

Research Article

Impact of Road Environment on Drivers' Preference to Merging Location Selection in Freeway Work Zone Merging Areas

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In view of the compulsory merging behavior and complex driving environment in freeway work zones, the factors influencing drivers' merging behavior need to be focused on the given road environment. Realizing the need to mitigate the impact of such a challenging scenario, this study aims to explore the impact of road environment on drivers' merging location selection in freeway work zone merging areas. The survey data for modelling were collected through questionnaires survey based on the stated preference (SP) method. The logistics regression model was utilized to extract the significant factors influencing merging location selection. The results of fitting effect analysis show that the developed logistics regression models provide a good fit for the survey data. The road conditions and speed limit strategies are the significant factors affecting the drivers' preference to merging location selection in upstream transition area. The road conditions, traffic environment conditions, speed conditions, and speed limit strategies are the prominent influencing factors to the latter part of advance warning area. It is a comprehensive analysis to consider the influence of road environment on merging location selection from the perspective of drivers, which is expected to support the merging control strategy and avoid the occurrence of traffic crash in work zones.

1. Introduction

The mandatory merging behavior and complex traffic environment disrupt traffic flow and usually result in traffic crashes owing to lane closures in freeway work zones [1, 2]. Moreover, the rate and severity of traffic crashes that mostly occur in work zones are higher than those on normal road sections [3–10]. Typically, the two-way four-lane freeway work zone is generally divided into 6 parts, namely, advance warning area, upstream transition area, buffer area, work activity area, downstream transition area, and termination area [11]. And the advance warning area and upstream transition area are taken as the merging areas. In this area, the vehicle speed slows down gradually due to the lane closure and speed limit signs layout. In the process of speed adjustment, the drivers need to find the acceptable gaps and change lanes in merging areas. The mandatory merging

behavior and mutant traffic environment increase the complexity of drivers' response, judgment, decision-making, operation, and other links, seriously affecting traffic safety [12–14].

In terms of traffic safety, previous studies have shown that the necessary merging behavior induces the driving errors of drivers, which results in misjudgment and misoperation, increases traffic conflicts risk, and even leads to traffic crashes. Zheng et al. utilized the method of bivariate threshold excess model to estimate traffic crashes relating to merging events on freeway entrance merging areas [15]. Meng et al. explored the relationship between the merging behavior and rear-end crash risk in work zone and believed that the drivers' merging behavior had a significant impact on rear-end crashes [16]. The authors analyzed the rear-end crash risk and identified the risk factors in freeway work zone, and the results showed that the vehicle operation state

was the main factor influencing rear-end crash risk, and each additional merging would increase rear-end crash risk by 3.9 times [17]. Due to the necessary merging behavior and mutant traffic environment, the rate of traffic crashes is relatively high in work zone merging areas [18–20]. Therefore, it is necessary to analyze the impact of road environment on drivers' merging behavior in freeway work zones. This study makes a positive exploration in this regard. This study aims to collect the survey data including road conditions, road alignment conditions, traffic environment conditions, traffic control signs, speed conditions, and speed limit strategies, develop a proper model, and quantify the impact of road environment on the drivers' preference to merging location selection, as well as to provide support for the merging control strategy and driving safety environment improvement in work zones.

2. Literature Review

In order to determine an appropriate model on drivers' merging behavior influenced by road environment in freeway work zone merging areas, it is carried out by reviewing the findings of previous studies, focusing on the factors influencing merging behavior and the modelling approaches for merging behavior. The section below underpins the findings from past studies in this regard.

2.1. Review of Influencing Factors on the Merging Behavior in Work Zones. Many studies have been conducted to explore the factors influencing drivers' merging behavior in work zones. The contributory factors are grouped into five categories: driver, vehicle, roadway, environment, and crash characteristics. Drivers' characteristics include gender, age, education background, and profession. Weng et al. found that the male drivers engage in risky driving behavior more frequently than the female drivers in middle-aged [21]. Hang et al. found that the male drivers tended to finish merging maneuvers earlier than the female drivers [22]. Li et al. found that the impacts of gender on the lane-changing response time and distance were indistinctive [23]. The authors explored that the young drivers and highly educated drivers performed noticeably less in lane-changing response time and distance in work zone [24]. The drivers' professional characteristics contributed to different driving behavior patterns. For example, the taxi drivers tended to merge earlier than the regular drivers during the merging process [22].

