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Determination and Utilization of Dilemma Zone Length and Location for Safety Assessment of Rural High-Speed Signalized Intersections

Min-Wook Kang[1], Moynur Rahman[1], and Joyoung Lee[2]

Abstract

The objective of the present study is to see how the dilemma zone length and location are related to intersection safety at rural high-speed signalized intersections. For that, dilemma zones at 30 rural signalized intersection approaches where similar traffic operations and land-use conditions are present were identified, and traffic conflicts associated with the dilemma zones were investigated. Drivers' stop or go behaviors as well as vehicle dynamics (e.g., vehicle speeds and locations) during the yellow and red clearance intervals were collected and analyzed to determine the dilemma zone length and location of each site. Red-light running violations and vehicles' abrupt stops were also collected to investigate the relationship between such conflicts and dilemma zone length and location. As a result, two dilemma zone conflict models were developed. The analysis results show that the conflict models are accurate enough to predict the safety level of high-speed signalized intersections using the two dilemma zone variables. Results show that the chance of intersection angle conflicts increases if the dilemma zone is located farther from the intersection stop bar. Results also show that there would be a high chance of rear-end conflicts if the dilemma zone length is longer. The models were validated with additional datasets, and acceptable root means square error and mean absolute percentage error values were obtained as a result.

Intersections are one of the major traffic safety challenges to road users. About 40% of the total crashes in the U.S. occur at intersections (*1*). A recent report published by the Center for Advanced Public Safety (CAPS) in Alabama also showed that 56% of all crashes in the state occurred at intersections (*2*). Particularly at intersections operated with traffic signals, drivers' misjudgment in response to signals largely contributes to severe crashes (*1*).

Dilemma zone (Type II) is an area prior to the intersection stop bar where it may be difficult for a driver, when faced with a yellow indication, to decide whether to stop or proceed through an intersection before the traffic signal turns to a red indication (see Figure 1) (*3*). In a dilemma zone situation, stopping increases the risk of rear-end crashes whereas proceeding increases the risk of angle crashes (*4*). According to a study by Federal Highway Administration (FHWA), intersection angle and rear-end crashes (typically classified as dilemma zone crashes) account for 47% and 6% of fatal intersection crashes in the U.S., respectively (*5*, *6*).

The dilemma zone issue is more serious at a high-speed signalized intersection because it has greater variability in operating speeds and greater potential for serious crashes (*7*). As vehicle speeds at an intersection approach increase, the severity of the crashes also increases. Furthermore, crashes involving heavy vehicles are more likely to result in fatal outcomes. Thus, the dilemma zone is a key safety issue that needs to be addressed with a high priority to improve intersection safety.

Theoretically, it is possible to eliminate the dilemma zone if all vehicles drive at a constant speed and behave identically in response to traffic signals. However, because of the stochastic nature of human behavior, the dilemma zone always exists at every yellow interval, regardless of using the appropriate length of the yellow interval calculated based on operating speeds (*8*, *9*).

[1]Department of Civil, Coastal, & Environmental Engineering, University of South Alabama, Mobile, AL
[2]Department of Civil & Environmental Engineering, New Jersey Institute of Technology, Newark, NJ

Corresponding Author:
Min-Wook Kang, mwkang@southalabama.edu

Furthermore, the length and location of the dilemma zone vary with numerous factors, including operational characteristics of individual vehicles in the traffic stream, drivers' aggressiveness, and intersection design components (*10*). In this context, the present study adopted the Type II dilemma zone concept and used it to measure dilemma zone length and location at high-speed signalized intersections. Note that there are two different types of dilemma zones in transportation literature, called Type I and Type II. Type I dilemma zone was first defined by Gazis et al. in 1960 (*3*). The Type I dilemma zone is defined as an area prior to the intersection stop bar where drivers neither safely stop nor proceed to the intersection before the end of yellow indication (*3*, *4*). The Type I dilemma zone concept seems simple; however, it is difficult to measure in the field, as vehicle speed and decision to stop or go at the intersection vary from person to person. Traffic engineers thus typically assume a constant (operating) speed to determine Type I dilemma zone with vehicle's stopping sight distance and travel distance during the yellow time. To remove such an unrealistic aspect of measuring Type I dilemma zone, the Type II dilemma zone concept was proposed in 1974 in the technical report from the Institute of Traffic Engineers (ITE) (*11*), and has been extensively used for intersection safety and traffic operation research since then (*4, 7, 8, 10–13*). Figure 1 describes the Type II dilemma zone, and its definition was defined earlier.

