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Driver preference of merging locations at freeway exits

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Abstract

Freeway ramp areas are vulnerable to safety critical events due to congestion leading to increased risk of crashes. To improve safety and efficiency in the ramp areas, it is important to comprehensively understand drivers' merging behaviour in freeway exit areas, but limited knowledge available in the literature on this topic. This paper aims to fill this important gap in the literature by undertaking an online survey among 502 drivers in Australia to understand their preferences in merging location selection for different traffic volume conditions at freeway exit areas. A multilevel mixed effects ordered probit model, which accounts for potential correlations in the merging preferences of individual drivers for different traffic volume conditions, was developed to examine the influential factors of driver preferences in merging location selection. Results showed that drivers prefer to merge 1-2kms ahead of off-ramp location in high volume conditions. Experienced drivers tended to prefer merging early and drivers with probationary and learner driver licenses preferred to merge late than other drivers. These findings have important implications for making freeway operations safer and efficient in the exit areas.

1. Introduction

Freeway ramp areas are often subjected to congestion and safety critical events, including crashes with high severity outcomes (Mergia et al. 2013) often with increased risk of crashes due to sudden acceleration and deceleration by drivers (Xu et al. 2021a). These high-risk ramp areas often create bottlenecks on freeways requiring drivers to change lanes both in the form of a mandatory lane change and discretionary lane change depending on traffic conditions and lane configuration in the merging areas (Munoz and Daganzo 2002; Zheng et al. 2019). In addition to lane changing events, level of traffic volume also affects the probability of a conflict or crash occurrence in the merging areas. Furthermore, other factors that affect crash risks in the merging areas include adverse lighting conditions, heavy vehicle involvement, number of lanes on a ramp, weather conditions, and speeding behaviour (Mergia et al. 2013).

To reduce the crash risks, ramp metering is often used in high traffic volume conditions by reducing driving load on decision making related to lane changing (Xu et al. 2021b). However, ramp metering applicable for on-ramps (for vehicles entering a freeway), but not practical for off-ramps (when vehicles are existing a freeway~~.~~ Researchers have used control algorithms (Spiliopoulou et al. 2016; Dong et al. 2018) and microscopic simulation models to evaluate congestion and crash reduction methods for freeway off-ramps (e.g., Arnaout and Bowling 2011; Mo et al. 2020; Gressai et al. 2021). The focus of developing control algorithms was to reduce inefficiencies related to traffic flow, whereas the simulation models focused on assessing reductions in levels of congestion and crashes.

Lane changing behaviour involves primarily three elements: the probability of changing lane(s), the need to change lane(s) and the trajectory of changing lane(s) (Li et al. 2015). These elements can be further divided into factors such as lane changing rate, velocity motivation, target lane choice, gap acceptance, etc. (Xu et al. 2021a). These factors, combined with variability in individual driver behaviour, require significant amount of information to accurately simulate lane changing events in the ramp areas. Often simulation models are developed using given driver behaviour parameters in simulation platforms with assumptions made for unknown parameters. As lane changing behaviour of drivers are complicated and could be difficult to accurately replicate through simulation models, there is need for research on understanding lane changing behaviour of drivers using other sources of data.

To understand driver merging behaviour and perception, researchers have used video data and survey-based methods for data collection (e.g., Ahn et al. 2010; Lu et al. 2022; Wu et al. 2022). While video data is useful to understand interactions between vehicles and estimate crash risks, survey-based methods are usually used for understanding driver perception and preference in lane changing situations. Survey based methods also allow gathering socio demographic characteristics (Li et al. 2015) which cannot be gathered through video data analysis.

While studies have looked into understanding driver preference of merging location for freeway work zones (Wu et al. 2022), there is a lack of comprehensive understanding for non-work zone freeway exit areas. Specifically for Australian freeways, no studies have examined the driver preference of merging locations. This paper aims to fill this important gap in the literature by undertaking an online survey among drivers in Australia to understand their preferences in merging location selection for different traffic volume conditions at freeway exits.

2. Literature review

While freeways improve traffic flow and travel time, freeway entry and exit ramp areas are found to be more hazardous than basic freeway sections (e.g., Kondyli and Elefteriadou 2009; Günther et al. 2012; Zheng et al. 2019). Congestion in the off-ramps, as vehicles attempt to exit a freeway, reduces the efficiency of the overall freeway traffic flow (Mo et al. 2020). Furthermore, variability in vehicle speeds and acceleration/deceleration levels increases the risk of rear-end and sideswipe collisions (Zhang et al. 2018).