Vehicle characteristics include vehicle speed and vehicle types. Merging vehicle speed exhibits a positive effect in increasing the merging probability [21, 24–28]. Merging vehicles at lower speed would merge into through-lane more easily [24]. The merging probability is positively affected by the relative speed between the through lead vehicle and merging vehicle but negatively influenced by the relative speed between the lag vehicle and merge vehicle [21]. Meng et al. proposed that the most important factor affecting drivers' merging behavior was the relative speed of the through-lane lead vehicle concerning the merging vehicle

[29]. The higher speed of merging vehicles and through lead vehicles will make vehicles more convenient for merging [28]. The lead vehicle speed has a constant effect on the drivers' merging behavior. The through-lane lead vehicle speed and lag vehicle speed are found to exhibit heterogeneous effects at different times of the merging processing period [26]. The vehicle types affect greatly the drivers' merging behavior [25–27]. The merging vehicle has a decreasing preference to taking the choice of "complete a merging maneuver" as the elapsed time increases if the through-lane lead vehicle is a heavy vehicle [26]. The probability of the merging driver taking the choice of "completing a merging maneuver" will be high when the lead vehicle is heavy vehicle [26]. Weng et al. found that a car preferred to complete a merging maneuver more quickly than a heavy vehicle [27].

Roadway characteristics include the location of warning sign and the length of upstream transition zone. The warning sign position has a profound influence on drivers' merging behavior and performance in freeway work zone [22, 30–34]. With the increase of the length of upstream transition zone length, the driver tends to choose a larger gap to complete a merging maneuver [24]. Environmental characteristics include traffic volume, lead-lag headway, longitudinal gaps, the remaining distance to work zone, and time elapsed. The conditions of different traffic volume can significantly impact drivers' merging decision-making in work zones [24, 33]. Sun et al. found that the probability of completing a merging maneuver decreased and the required length of upstream transition zone increased with the increase of traffic volume [24]. The through lead-lag headway is found to be the most significant variable influencing drivers' merging choice [28]. The longitudinal gap between the merging and lead vehicles presents a negative effect on the probability of taking the choice "complete a merging maneuver" but this negative impact gradually decreases as the elapsed time increases [26]. The remaining distance to the work zone has a negative but fixed effect on the drivers' preference to completing a merging maneuver [25, 26]. The merging driver is more willing to merge into a smaller adjacent gap as she/he is closer to the taper [21]. The probability of completing a merging maneuver increases over the time elapsed [25]. Crash characteristics include crash probability and crash severity. Vehicle crash probability is regarded as a contributing factor affecting merging behavior in work zones [27]. The high vehicle crash probability and severity in the merging lane will cause the merging vehicle to enter the through-lane as quickly as possible [27].

2.2. Review of Modelling Approaches for Merging Behavior in Work Zones. To date, several methodological approaches have been developed to explore the merging behavior in work zones. Most of the previous research efforts used parametric models to describe the drivers' merging behavior/lane-changing in work zone merging areas. Weng et al. developed a binary logit model to identify drivers' merging behavior in work zone merging areas [21, 28]. Sun

et al. developed a logistic model to describe the driver behavior of gap acceptance and rejection in the upstream transition area [35]. Li et al. proposed a fuzzy logic-based model to describe mandatory lane-changing behavior in work zone considering drivers' sociodemographics [23]. Weng et al. developed a mixed probit model to describe drivers' merging behavior in work zone merging areas [25]. Weng et al. developed a time-dependent logistic regression model to describe the merging behavior in work zone merging areas considering the possible time-varying effects of influencing factors [26]. Taking vehicle crash probability and severity as contributory factors affecting merging behavior, Weng et al. used the time-varying mixed logit model to predict drivers' merging behavior based on the merging traffic data in work zones [27].

Apart from the parametric statistical approach, many researchers also established nonparametric models, which provided higher prediction accuracy for merging choices. For instance, Meng et al. developed Cellular Automata models incorporating the sequential lane-changing behavior [36, 37]. Meng et al. used the method of classification and regression tree to predict the drivers' merging behavior in short-term work zone [30]. Hang et al. presented a driving simulator-based experiment method to understand the effects of lane-end sign distance and traffic volume on drivers' merging behaviors in work zone merging areas [22].

In summary, the existing literature has carried out beneficial research on the drivers' merging behavior in work zones. Nonetheless, the literature has not fully revealed the impact of road environment on the choice of "completing a merging maneuver" in work zone merging areas. It is necessary to explore the impact of road environment on drivers' merging behavior in work zone merging areas. Therefore, this paper uses the SP method to collect survey data on drivers' merging preference and explores the impact of road environment on drivers' preference to choosing merging locations in work zone merging areas. The logistic regression model is used to build a model on drivers' preference to choosing the merging location influenced by road environment in freeway work zones.

3. Data Collection

Since Louviere et al. used the SP approach to develop the traffic mode choice of urban residents, this method has been widely applied in the field of travel mode choice, parking choice, route choice, and traffic safety perception [38–40]. In this study, the SP approach is utilized to collect information on drivers' preference to merging location selection and detail the influence factors. The investigation is conducted in online and offline ways.

3.1. Survey Design. The drivers' merging belongs to necessary lane-changing behavior in work zones. To analyze the impact of road environment on drivers' merging preference to merging location selection, it is necessary to obtain the basic characteristics of drivers, the preference to the merging location selection, and the attribute factors of road

environment affecting drivers' merging behavior in work zones. Above all, the drivers' preference to merging location selection means merging locations selection and its influence factors in this study. As such, the survey questionnaire of this study is divided into three parts: (1) the basic information of drivers; (2) the preference to merging location selection in work zone merging areas; (3) the attribute factors of road environment influencing drivers' merging behavior in work zone merging areas.