The objective of the present study is to see how the dilemma zone length and location are related to intersection safety at rural high-speed signalized intersections. Below are two hypotheses that motivated the present study. The present study seeks to answer the hypotheses and examine how the dilemma zone length and location are related to intersection safety.

- If the dilemma zone length is longer, there would be more variations in drivers' decision to stop or go during the yellow interval. As a result, there would be a high chance of rear-end conflicts.
- If the dilemma zone is located farther from the intersection stop bar, there would be a high chance that a driver makes a red-light running (RLR) violation, passing the stop bar after (or at the time when) the signal turns to a red indication. As such, there would be a high chance of intersection angle conflicts.

The organization of the present study is as follows. After the introductory discussion of the dilemma, the next section discusses sites selected for the present study. Site selection criteria and characteristics of selected high-speed signalized intersections are discussed. Following this, data collection and analysis are discussed; how driver behavior data were collected and used to analyze dilemma zone length and location are discussed. The next section discusses the dilemma zone conflict models developed in the present study, which include (i) angle conflict and (ii) rear-end conflict models. The final section summarizes the overall research work with study limitations and future work.

Rural High-Speed, High-Risk Signalized Intersections

The present study employed 10-year Alabama police-reported crash data (for a period from 2006 to 2015) to identify high-risk signalized intersections in the state in which dilemma zone crashes were an issue. The Critical Analysis Reporting Environment (CARE 10) software program by CAPS was used in the study to narrow down a search for dilemma zone crashes, such as angle and

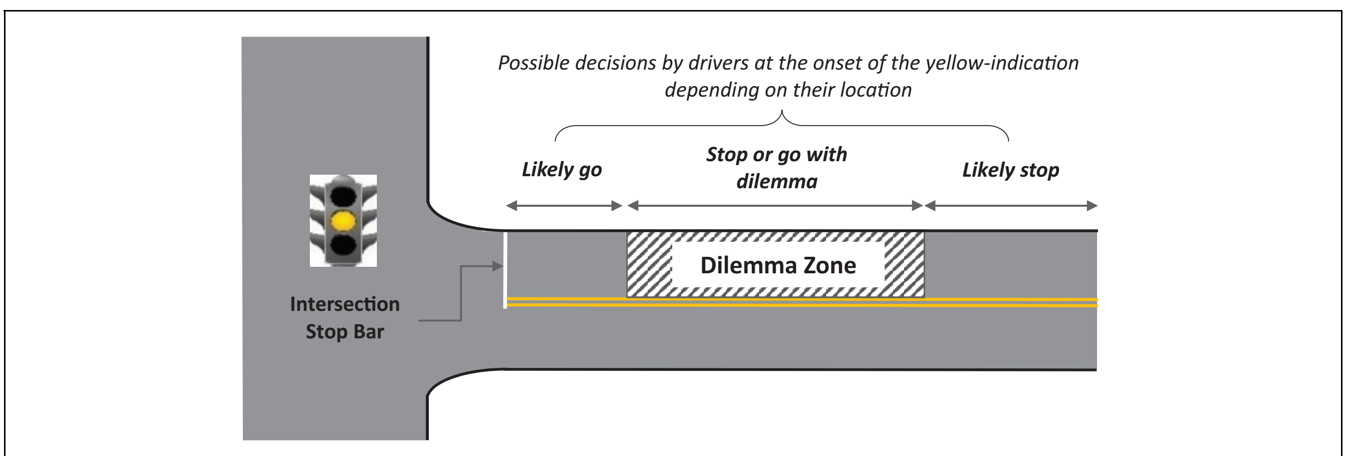

Figure 1. Illustration of a Type II dilemma zone at a signalized intersection.

rear-end crashes (*14*). Crashes caused by defective vehicles, signals, and roadways as well as by weather, drowsy driving, and DUI were excluded in the analysis. As a result, 100 high-risk signalized intersections were identified across the state. The study focus then moved to driver behavior data collection at high-speed signalized intersections in rural Alabama. For that, 15 four-legged intersections that satisfy the following criteria were selected:

- Listed in the high-risk signalized intersections identified through the crash analysis;
- Located in rural areas;
- Located on high-speed roads with the posted speed limit of 50 mph or higher;
- Located on freight routes in Alabama;
- Located on multi-lane highways
- Located on divided highways;
- Located on federal or state highways; and
- No red-light cameras on intersection approaches.