Driver behaviour in freeway off-ramp areas have been the subject of research in many studies which primarily used simulation and naturalistic driving data (Kondyli and Elefteriadou 2011; Zhang et al. 2018; Li et al. 2020; Mo et al. 2020) and reported some variables that affect the lane changing decision at the off-ramp areas. Zhang et al. (2018) tested 20 road environment related variables and found statistically significant relationships for 5 variables including number of lane changes required to be in the correct lane, the distance to the point where the driver needs to be off-ramp, the adjacent lane lead vehicle type, current lane lead vehicle headway, adjacent lane lead vehicle headway.

Following relationships between headways and traffic volumes, the traffic volumes in the merging areas are also considered among the influencing factors of merging behaviour at off-ramps. The role of traffic volume in off-ramp merging was further studied by Mo et al. (2020) and Li et al. (2020). The studies found that under high traffic volume condition, vehicles merge to the targeted lane in advance. Both studies were done using VISSIM simulation models to analyse lane-changing behaviour. These studies showed that with high traffic volume, the number of vehicles on the off-ramp and the average delay time will be higher than under lower traffic volume. Furthermore, Mo et al. (2020) found that under high traffic volume conditions, the efficiency of traffic flow can be maintained by having the off-ramp vehicles merge to the exiting (targeted) lane in advance. Apart from traffic volume, speed characteristics and environmental factors were also found to influence drivers' merging behaviour (Ahammed et al. 2008; Kondyli and Elefteriadou 2009; Wu et al. 2022).

Despite these studies, a gap exists in the literature that the relationships between demographic factors and drivers' merging behaviour at freeway off-ramps are not well understood. A study on merging at work zones Li et al. (2015) found that demographic characteristics, such as educational background and age of drivers, significantly influence drivers' merging behaviour but mixed results were found for gender. While this study looked at merging behaviour at work zones, it is argued that driver's demographic characteristics could possibly influence their merging behaviour at non work zones, such as freeway off-ramps.

Another important gap identified in the literature is that there is very limited understanding available on drivers' preference of merging locations and how these preferences could vary in different traffic conditions. Understanding drivers' preferred merging locations and their associated factors, including the demographic factors and traffic characteristics is important to comprehensively understand driver behaviour in the merging areas.

3. Methodology

Drivers' preferred merging locations and the associated factors were studied using an online survey and statistical analysis of the survey data. Details of the survey and the analysis methodology are presented in this section.

3.1 Survey design

A stated preference survey was used to collect data on drivers' preferred merging locations on freeway off-ramp areas. This method has been widely used by researchers to analyse driver perception on factors such as traffic safety, travel choice, merging choices of drivers at work zones, etc. (e.g., Louviere and Hensher 1982; Cherry and Adelakun 2012; Wu et al. 2022).

The survey was created in the Qualtrics platform and contained questions in two parts: (i) Demographic characteristics and (ii) Merging location preference for high and low traffic volume conditions.

The first part of the questionnaire was on basic information, such as age, gender, driving experience, experience with traffic control and road design (TCExp) and freeway usage. The TCExp was recorded to evaluate if experience and knowledge on traffic control and road design would have an impact on an individual's driving behaviour. The responses were recorded by asking if the participant is employed in traffic control or road design or was employed in the past 5 years.

In the second part, the participants were presented with two scenarios of a typical Australian freeway off-ramp of a three-lane each-way section (see Figures 1 and 2). These two scenarios and their associated text in the survey qualitatively represented low and high traffic volume conditions.

The two scenarios had the off-ramp section divided into 4 areas using signage. Area 1 represent the section after the last sign where the off-ramp starts. Area 2 is the section between 'Exit 1km ahead' to the last off-ramp sign. Area 3 is the 1km road section between 'Exit 2km ahead' and 'Exit 1km ahead'. Area 4 represent the area before any signage is available. The participants were asked to mark their preferred area to be on the leftmost lane (exiting lane) if they were to exit the freeway.