In the first part of questionnaire, the basic information of drivers includes gender, age, driving years, education background, and monthly income. The aspect of merging location selection is the second part of questionnaire. The two-way four-lane freeway work zone is taken as an example, which locates in northeast China. Considering the lane configuration of work zone and related regulation of *Road Traffic Signs and Markings-Part4: Work Zone* (GB5768.4-2017) and *Safety Work Rules for Highway Maintenance* (JIT H30-2015) in China [11], the work zone is divided in three merging locations (Location I, Location II, and Location III) for merging area selection, as shown in Figure 1.

The Location I represents the upstream transition area, which is 120 m long with a speed limit of 60 km/h. The Location II is located between the merging guidance sign and upstream transition area with the length of a quarter of advance warning area, namely, about 400 m. The Location III is the else part of advance warning area except for the Location II, whose length is about 1,200 m. The division of merging areas in freeway work zone is listed and explained in the questionnaire to help the respondents understand merging areas clearly. The last part of questionnaire is attribute factors of road environment, which mainly include road conditions, road alignment conditions, traffic environment conditions, traffic control signs, speed conditions, and speed limit strategies in work zones. This study mainly considers the factors of road alignment, number of closed lanes, and length of closed lanes in terms of road conditions. Road alignment conditions include the factors of straight line section, horizontal curve segment, longitudinal slope segment, and curve slope combination segment. Traffic environment conditions include the factors of traffic volume and its composition, work zone location, work zone layout, and traffic organization and control measures. This paper mainly considers the factors of warning sign, speed limit sign, and merging guide sign from the aspect of traffic control signs. This study mainly considers the factors of speed difference with the front vehicle, speed difference with the front side vehicle, speed difference with the rear vehicle, and speed difference with the rear side vehicle from the perspective of speed conditions. The speed limit strategies mainly include the factors of single-speed limit, repeated speed limit, and hierarchical speed limit.

3.2. Data Collection and Preprocessing. In this study, two kinds of online and offline survey ways were adopted to obtain the relevant data. The survey was conducted in Harbin City, China, in 2015. To ensure the randomness of

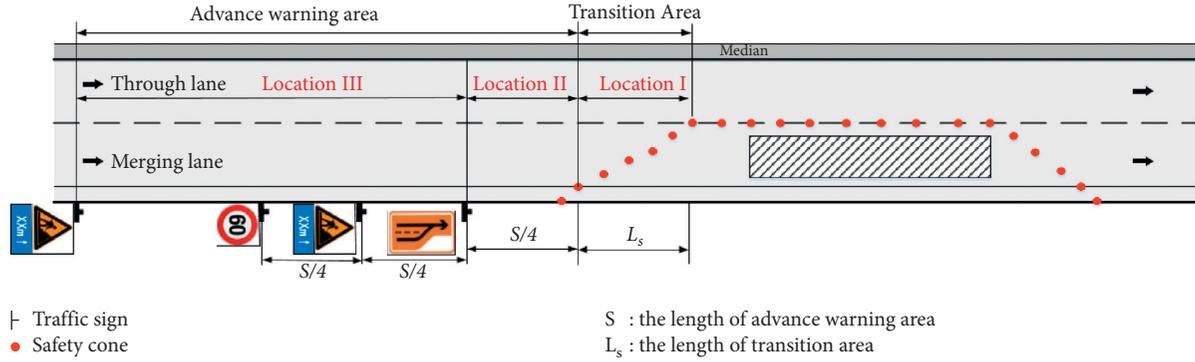


FIGURE 1: Division of merging areas in freeway work zone.

survey, the respondents were randomly selected regardless of their gender, age, education background, and income. The respondents participated in the survey voluntarily and anonymously. The online survey was carried out anonymously through the questionnaire platform of Wenjuanxing. For the offline survey, the investigators were university students majoring in traffic engineering. Both online and offline survey ways, the purpose, invitation, and personal information protection were all explained.

Initially, 350 questionnaires were collected. The 22 samples were excluded because of two cases: (1) incomplete information; (2) respondents without driver's license. At last, 328 questionnaires were valid, accounting for 93.7% of the total. Due to the short time of lane closure and less traffic volume in work zones, this study did not adopt the general methods of sample size determination such as the resident trip survey. The sample size was determined based on the principle of 10 outcomes events per variable principle (10EPV) in this study [41]. This study considered initially 21 variables from 6 kinds of factors, and the valid sample size should be more than 210 according to 10EPV. So the 328 valid questionnaires met the requirements on the minimum sample size. The merging behavior variables are extracted from the questionnaire for each sample including driver information, road environment conditions, and the drivers' merging preference. The descriptive statistics and frequency distribution of the influential factors are illustrated in Table 1. The relationship between road environment factors and drivers' preference to choosing merging behavior is shown in Figure 2.