The geographical locations of the 15 selected intersections are shown in Figure 2. Note that urban signalized intersections were not considered in the present study because there would be many other extraneous factors (e.g., the number and location of driveways within an intersection functional area, sight distance, and signal coordination) besides dilemma zone length and location that could significantly contribute angle and rear-end conflicts.

An extensive field observation was made to collect site-specific information for the 15 selected intersections. Note that the field observation was conducted within the intersection functional area, which extends the intersection physical area to include auxiliary lanes and associated intersection channelization (*15*). Site-specific information collected in this stage included, but was not limited to:

- Intersection configuration, such as width, the number of approaches, the number of lanes per approach, lane width, approach grade, and queue-storage distance;
- Signal phase, timing, and controller information;
- Posted speed limits and other traffic control devices;
- Land use near the intersection;
- Location of roadside signs and utility posts; and
- Distance to adjacent signalized intersections.

Table 1 shows site-specific information of the 15 high-speed, high-risk signalized intersections selected for driver behavior data collection and analysis. The present study focused only on the major road approaches at the

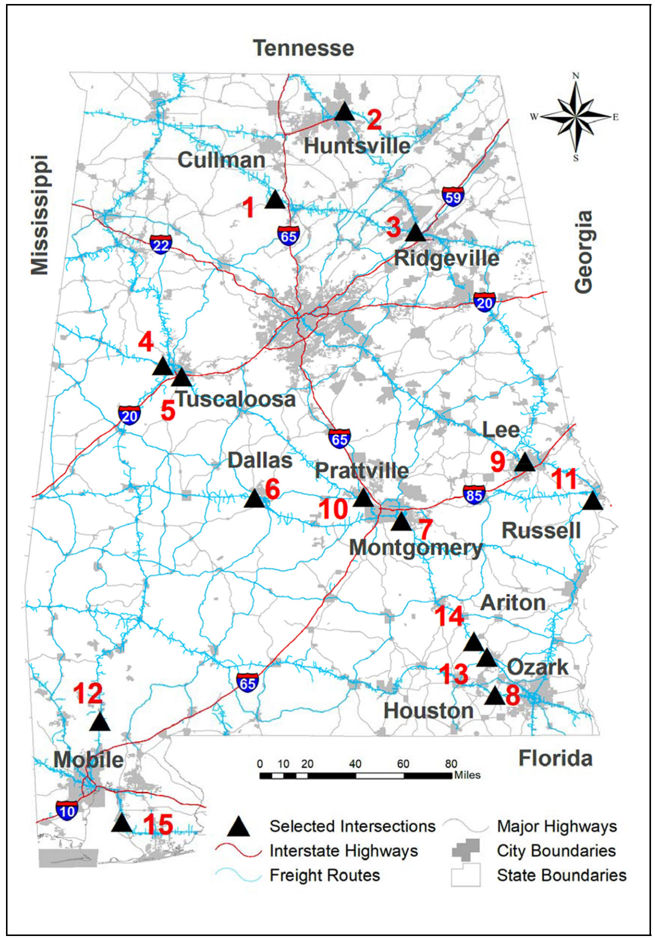

Figure 2. Geographical location of signalized intersections selected for the dilemma zone study.

intersections, and thus in total 30 intersection approaches were investigated. Note that the availability of roadside signs and utility posts to mount data collection units was also considered when selecting the sites in addition to the major site selection criteria discussed earlier.

Data Collection and Analysis

Driver Behavior Data Collection

There are two methods available in the transportation literature to measure the Type II dilemma zone at signalized intersections. The first was proposed by Chang et al. (*16*), in which a vehicle's operating speed plays an important role to identify the dilemma zone location, calculated based on 2.5–5.5 s of the estimated time of vehicle arrival to the intersection stop bar with that speed. This method is easy to use, and thus many states and federal agencies use it. However, it is solely based on operating speeds and does not fully take account of the site-specific conditions of an intersection, such as approach grade,