Figure 1: Freeway exit with low traffic volume

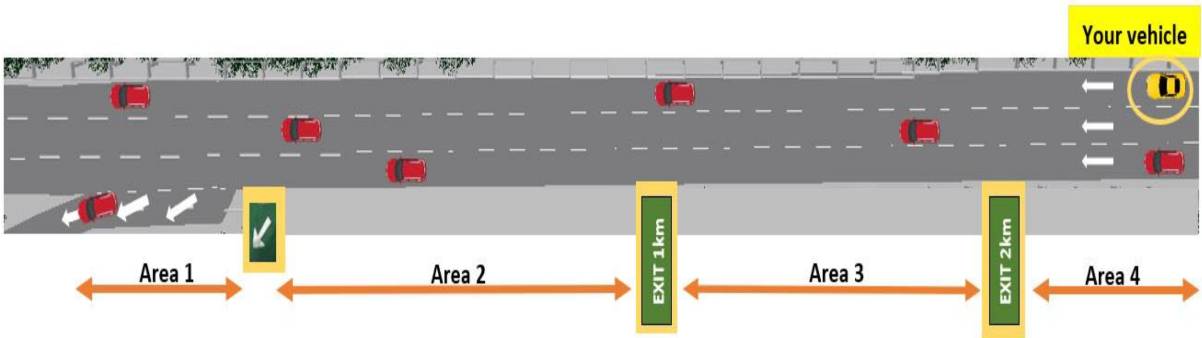
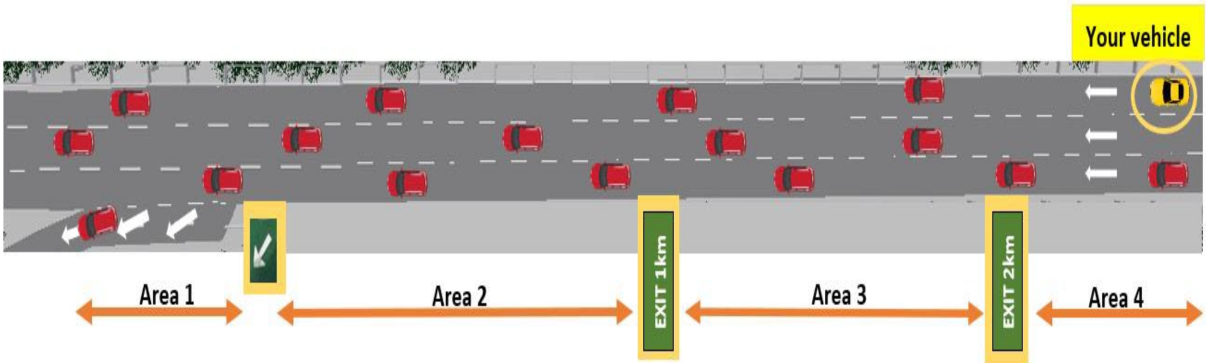


Figure 2: Freeway exit with high traffic volume



3.2 Model development

To evaluate the influence of demographic factors and traffic volume on the four merging areas at off-ramps, an Ordered Probit regression model was developed. Since the merging areas could ideally be represented on an ordinal scale from early merging (Area 4 and then Area 3) to relatively late merging (Area 2 and then Area 1), an ordered regression model was considered suitable for modelling this variable. To account for potential correlations in the merging preferences of individual drivers for the low-volume and high-volume scenarios, it is important to consider the potential within-panel correlation of the response variable. It is hypothesised that an individual driver's preferred merging locations would be correlated in the two scenarios due to their general driving behaviour and demographic characteristics. Models that do not appropriately consider such potential within-panel correlation might yield biased results. Therefore, a Multilevel Mixed Effects Ordered Regression (MMEOR) model was used for this study. Similar hierarchical models were developed in the literature to analyse injury severity (Fountas and Anastasopoulos 2017) and safety perception (Debnath and Chin 2009b).

The Ordered Probit model can be re-structured for a multi-level model in the following form (Bosker and Snijders 2011; Washington et al. 2020):

$$y_{ij} = \beta_{0j} + X_{ij}\beta_1 + Z_j\beta_2 + e_{ij}, \qquad i = 1, 2, \qquad j = 1, \dots, P \tag{1}$$

where, y_{ij} is the variable measuring the ordering of the merging area in volume i (volume level low = 1 or high = 2) by participant ID j; X_{ij} and Z_j are vectors of explanatory variables of the two levels; β_1 and β_2 are vectors of the unknown parameters; e_{ij} is the random errors to be normally distributed; and P is the total number of survey participants.