As shown in Figure 2, 79.3% of drivers choose to merge in Location III under the influence of road environment. The results indicate that the drivers have an obvious preference to Location III in work zone merging areas. The number of drivers selecting early merging increases in Location III under the complex driving environment.

4. Methodology

4.1. Logistic Regression Model. The logistic regression model is a multivariable analysis method to explore the relationship between observation results of two or more continuous categorical explanatory variables [42, 43]. The factors influencing drivers' merging preference belong to the

problem of multiple categories including road conditions, road alignment conditions, traffic environment conditions, traffic control signs, speed conditions, and speed limit strategies. The logistic regression model will be able to identify the contributing factors related to drivers' merging preference.

The drivers' merging preference is taken as a dependent variable, which is recorded as y_i . Based on the division of merging locations, there are three categories as follows: (1) If drivers choose Location I as merging location, then $y_i = 1$; (2) if drivers choose Location II, then $y_i = 2$; (3) if drivers choose Location III, then $y_i = 3$. There are many influencing factors acting on the dependent variable y_i , which are recorded as the independent variables x_1, x_2, \dots, x_m . Then, the model of drivers' preference to choosing merging behavior can be expressed by

$$p = p(y_i = 1 | x_{i1}, x_{i2}, \dots, x_{im}) = \frac{\exp(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_m x_{im})}{1 + \exp(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_m x_{im})}, \quad i = 1, \dots, N, \quad (1)$$

where β_j ($j = 1, \dots, m$) is the coefficient associated with the j th explanatory variable, and P is the probability that the driver chooses to merge maneuver.

4.2. Parameter Estimation of the Model. The maximum likelihood approach is employed to estimate the coefficients of logistic regression model. The likelihood function of y_1, y_2, \dots, y_n is shown as follows:

$$L(\theta) = \prod_{i=1}^n p(y_i) = \prod_{i=1}^n [P(x_i)]^{y_i} [1 - P(x_i)]^{1-y_i}. \quad (2)$$

The corresponding log-likelihood function of $P(x_i) = \exp(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_m x_{im}) / 1 + \exp(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_m x_{im})$ is

$$\ln L(\theta) = y_i(\beta_0 + \beta_1 x_{i1} + \dots + \beta_m x_{im}) - \ln(1 + e^{\beta_0 + \beta_1 x_{i1} + \dots + \beta_m x_{im}}). \quad (3)$$

The estimated value of $\hat{\beta}_0, \hat{\beta}_1, \dots, \hat{\beta}_m$ is the maximum likelihood estimation of $\beta_0, \beta_1, \dots, \beta_m$.

TABLE 1: Characteristics and descriptive statistics of factors.

Category	Factor	Coding	Percentage (%)	Mean	SD
Drivers	Gender	Male	67.4	1.33	0.47
		Female	32.6		
	Age	18–25	11.0		
		26–30	20.4		
		31–40	47.3		
		41–50	20.7		
		31–60	0.6		
	Driving year	Under 3 years	17.4		
		3–5 years	26.8		
		5 years and above	55.8		
	Education level	Secondary school and below	32.0		
		University	43.3		
Average monthly income	Above university	24.7			
	Under 2000 yuan	5.8			
Road environment	Road conditions	2000 yuan and above	94.2	1.72	0.45
		Road alignment	56.4		
		Number of closed lanes	32.6		
		Length of closed lanes	11.0		
	Road alignment conditions	Straight line segment	21.0		
		Horizontal curve segment	60.7		
		Longitudinal slope segment	6.4		
		Curve slope combination segment	11.9		
	Traffic environment conditions	Traffic volume and its composition	43.6		
		Work zone location	29.6		
		Work zone layout	4.9		
		Traffic organization and control measures	22.0		
	Traffic control signs	Work zone warning sign	35.4		
		Speed limit sign	34.4		
		Merging guide sign	30.2		
		Speed difference with the front vehicle	26.8		
	Speed conditions	Speed difference with front side vehicle	56.4		
		Speed difference with rear vehicle	7.3		
		Speed difference with rear side vehicle	9.5		
	Speed limit strategies	Single-speed limit	13.1		
Repeated speed limit		33.5			
Hierarchical speed limit		53.4			
Drivers' preference	Drivers' preference	Location I	2.1	2.77	0.47
		Location II	18.6		
		Location III	79.3		

4.3. *Model Test.* The fitting effect test methods of logistic regression model include the significance test of regression coefficient and goodness-of-fit test [44, 45].

- (1) *Significance Test of Regression Coefficient.* The Wald test is used to analyze the significance of logistic regression model coefficient in this study. The Wald statistics is calculated as follows:

$$W = \left(\frac{\hat{\beta}_k}{S_{\hat{\beta}_k}} \right)^2, \quad (4)$$

$\hat{\beta}_k$ is the parameter estimated value and $S_{\hat{\beta}_k}$ is the standard deviation of parameter estimated value.