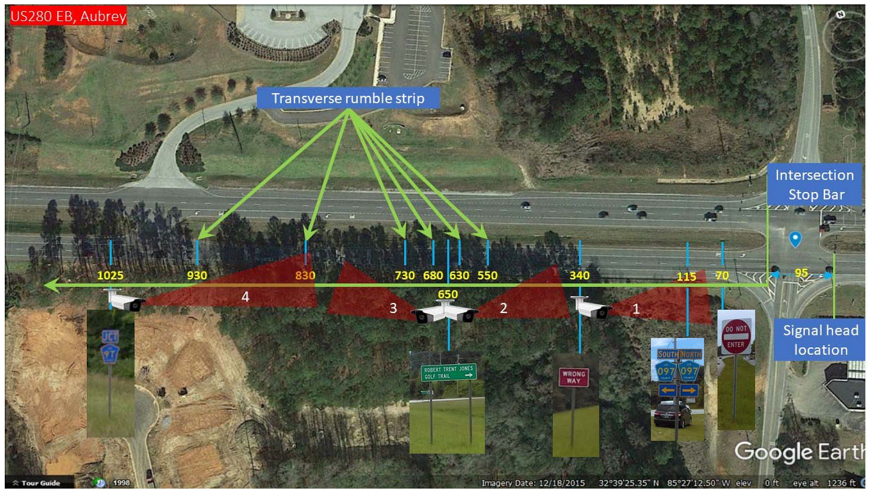

Figure 3. Video sensor installation layout and existing references to capture driver behavior data.

and traffic mix and drivers' aggressiveness changing by time of day.

The second method is a probabilistic approach proposed by Zegeer and Deen, in which the dilemma zone is determined based on actual decisions made by drivers in response to a yellow indication at a time when they approach a signalized intersection (*17*). In this method, the Type II dilemma zone is defined as an area prior to the intersection stop bar, measured between locations where 90% of drivers go and 90% of drivers stop at the onset of the yellow indication (*17*). Zegeer's method is superior to Chang's method (in relation to understanding the stochastic nature of driver behavior) as it considers relevant site-specific conditions (e.g., approach grade, sight distance, traffic, and traffic mix) that possibly affect drivers' decision to stop or go in a dilemma zone situation.

The present study adopted the Zegeer and Deen's method to measure the Type II dilemma zone at the 30 selected intersection approaches. A series of four high-definition video sensors were installed upstream of each intersection approach to collect seamless video data. Figure 3 shows the layout of video sensors used in the data collection, which covered up to 1,000 ft upstream of the intersection stop bar. Note that data collection methods described in the NCHRP report 731 (*10*) were adopted in the present study to effectively capture driver behavior during a dilemma zone situation.

Totally 1,500 h of video data (50 h for each of the 30 intersection approaches) were collected. The collected data included arrival time, speed, type, location, and stop or go behaviors of vehicles approaching each intersection during the yellow and red clearance intervals. These video data were manually extracted for further analysis. Reference lines placed upstream of the intersection stop bar (see Figure 3) were used as a guideline to determine approaching vehicles' location and speed when extracting the video data. Each approaching vehicle captured at the onset of yellow indication was then tracked individually to identify if it actually stopped or passed the intersection during the yellow, red, or both, intervals. These data were then further analyzed to determine the dilemma zone length and location. RLR violations and vehicles' abrupt stops identified during the dilemma zone situation were used for dilemma zone conflict model development.

Type II Dilemma Zone

To determine Type II dilemma zone, the present study used two parameters: (i) the location where 90% of drivers go and (ii) the location where 90% of drivers stop when they first encounter the yellow signal indication. Table 2 shows descriptive statistics of the Type II dilemma zone start- and end-points and length (denoted as DZ_{start}, DZ_{end}, and DZ_{length}, respectively) for all 30 approaches selected for the study. Here, DZ_{start} and DZ_{end} are measured from the intersection stop bar, and DZ_{length} is computed by subtracting DZ_{start} from DZ_{end}. Note that DZ_{start} and DZ_{length} were used as an explanatory variable of dilemma zone conflict models.

As described in Table 2, the dilemma zone start point (i.e., DZ_{start}) varies over the 30 approaches, ranging from 180 to 390 ft. Dilemma zone length (i.e., DZ_{length}) also significantly varies from one approach to another, ranging from 150 to 360 ft. The sample mean, standard deviation, and 95% confidential level of these parameters tell us how the dilemma zone location varies over all the 30

Table 1. Site-Specific Information of Intersections Selected for the Dilemma Zone Study