In the model the correlation among merging area of each driver is given by:

$$\beta_{0j} = \alpha + u_j \tag{2}$$

Where α is the average intercept across all observations and u_j is an unobserved random effects of driver j which is assumed to follow a normal distribution where the mean is zero and the variance is σ^2_u.

Therefore, the merging area in volume level i by participant j can be calculated using:

$$Y_{ij} = n \; if \; \tau_{n-1} \leq y_{ij} < \tau_n, for \; n = 1, \dots, N \tag{3}$$

Where N is the number of ordinal outcomes in Y_{ij} (1 = Area 1, 2 = Area 2, 3 = Area 3, and 4 = Area 4), τ are threshold values describing y_{ij}. The Y_{ij} is divided into the four categories as shown in Table 1.

Table 1: Threshold values for each category

Category	From	To
Area 1	$-\infty$	$\tau 1$
Area 2	$\tau 1$	$\tau 2$
Area 3	$\tau 2$	$\tau 3$
Area 4	$\tau 3$	$+\infty$

To identify the statistically significant variables of the model a likelihood-ratio test was done followed by selecting the most parsimonious models by minimising the Akaike Information Criteria (AIC). To analyse the degree of correlations among the two levels, the Intra-class Correlation Coefficient (ICC) was calculated using:

$$\rho = \frac{\sigma_u^2}{\sigma_u^2 + 1} \tag{4}$$

When the ρ value is larger it shows that a significant variation is presented within drivers preferred merging area and the traffic volume, which justify the need of a multilevel model. Is the ρ value is close to zero an ordered probit model can be used without considering multiple levels.

Finally, to further examine the effect of explanatory variables, the rate of change in the predicted probabilities for each merging area were computed. The marginal effects presented in Table 4 shows the effect of change in merging area when a categorical variable change from 0 to 1 while holding the other variables at their mean values.

3.3 Data collection and processing

The survey was distributed among participants using online and offline platforms. Participation was anonymous and voluntary. Eligibility criteria of the survey included drivers older than 18 years of age, who holds a valid drivers' license and have driving experience of at least 6 months in Australia. The survey design and the data collection process received ethics approval from Deakin University (SEBE – 2022 – 63).

A total of 502 survey completions were identified as valid responses. The survey sample was found to be a representative sample of the Australian population with a similar number of participants across all age groups with about 28% and 40% respondents in the 18-25 years and 26-35 years age groups. About 60% of the respondents were male drivers and 80% had full driving license. One third of the respondents had more than 5 years' driving experience and about 42% had experience of 6 months to 3 years. Less than half of the respondents had some levels of experience with traffic control or road design.

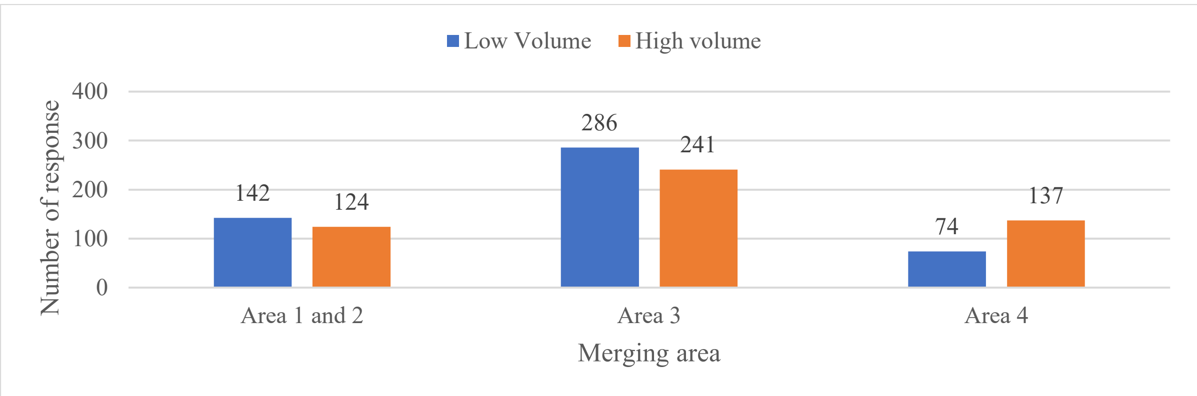
A pairwise correlation test was done to identify variables with significant levels of correlation. As gender and license type had within variable correlations, the categories of these variables were considered in the form of binary variables which removed such correlations. No other correlation between variables were found in the dataset. The descriptive statistics used for further analysis is shown in Table 2.