- (2) *Goodness-of-Fit Test.* The Pearson statistics and deviance statistics are employed to test the goodness-of-fit of logistic regression model. The Pearson statistics can be expressed by

$$\chi^2 = \sum_{j=1}^J \frac{O_j - E_j}{E_j}, \quad (5)$$

where j is the number of covariant types, O_j and E_j are the observation frequency and prediction frequency of type J covariant types, respectively.

The deviation standard D is calculated by

$$D = -2 \ln \left(\frac{\hat{L}_s}{\hat{L}_f} \right) = -2(\ln \hat{L}_s - \ln \hat{L}_f), \quad (6)$$

where D is deviation.

5. Results

5.1. *Model Independent Variable Selection.* To objectively analyze the impact of road environment on drivers' merging preference in work zones, 6 independent variables are

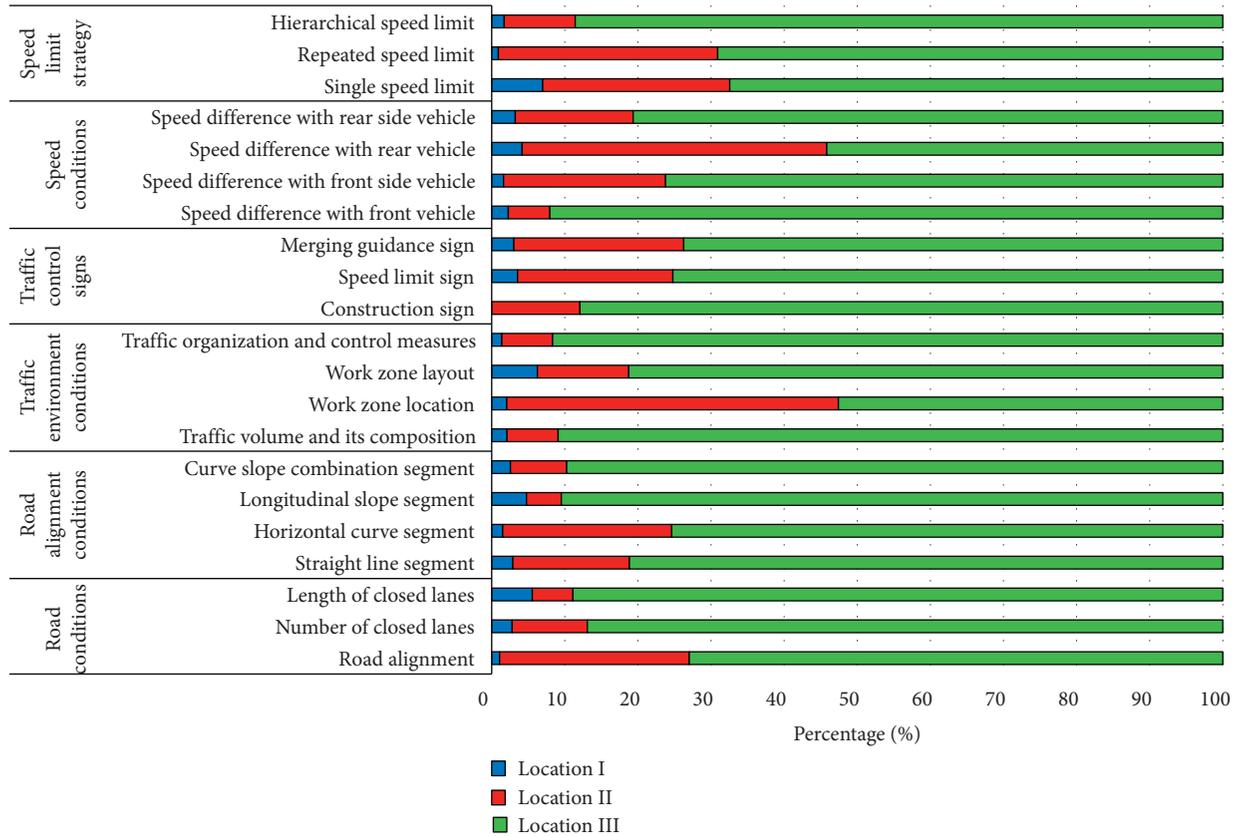


FIGURE 2: Relationship between factors of road environment and drivers' preference to choosing merging behavior.

initially selected, including road conditions, road alignment conditions, traffic environment conditions, traffic control signs, speed conditions, and speed limit strategies, and the classified variables are assigned, as shown in Table 2.

All 6 influencing factors are the multiple-classification variables after assignment in Table 2, so they should be set to dummy variables. In the process of calculation, the dummy variables of model will be transformed and assigned actually. If a dummy variable has k categories, the dummy variable will be converted to $k-1$ variables, as shown in Table 3.

The variables of road alignment conditions, traffic environment conditions, traffic control signs, speed conditions, and speed limit strategies belong to multi-classification variables. It is necessary to carry out dummy variable conversion, and the method of dummy variable conversion is the same as the variables of road conditions.