	Intersection	Approach	V_{limit}	Grade	TAADT	AADT	W_{is}	Y	N_l	D_u
1	SR 157 at CR 1242	EB	65	4%	1538	7690	105	5	2	20.5
		WB	65	4%	2312	13600				5.5
2	US 72 at CR 53	EB	65	−3%	3281	54690	200	4	2	35.6
		WB	50	1%	3281	54960				0.7
3	US 431 at SR 77	NB	65	0%	1145	11450	100	4	2	2.5
		SB	65	0%	1739	15810				10.5
4	US 82 at CR 16	EB	65	1%	2095	23280	150	6	2	18
		WB	55	1%	2178	24200				1.3
5	US 82 at US 11	NB	65	−4%	3230	23070	115	6	2	75.5
		SB	55	−4%	3045	38060				0.1
6	US 80 at SR 219	EB	65	1%	992	6610	70	4	2	28.7
		WB	55	−1%	1381	10620				1.5
7	US 82 at SR 14	EB	55	0%	1559	9170	140	4	2	65
		WB	45	0%	996	14230				0.5
8	US 231 at SR 271	EB	65	0%	3650	18250	125	5	2	19
		WB	65	−1%	5024	25120				2
9	US 84 at SR 123	EB	65	−3%	1220	13550	85	4	2	9.5
		WB	65	−2%	664	16600				6.5
10	US 280 at CR 97	EB	65	−5%	1157	14460	140	5	2	24.5
		WB	65	−5%	2323	29040				1.3
11	US 431 at SR 165	NB	65	−7%	1859	16900	180	5	2	43
		SB	65	6%	1620	13500				1.8
12	US 43 at CR 96	NB	55	0%	2516	10938	150	4	2	45.2
		SB	55	0%	2516	10938				5.8
13	US 231 at SR 51	NB	55	−5%	3050	9838	135	6	2	15.9
		SB	55	+ 2%	3050	9838				12.5
14	US 231 at CR 38	NB	55	0%	1888	7550	110	4	2	2.5
		SB	55	−4%	1888	7550				12.8
15	US 98 at CR 32	NB	55	0%	311	7790	80	4	2	2.2
		SB	55	0%	461	15380				15.4

Note: V_{limit} = posted speed limits (mph); Grade = grade of intersection approach (%); TAADT = annual average daily freight traffic per direction [vehicles per day (vpd)]; AADT = annual average daily traffic per direction (vpd); W_{is} = intersection width (feet); Y = existing yellow time (seconds); N_l = the number of lanes per approach; and D_u = distance to an adjacent signalized intersection on a major road. Thus, two D_u values exist for each signalized intersection; EB = eastbound; WB = westbound; NB = northbound; SB = southbound.

intersection approaches despite the similarity of their land use, facility type, and traffic operating conditions.

Figure 4 shows Type II dilemma zones measured at the north- and southbound approaches of a sample intersection, US431 at SR165 as an example. The dilemma zone at the US431 northbound approach of the intersection (Figure 4*a*) starts at 390 ft away from the intersection stop bar and ends 750 ft, which results in 360 ft of dilemma zone length. On the contrary, the dilemma zone at the US431 southbound approach (Figure 4*b*) starts and ends much earlier than that at the northbound approach. DZ_{start}, DZ_{end}, and DZ_{length} at the southbound approach are 180, 420, and 240 ft, respectively, as shown in Figure 4*b*. These two approaches show a good example of varying dilemma zone length and location although they are on the same intersection and the same route and use the same posted speed limit (i.e., 55 mph). To understand why such variations exist on the dilemma zone length and location for the two approaches, a detailed investigation of site-specific data would be needed. For example, an analysis to see how the dilemma zone location varies with different truck traffic and different levels of approach grade would be needed to answer the question. It is important to note, however, that the present study limits its scope to find relationships between dilemma zone variables and intersection safety. How the dilemma zone length and location vary with varying site-specific data is not discussed here. Instead, the authors reserve such tasks for future research.

Model Development

Dilemma Zone Conflicts

The likelihood of crashes at a signalized intersection increases with the increase of angle and rear-end conflicts (*10*). Furthermore, such conflicts are largely attributed to RLR violations and abrupt stops at the intersections (*18–21*). Thus, RLR violations and abrupt stops could be used as a surrogate measure to assess intersection