As presented in Table 2, while Area 3 attracted the largest number of responses, Area 1 had the least number of responses as preferred merging location. Only 8 and 14 respondents noted Area 1 as the preferred merging location under the low and high traffic volume conditions, respectively. Due to the relatively low number of responses, the responses for Area 1 were combined with those of Area 2 for modelling in the MMEOR model as presented in Figure 3.

Table 2: Descriptive statistics

Factor	% (n=502)	% Responses for merging areas at low traffic volume scenario				% Responses for merging areas at high traffic volume scenario			
Age		**Area 1**	**Area 2**	**Area 3**	**Area 4**	**Area 1**	**Area 2**	**Area 3**	**Area 4**
18 - 25 years	27.69	0.8	8.2	13.9	4.8	1.0	7.2	13.5	6.0
26 - 35 years	39.44	0.2	10.4	24.5	4.4	0.6	8.0	22.9	8.0
36 - 45 years	18.73	0.6	4.2	11.8	2.2	0.8	3.6	7.2	7.2
Above 45 years	14.14	0.0	4.0	6.8	3.4	0.4	3.2	4.4	6.2
Gender									
Male	58.57	0.6	18.1	31.1	8.8	1.8	12.9	26.1	17.7
Female, Others	41.43	1.0	8.6	25.9	6.0	1.0	9.0	21.9	9.6
Driving Experience									
6 months - 1 year	20.12	0.2	6.0	12.5	1.4	0.8	4.2	12.7	2.4
1 - 3 years	22.31	0.6	6.0	12.9	2.8	1.0	5.2	10.8	5.4
3 - 5 years	24.1	0.4	5.8	14.3	3.6	0.2	6.2	11.6	6.2
More than 5 years	33.47	0.4	9.0	17.1	7.0	0.8	6.4	12.9	13.3
License type									
Full driving license	78.88	0.8	20.1	44.6	13.3	1.6	14.3	38.4	24.5
Other	21.12	0.8	6.6	12.4	1.4	1.2	7.6	9.6	2.8
TCExp									
Yes	46.61	1.0	10.6	29.7	5.4	0.6	10.2	21.9	13.9
No	53.39	0.6	16.1	27.3	9.4	2.2	11.8	26.1	13.3
Highspeed road use									
Daily	14.54	0.2	3.2	9.0	2.2	0.4	2.4	5.8	6.0
4-6 days a week	23.51	0.4	9.0	11.8	2.4	0.4	5.8	11.8	5.6
2-3 days a week	24.1	0.4	6.4	14.5	2.8	1.2	4.2	13.3	5.4
Once a week	21.12	0.6	4.6	12.5	3.4	0.4	5.6	9.8	5.4
Occasionally/ never	16.73	0.0	3.6	9.2	4.0	0.4	4.0	7.4	5.0

Figure 3: Number of drivers merging at each area under low and high traffic volumes



4. Results

The formulated MMEOR model was calibrated using STATA/BE 17.0. The most parsimonious model produced an AIC value of 1994. From the initial set of explanatory variables considered in the model, three variables (age, gender, and highspeed road use) were removed in the most parsimonious model. Table 3 presents the variables along with the beta value, p-values and 95% confidence interval. Since area 1 and 2 was combined for the analysis, only two threshold values ($\tau 2$ and $\tau 3$) will be used for Equation 3. Marginal effects of the variables retained in the most parsimonious model are also presented in Table 4.

The ICC value for the fitted model was 0.2 with a between-driver variance of 0.24. The between-driver variance accounts for 20% of the total variance which strongly suggests that a multilevel model is preferred over a general ordered model for this dataset. The model results are further described in the following sections.