5.2. Model Results. The logistic regression model is specified using the maximum likelihood estimation method by means of the statistical analysis software of SPSS. The forward-selection technique is used to select independent variables which should be included in the developed models. The Wald statistics of each independent variable are calculated and reflected the contribution of the variable. The p -values for these Wald statistics are compared to the preset α_{entry} . If the value of Wald statistic has a significance level greater

than α_{entry} , the selection will stop. Otherwise, the variable will be added with the largest Wald statistic to the developed models. It will continue calculating the Wald statistics for the else variables remaining outside the developed models and repeat the evaluation process. With this method, the variables will be added to the developed models one by one until no remaining variables produce significant Wald statistics. In this study, the parameter α_{entry} is 0.05. With the collected 328 328 valid samples, the results of the logistic regression models are presented in Tables 4 and 5.

As shown in Table 4, the Wald statistics significant level of road conditions and speed limit strategies is less than 0.05 in Location I compared with Location III. The variables of road alignment conditions and speed limit strategies have statistical significance to the logistic regression model, while the others do not.

As shown in Table 5, the Wald statistics significant level of road conditions, traffic environment conditions, speed conditions, and speed limit strategies is less than 0.05 in Location II compared with Location III. It is considered that the variables of road alignment conditions, traffic environment conditions, speed condition, and speed limit strategies have statistical significance to the logistic regression model, and other variables do not.

Therefore, the following logistic regression models can be obtained to describe the drivers' preference to choosing merging behavior in work zone merging areas:

TABLE 2: Variable assignments and explanations of factors influencing drivers' preference to choosing merging behavior in work zones.

No.	Influence factors	Variables	Assignments and explanations
1	Road conditions	x_1	Road alignment = 1; number of closed lanes = 2; closed length = 3
2	Road alignment conditions	x_2	Straight line segment = 1; horizontal curve segment = 2; longitudinal slope segment = 3; curve slope combination segment = 4
3	Traffic environment conditions	x_3	Traffic volume and its composition = 1; work zone location = 2; work zone layout = 3; traffic organization and control measures = 4
4	Traffic control signs	x_4	Construction sign = 1; speed limit sign = 2; merging guidance sign = 3
5	Speed conditions	x_5	Speed difference with front vehicle = 1; speed difference with front side vehicle = 2; speed difference with rear vehicle = 3; speed difference with rear side vehicle = 4
6	Speed limit strategies	x_6	Single-speed limit method = 1; repeated speed limit method = 2; hierarchical speed limit method = 3

TABLE 3: Dummy variable assign transform of road conditions.

Road conditions	Number of closed lanes	Closed length
Road alignment	0	0
Number of closed lanes	1	0
Closed length	0	1

TABLE 4: Logistic regression model estimation results for Location I.

Merging area: Location I		B	S.E.	Wald	DF	Sig.	Exp (B)	95% confidence interval	
								Lower bound	Upper bound
	Intercept	-2.915	2.123	1.885	1	0.170	—	—	—
Road conditions	Road alignment	-4.222	1.676	6.342	1	0.118	0.015	0.001	0.392
	Number of closed lanes	4.393	1.969	4.978	1	0.026	1.012	0.000	0.586
	Length of closed lanes	0	—	—	0	—	—	—	—
Road alignment conditions	Straight line segment	-1.024	1.887	0.295	1	0.587	0.359	0.009	14.497
	Horizontal curve segment	-0.841	1.794	0.220	1	0.639	0.431	0.013	14.494
	Longitudinal slope segment	-0.487	2.612	0.035	1	0.852	0.614	0.004	102.816
	Curve slope combination segment	0	—	—	0	—	—	—	—
Traffic environment conditions	Traffic volume and composition	3.297	1.742	3.583	1	0.058	27.033	0.890	821.442
	Work space location	3.155	1.916	2.710	1	0.100	23.450	0.548	1003.347
	Work zone layout	3.845	2.510	2.345	1	0.126	46.741	0.341	6405.209
	Traffic organization and control measures	0	—	—	0	—	—	—	—
Traffic control signs	Work zone warning sign	-24.87	0.000	—	1	—	0.000	0.000	0.000
	Speed limit sign	-0.289	1.257	0.053	1	0.818	0.749	0.064	8.794
	Merging guide sign	0	—	—	0	—	—	—	—
Speed conditions	Speed difference with front vehicle	1.858	2.175	0.730	1	0.393	6.413	0.090	455.081
	Speed difference with front side vehicle	0.452	1.729	0.068	1	0.794	1.572	0.053	46.578
	Speed difference with rear vehicle	1.543	2.465	0.392	1	0.531	4.681	0.037	587.031
	Speed difference with rear side vehicle	0	—	—	0	—	—	—	—
Speed limit strategy	Single-speed limit	3.695	1.384	7.127	1	0.008	40.238	2.670	606.354
	Repeated speed limit	-0.226	1.352	0.028	1	0.867	0.798	0.056	11.290
	Hierarchical speed limit	0	—	—	0	—	—	—	—

$$p = p(y_i = 1|x) = \frac{\exp(-2.915 + 4.393x_{12} + 3.695x_{51})}{1 + \exp(-2.915 + 4.393x_{12} + 3.695x_{51})}, \tag{7}$$

$$p = p(y_i = 2|x) = \frac{\exp(-3.662 + 0.896x_{12} + 2.352x_{32} - 2.057x_{51} + 1.833x_{53} + 1.925x_{61})}{1 + \exp(-3.662 + 0.896x_{12} + 2.352x_{32} - 2.057x_{51} + 1.833x_{53} + 1.925x_{61})}. \tag{8}$$