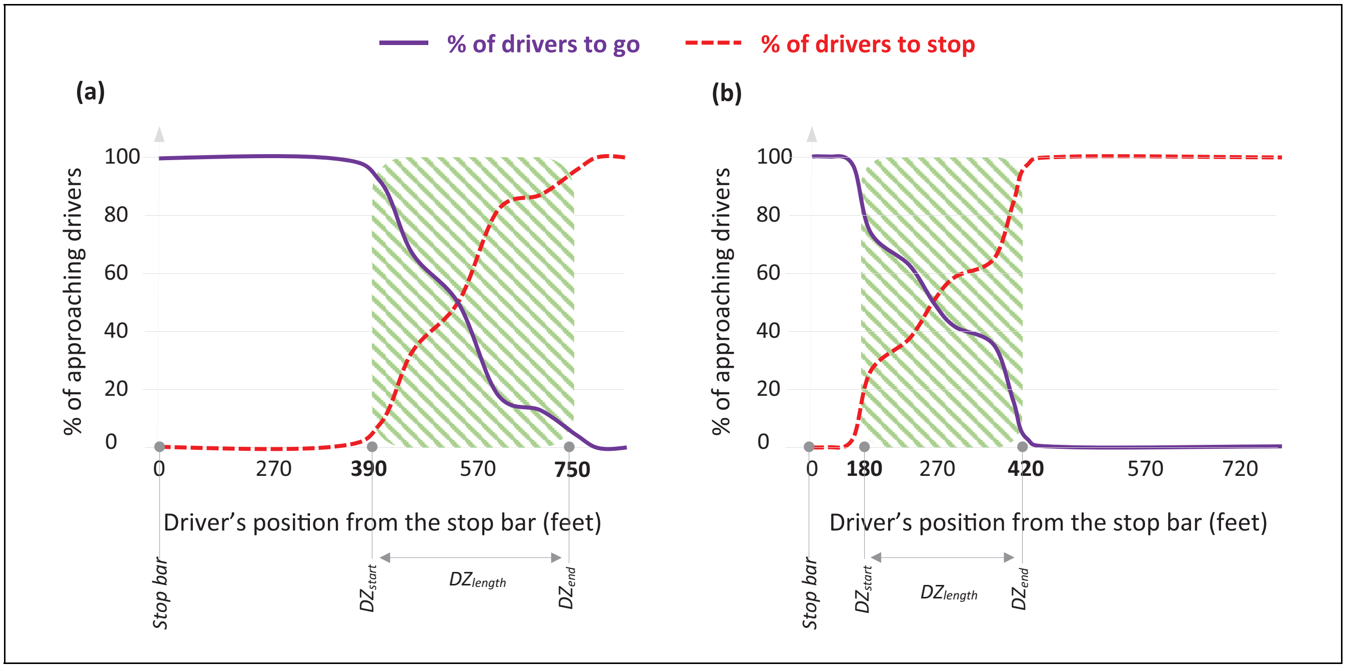

Figure 4. Type II dilemma zones measured at: (*a*) northbound and (*b*) southbound approaches of US431 at SR165.

safety associated with dilemma zone conflicts. There is no clear definition of an abrupt stop available in transportation literature. The present study thus employed two criteria to determine if a vehicle makes an abrupt stop at an intersection approach during the yellow and red clearance intervals. It was determined in a field data review process that an approaching vehicle made an abrupt stop if it satisfied both criteria below:

a. Speed of a vehicle within 200 ft upstream of the intersection stop bar is equal to or exceeding the posted speed limit, and
b. This vehicle physically stops before the intersection stop bar during the yellow and red clearance intervals.

It is important to note here that the frequency of RLR violations and that of abrupt stops are both highly correlated with traffic volume in general. In other words, the more vehicles use an intersection, the higher chance such conflicts would occur (*20–23*). Thus, the present study normalized these two measures by dividing them with average daily traffic entering an intersection, and 1,000 was multiplied onto the conflict measure to have their values per thousand entering vehicles. Note that such normalization is to remove the traffic effect when analyzing the effect of dilemma zone length and location on intersection angle and rear-end conflicts. Mathematical expressions of the two conflict measures (i.e., RLR_{rate} and $ASTOP_{\mathrm{rate}}$) used in the present study are shown in Equations 1 and 2. These measures were used as a dependent variable of dilemma zone conflict models later in the next section.

$$RLR_{\mathrm{rate}} = \frac{RLR_{\mathrm{freq}} \times 1,000}{ADT} \tag{1}$$

$$ASTOP_{\mathrm{rate}} = \frac{ASTOP_{\mathrm{freq}} \times 1,000}{ADT} \tag{2}$$

where RLR_{rate} = a rate of red-light running violations per thousand entering vehicles;

RLR_{freq} = observed red-light running violation frequency in a day;

$ASTOP_{\mathrm{rate}}$ = a rate of abrupt stops per thousand entering vehicles;

$ASTOP_{\mathrm{freq}}$ = observed abrupt stop frequency in a day;

ADT = average daily traffic entering an intersection approach.

