideline markings and the ratio of the degree of interference for both through movement and left-turns (p-value = 0.017 < 0.05 for through movement and p-value = 0.01 < 0.05 for left-turns). Therefore,

Table 8: Degree of interference for through movement.

Number of lanes	Offset	Guidelines	Degree of interference	Ratio of interference
2	Small	With	0.208	0.506
		Without	0.411	
3	Small	With	0.271	0.536
		Without	0.506	
2	Medium	With	0.236	0.518
		Without	0.456	
3	Medium	With	0.31	0.585
		Without	0.53	
2	Large	With	0.28	0.526
		Without	0.532	
3	Large	With	0.342	0.605
		Without	0.565	

Table 9: Degree of interference for left-turns.

Number of lanes	Turning angle	Guidelines	Degree of interference	Ratio of interference
2	Acute angle	With	0.24	0.549
		without	0.439	
3	Acute angle	With	/	/
		without	0.389	
2	Right angle	With	0.174	0.511
		without	0.341	
3	Right angle	With	/	/
		without	/	
2	Obtuse angle	With	0.153	0.484
		without	0.316	
3	Obtuse angle	With	0.24	0.504
		without	0.476	

/ means that the value is unavailable owing to the lack of surveyed data.

Table 10: Correlation analysis.

Movement			Adjustment factor	Ratio of interference
Through movement	Adjustment factor	Pearson correlation	1	0.891*
		sig.(2-tailed)		0.017
		N	6	6
	Ratio of interference	Pearson correlation	0.891*	1
		sig.(2-tailed)	0.017	
		N	6	6
Left-turn	Adjustment factor	Pearson correlation	1	0.990*
		sig.(2-tailed)		0.01
		N	4	4
	Ratio of interference	Pearson correlation	0.990*	1
		sig.(2-tailed)	0.01	
		N	4	4

painting guideline markings can minimize the interference and improve the saturation flow rate.

6. Conclusion

Painting guideline markings have become an important way to deal with traffic problems caused by intersection geometries where the approach and exit lanes are offset or cross at oblique angles. This study investigated the influence of guideline markings on the saturation flow rate at signalized intersections. An adjustment estimation model was developed based on field data collected at 33 intersections in Shanghai, China. From the analysis, the following conclusions can be drawn.

(1) Painting guideline markings can improve the saturation flow rate at signalized intersections. The improvement has a positive correlation with the number of traffic lanes, offset of through movement, and turning angle of left-turns. On average, improvements of 7.0% and 10.3% can be obtained for through and left-turn movements, respectively.

(2) The proposed model was validated on the basis of a before–after case study. Nonparametric test results show that no statistically significant difference exists between the results estimated by the proposed model and those obtained from the field survey, which confirms the accuracy of the proposed model.

(3) There is a positive correlation between the adjustment factor for guideline markings and the ratio of the degree of interference at the intersection with and without guideline markings, which explains why guideline markings can minimize the interference at irregular intersections. On average, 45.4% and 49.6% of the interference between the lanes at the same approach can be eliminated for through and left-turn movements, respectively.

This investigation only focused on the influence of guide line markings. In a future study, other traffic channelization measures such as the influence of traffic islands on the saturation flow rate may be investigated. Moreover, considering the impact of pedestrians and bicycles, the effectiveness of guideline markings to separate vehicles into different lanes and for separating vehicles and bicycles should be analyzed simultaneously.

Data Availability

The saturation headway data used to support the findings of this study are included within the supplementary information file(s) available here.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

The supplementary materials are the original data of the saturation headways for left-turn and through movement at each surveyed intersection. *(Supplementary Materials)*

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