According to the results shown in equation (7), it can be seen that the coefficients of two variables including road

conditions and speed limit strategies are modelled as a function, suggesting that these two variables have more

TABLE 5: Logistic regression model estimation results for Location II.

Merging area: Location II		B	S.E.	Wald	DF	Sig.	Exp (B)	95% confidence interval	
								Lower bound	Upper bound
Intercept	-3.662	1.262	8.426	1	0.004	—	—	—	—
Road conditions	Road alignment	1.579	0.911	3.003	1	0.083	4.851	0.813	28.942
	Number of closed lanes	0.896	0.988	0.823	1	0.036	1.408	0.059	2.829
	Length of closed lanes	0	—	—	0	—	—	—	—
Road alignment conditions	Straight line segment	0.644	0.858	0.564	1	0.453	1.904	0.355	10.226
	Horizontal curve segment	0.299	0.816	0.134	1	0.714	1.349	0.272	6.679
	Longitudinal slope segment	-0.160	1.606	0.010	1	0.921	0.852	0.037	19.847
	Curve slope combination segment	0	—	—	0	—	—	—	—
Traffic environment conditions	Traffic volume and composition	-1.157	0.733	2.492	1	0.114	0.315	0.075	1.322
	Work space location	2.352	0.676	12.094	1	0.001	10.508	2.791	39.559
	Work zone layout	0.628	1.261	0.248	1	0.619	1.873	0.158	22.178
	Traffic organization and control measures	0	—	—	0	—	—	—	—
Traffic control signs	Work zone warning sign	-0.650	0.561	1.340	1	0.247	0.522	0.174	1.568
	Speed limit sign	-0.134	0.515	0.067	1	0.795	0.875	0.319	2.399
	Merging guide sign	0	—	—	0	—	—	—	—
Speed conditions	Speed difference with front vehicle	-2.057	0.849	5.868	1	0.015	0.128	.024	0.675
	Speed difference with front side vehicle	0.231	0.720	0.103	1	0.748	1.260	0.307	5.163
	Speed difference with rear vehicle	1.833	0.875	4.389	1	0.036	6.252	1.125	34.734
	Speed difference with rear side vehicle	0	—	—	0	—	—	—	—
Speed limit strategy	Single-speed limit	1.925	0.615	9.815	1	0.002	6.856	2.056	22.864
	Repeated speed limit	0.780	0.454	2.947	1	0.086	2.181	0.895	5.311
	Hierarchical speed limit	0	—	—	0	—	—	—	—

significant influences on the drivers' merging location preference in upstream transition area. Also, the significant influences of four variables including road conditions, traffic environment conditions, speed conditions, and speed limit strategies are reflected from equation (8) in Location II (advance warning area near upper transition area).

5.3. Model Fitting Effect Analysis. The Wald test is employed to analyze the regression coefficient significance of developed models. The Wald statistics can be calculated by (4). The test results are shown in Table 6.

The results showed that the Wald statistic is 155.832 with 30 degrees of freedom and the corresponding p -value < 0.001 . So the developed models can be applied to describing drivers' merging location selection preference in work zones.

The Pearson statistics and deviance statistics are utilized for the goodness-of-fit test of developed models. The Pearson statistics and deviance statistics are calculated, respectively, by equations (5) and (6). The test results are shown in Table 7.

From Table 7, it can be seen that the Pearson statistics and Deviance statistics are 1976.945 and 221.288 with 248 degrees of freedom. The corresponding p -values are 1.163 and 0.888, respectively, indicating that the developed models are suitable to analyze drivers' merging location selection preference in work zones.

6. Discussion

Involving complicated road environment, the merging behavior in freeway work zones is significantly different from

TABLE 6: Significance test of regression coefficient.

Model	Model fitting standard		Likelihood ratio test	
	-2 log-likelihood	χ^2	DF	Sig.
Intercept only model	222.674	—	—	—
Final model	378.507	155.832	30	0.000

TABLE 7: Goodness-of-fit test.