Recall the signalized intersection of US431 and SR165 described earlier. RLR_{rate} and $ASTOP_{\mathrm{rate}}$ at the US431 northbound approach of the intersection were found to be 3.8 and 3.5, respectively. It is interesting to note, however, that such conflict measures at the opposite (i.e., southbound) approach were significantly lower than those at the northbound approach despite the same posted speed limit and similar traffic and traffic mix conditions at both approaches. RLR_{rate} and $ASTOP_{\mathrm{rate}}$ at the southbound approach were found to be 1.7, and 0.7, respectively. To see if such conflict variations between north- and southbound approaches are attributed to

Table 2. Descriptive Statistics of Type II Dilemma Zones at the 30 Selected Intersection Approaches

	DZ_{start}	DZ_{end}	DZ_{length}
Mean	266.33	535	268.67
Median	240	535	280
Mode	220	500	300
Standard deviation	60.83	88.46	54.63
Sample variance	3699.89	7825.86	2984.37
Standard error	11.11	16.15	9.98
Kurtosis	−0.96	0.18	−0.60
Skewness	0.65	0.53	−0.43
Minimum	180	380	150
Maximum	390	750	360
Count	30	30	30
Confidence level (95.0%)	22.71	33.03	20.40

Note: Units = feet.

their dilemma zone length and location, two dilemma zone conflict models were developed with RLR_{rate} and $ASTOP_{rate}$ as a dependent variable and DZ_{start} and DZ_{length} as an independent variable.

Dilemma Zone Conflict Models

Table 3 shows correlations between the dependent and independent variables used in the dilemma zone conflict model development. As described in the table, each of dependent variables, RLR_{rate} and $ASTOP_{rate}$ have significant correlations with independent variables DZ_{start}, DZ_{length} and Y_{diff}, with *p*-values significantly lower than 0.05. Note that another independent variable, called yellow time difference (Y_{diff}) is also analyzed here to see if it has a correlation with the dependent variables. Y_{diff} is the deviation of an existing yellow time length from a recommended yellow time length calculated based on the ITE (*23*). Y_{diff} is always greater than or equal to 0 and varies considerably over the 30 intersection approaches, ranging from 0 to 4 s. As shown in Table 3, Y_{diff} has a significant correlation with the dependent variables; the longer length of the yellow time difference, the higher chance getting high RLR and ASTOP rates. A correlation analysis between the dilemma zone variables (i.e., DZ_{start} and DZ_{length}) was also made in the present study. The analysis result showed that no significant correlation exists between the variables.

Table 4 shows two conflict models developed in the present study, (i) M_A: angle and (ii) M_R: rear-end conflict models, which are both a function of dilemma zone length and location. The results show that the conflict models are all statistically significant with high R^2 and low *p*-values less than 0.05 (*24*). As shown in the table, the dilemma zone variables account for 66% and 84% of RLR_{rate} and $ASTOP_{rate}$, respectively. It is important to note that the models are only valid within a certain range of a domain, which was found from the descriptive statistics of independent variables obtained at the 30 intersection approaches; the minimum values of each independent variable were used to define the model domain. Note that Y_{diff} was only included in the angle conflict model (M_A) as it is significant in predicting RLR_{rate}, not $ASTOP_{rate}$.

To validate the models, six additional intersection approaches which satisfy the same criteria used for selecting the 30 sample approaches were identified. Data necessary to determine dilemma zone length and location as well as RLR and ASTOP rates were collected at the six additional approaches. With the inclusion of the additional dataset, the root means square error (RMSE) and mean absolute percentage error (MAPE) were calculated for the model validation. The analysis results show that the conflict models are accurate enough to predict the safety of high-speed signalized intersection approaches using the two dilemma zone variables with RMSE values of 0.293 and 0.278, MAPE values of 0.225 and 0.198 for M_A and M_R models, respectively.

Concluding Remarks

Summary

The present study analyzed driver behavior at 30 high-speed signalized intersection approaches in rural

Table 3. Correlation and Associated *p*-value between Dependent and Independent Variables

	Independent variables					
	DZ_{length}		DZ_{start}		Y_{diff}	
Dependent variables	COR	*p*-value	COR	*p*-value	COR	*p*-value
RLR_{rate}	0.716	9e-6	0.389	0.003	0.532	4e-6
$ASTOP_{rate}$	0.496	5e-3	0.844	5e-9	0.524	0.003

Note: DZ_{length} = dilemma zone length; DZ_{start} = dilemma zone start location measured from the stop bar; Y_{diff} = the deviation of an existing yellow time length from a recommended yellow time length calculated based on the ITE method in seconds; $Y_{diff} = Y_{ITE} - Y_{exist}$; $Y_{diff} \geqslant 0$; Y_{ITE} = the length of recommended yellow time calculated based on the ITE method; Y_{exist} = the length of existing yellow time; RLR_{rate} = a rate of red-light violations per thousand entering vehicles; $ASTOP_{rate}$ = a rate of abrupt stops per thousand enteriving vehicles; COR = correlation between variables.

Table 4. Dilemma Zone Conflict Models with Model Validation Results

Model	R^2	*p*-value	Model format	RMSE	MAPE
$M_{\mathbf{A}}$: Angle conflict model	0.66	3e-6	$RLR_{rate} = -2.40 + 0.005DZ_{start} + 0.010DZ_{length} + 0.485Y_{diff}$ (0.04) (0.09) (0.02) (0.02)	0.293	0.225
$M_{\mathbf{R}}$: Rear-end conflict model	0.84	2e-11	$ASTOP_{rate} = -3.37 + 0.013DZ_{start} + 0.007DZ_{length}$ (1e-7) (1e-10) (8e-5)	0.278	0.198

Note: M_A and M_R are only valid within the specified domain below.

- $180 \leq DZ_{start}$.
- $150 \leq DZ_{length}$.
- $0 \leq Y_{diff}$.

(*value*) = *p*-value for the coefficient of each independent variable; RMSE = root mean square error; MAPE = mean absolute percentage error.

Alabama to see how the dilemma zone length and location would affect the intersection safety. For that, an extensive data collection was made with a series of video sensors at each of the selected intersection approaches. As such, a significant amount of video data that captured speeds, locations, and stop or go decisions of approaching vehicles during the yellow and red clearance intervals were collected. RLR violations and abrupt stops of approaching vehicles during the dilemma zone situation were also collected for use as a dependent variable when developing dilemma zone conflict models.

Data extracted from the video data were first analyzed to determine the Type II dilemma zone of the selected intersection approaches. The data were then reviewed to identify any correlation between the dilemma zone variables (i.e., dilemma zone length and start location measured from the intersection stop bar) and dilemma zone conflicts (i.e., RLR violations and abrupt stops). Results showed that the dilemma zone start location and length at the selected intersection approaches significantly vary despite the similarity of their facility type, speed limit, and land use. It was also found that the chance of RLR violations increases if the dilemma zone start point is located farther from the intersection stop bar. Furthermore, the chance of abrupt stops by vehicles during the yellow interval increases if the length of the dilemma zone is longer. Two dilemma zone conflict models (i.e., angle and rear-end conflict models) were developed in the present study. It was found that they are both statistically significant with high R^2 and *p*-values less than 0.05.

Limitation and Future Work

The present study used driver behavior data collected from 30 high-speed signalized intersection approaches to develop the dilemma zone conflict models. A larger dataset would increase the reliability of the models. Future work would include: (1) the investigation of intersection site-specific variables (e.g., approach grade, posted speed limit, traffic volume, the amount of freight traffic in the traffic stream, and the length of yellow interval) that would affect the dilemma zone length and location; (2) the development of a model that predicts the dilemma zone length and location with the site-specific variables.

Author Contributions

The authors confirm contribution to the paper as follows. Study conception and design: Min-Wook Kang; funding acquisition and administration: Min-Wook Kang; framework development: Min-Wook Kang, Moynur Rahman and Joyoung Lee; draft manuscript preparation: Min-Wook Kang, Moynur Rahman and Joyoung Lee; data collection and analysis: Moynur Rahman and Min-Wook Kang. All authors reviewed the results and approved the final version of the manuscript.

Data Accessibility Statement

Please contact the corresponding author to obtain a link to access the data that support the findings of this study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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The findings and conclusions, as well as the facts and accuracy of data presented in this paper solely based on the views and opinions of the authors. This paper does not necessarily reflect the purpose and policies of the Alabama Department of Transportation.