Test method	χ^2	DF	Sig.
Pearson	1976.945	248	1.163
Deviation	221.288	248	0.888

normal road sections. In this study, the road environment factors influencing merging location selection are considered in freeway work zones. Among the three merging locations, the significance of the other two locations selection influencing factors is compared with Location III. The Location III is both the first section of advance warning area and the first section for vehicles merging. The drivers can merge and change lanes by choosing proper gaps or keep driving in the through-lane. However, the available distance for lane-changing will be reduced obviously when vehicles enter the Location II. From Tables 4 and 5, it is seen that the road conditions and speed limit strategies are both significant factors for Location II and Location I. In particular, the number of closed lanes and single-speed limit strategy are the main factors influencing merging location selection due to their significance values < 0.05 . The results are reasonable

in that the drivers will acquire the information on changes in lane layout from merging guide signs and traffic situations ahead. As such, the drivers can determine the merging direction and the number of lanes available during the two merging locations. Concerning Location I, namely, the upper transition area affected by the decrease in the number of available lanes, the more lanes are closed, the more strict temporal and spatial conditions are required for merging vehicles. Because the merging driver will merge into a smaller adjacent gap as she/he is closer to the taper [21], the probability of completing a merging maneuver increases over the time elapsed [25].

In addition, vehicle speed needs to be adjusted based on the speed limit value and traffic volume. The single-vehicle speed sign is located in three-quarters of advancing warning zone length from upstream transition zone and the speed limit value is 60 km/h [11]. It means that the vehicle speed will suddenly drop dramatically from 120 km/h or 100 km/h to 60 km/h compared with the hierarchical speed limit. Owing to the influence of road alignment consistency and speed range on traffic safety in work zone, the variation range of vehicle speed values is not recommended to exceed 16 km/h [46, 47]. The merging vehicle at lower speed would merge into the aim lane easier [24]. It can be found that the survey data results reflect drivers' preference to merging location selection considering the influencing factors from the subjective view. Therefore, it is necessary to carry out a comprehensive research based on the actual vehicle merging trajectory.

For Location II, namely, the else part of the advancing warning area, traffic environment conditions and speed conditions are the main factors. According to the questionnaire contents in Table 5, work zone location and speed difference between front vehicles and rear vehicles are also the specific influencing factors. The results can be intuitively explained as the through-lane lead vehicle speed and lag vehicle speed are found to exhibit heterogeneous effects at different times of the merging processing period [26]. And the relative speed of the lead vehicle concerning the merging vehicle is the most important factor affecting drivers' merging behavior [30].

7. Conclusions

Drivers' merging preference analysis is conducive to develop the influence of road environment on drivers' merging behavior in work zone merging areas. In this research, the two-way four-lane freeway work zone merging areas are divided into three merging locations according to the traffic signs layout and lane configuration. Based on the SP method, the data are collected to analyze the influence of road environment on drivers' merging preferences in the northeast of China. The questionnaire information includes the basic characteristics of drivers, the drivers' preference to choosing the merging location, and the characteristic attribute factors of road environment affecting merging behavior in work zone merging areas.

In this study, the developed logistic regression models are used to analyze the drivers' preferences and factors

influencing merging location selection with survey samples. The models are tested from two aspects: the significance of regression coefficient and goodness-of-fit. It is found that the two types of factors including road conditions and speed limit strategies have significant effects on drivers' preference in Location I (upstream transition area) compared to Location III (the first part of advance warning area). And the four factors of road conditions, traffic environment conditions, speed conditions, and speed limit strategies have obvious effects on drivers' merging preference in Location II (the else part of advancing warning area).

The former analysis suggests that road environment factors have a significant impact on drivers' preference to selecting merging locations. In addition, different sections are affected by road environment differently. The work presented in this paper has explored the quantitative influence of road environment on merging location selection to provide support for the merging control strategy and driving safety environment improvement in work zones. The coordinated control method of variable speed limits and active security management strategy based on vehicle-to-infrastructure (V2I) shall be adopted in work zones. Besides, it can be found that SP survey data results reflect drivers' preference considering the impact of road environment on merging location selection from subjective view. It can be seen that the logistic regression models have a good fitting effect from the regression coefficient and goodness-of-fit. However, due to the limited survey sample size, more actual road and simulation test are necessary to support this study. Studies combining questionnaire and driving simulator could help drivers' preference investigation in work zone merging areas. Further studies could focus on collecting the road and simulation test data of merging location distribution and exploring the risk factors on merging behaviors to get more insights on traffic safety in work zones.

Data Availability

The data used to support the findings of this study are mainly from the online survey and traditional questionnaire survey conducted in Harbin City, China.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Conceptualization was performed by B. W. and Y. L.; methodology was conducted by B. W. and C. Z.; software was obtained by C. Z.; validation was done by C. Z. and D. F.; formal analysis was carried out by B. W. and C. Z.; investigation was conducted by B. W. and C. Z.; resources were obtained by B. W.; data curation was performed by C. Z. and D. F.; the original draft preparation was done by C. Z. and D. F.; review and editing were carried out by B. W., Y. L., and S. Z.; funding acquisition was done by B. W. and Y. L. All

authors have read and agreed to the published version of the manuscript.

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Supplementary Materials

Supplementary material of questionnaire for this article is available online. (*Supplementary Materials*)

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