Table 3: Estimates of multilevel ordered probit model

Explanatory variable	Description	Beta	P-value	[95% Conf. Interval]	
Age		-			
Gender		-			
Driving Experience	6mo - 1 year	ref			
	1 - 3 years	0.21	0.107	-0.05	0.47
	3 - 5 years	0.23	0.080	-0.03	0.48
	more than 5 years	0.37	0.003	0.12	0.61
License type	Full	ref			
	Probationary and Learner	-0.48	<0.001	-0.70	-0.26
TCExp	No TCExp	-0.14	0.110	-0.31	0.03
Highspeed road use		-			
Traffic volume	High Volume	0.30	<0.001	0.16	0.45
Thresholds	$\tau 2$	-0.53		-0.75	-0.30
	$\tau 3$	1.13		0.89	1.37
Panel variance	Level 2 variance	0.24		0.12	0.48
	Level 1 variance	1.00			
	ICC	0.20			
Summary statistics					
Log-likelihood (model)	-987.84				
AIC	1993.68				

- Not retained in the most parsimonious model

Table 4: Marginal effects

Factor	Description	Area 1 and 2	Area 3	Area 4
Driving experience	6 months - 1 year	ref		
	1 - 3 years	-6.14	0.77	5.37
	3 - 5 years	-6.57**	0.82	5.75**
	More than 5 years	-10.64*	1.33**	9.31*
Licence type	Probationary and Learner	13.82*	-1.73*	-12.09*
TCExp	No TCExp	4.00	-0.50	-3.50
Traffic volume	High Volume	-8.68*	1.09*	7.60*

* Significant at 95% confidence level, ** Significant at 90% confidence level

Model results showed that experienced drivers prefer to move to the exit lane at earlier locations (areas 4 and 3) than the less experienced drivers. Drivers with more than 5 years of driving experience were 9.3% more likely to merge at Area 4 and 10.6% less likely to merge at Area 1-2 than drivers with experience of 6 months to 1 year. Similar results were found for drivers with 3-5 years' experience (5.8% more likely to merge in Area 4 and 6.6% less likely to merge in Areas 1-2). The results for drivers with 1-3 years' experience were not statistically significant at 90% confidence level.

Probationary and learner drivers were more likely to merge late than drivers with full license. Marginal effects showed a 13.8% higher likelihood of merging in Areas 1-2 and a 12.1% lower likelihood of merging in Area 4 by the probationary and learner drivers than the full-licensed drivers.

Drivers' experience in traffic control and road design (TCExp) appeared to influence their preference of merging locations, however, the results were not statistically significant at 90% significance level. It is noted that this variable was retained in the most parsimonious model despite its statistically non-significant results.

Under high traffic volume condition, drivers had greater likelihood of merging early than for low volume condition. Marginal effects showed that Areas 4 and 3 had 7.6% and 1.1% higher likelihood of being preferred for merging in high volume condition than low volume condition. Similarly, the corresponding reduction in likelihood for Areas 1-2 was 8.7%.

5. Discussion

This study analyses driver preference of merging locations in freeway exit areas under two traffic volume conditions. Results from the analysis of the driver perception survey data showed that driver' preferred merging locations vary significantly for high and low traffic volume conditions, as well as for different demographic characteristics of the drivers. These findings add new knowledge to the literature on drivers' merging behaviour in freeway exits. More experienced drivers are found to merge early when exiting freeways. Merging early at mandatory lane merging scenarios can avoid making risky manoeuvres (Tarko and Shamo 1999; Datta et al. 2004). Even though both mandatory lane merging and discretionary lane merging take place at off-ramp areas, this study focus on mandatory merging, therefore, as found in past studies merging early can avoid any confusion and accepting smaller gaps closer to the exit. Similar results were obtained from license type. Drivers holding probationary or learner permits were found to merge late at off-ramp areas than drivers with full licence. Probationary license holders and drivers with learner permits might prefer to merge late to reduce their travel time in high volume conditions (Beacher et al. 2005). This shows that when drivers are more experienced in driving, they would prefer to take less risks on the road when compared to the relatively new drivers. The marginal effects also show that less driving experience and probationary or drivers with learner permits are most likely to merge at Areas 1-2 which may be associated with accepting small gaps for merging (Jin et al. 2017).

Even though age and gender were not retained in the calibrated model, past studies found these variables to influence driver behaviour including merging behaviour. For example, young drivers are reported to be more likely to have more risky behaviour at merging areas than other drivers. Studies showed that young drivers accept smaller gaps for mandatory lane merging (Ali et al. 2019) and drivers younger than 30 years are more involved in high risk traffic conflicts than mature age groups (Montgomery et al. 2014). Findings on the gender effects on merging behaviour have been mixed in the literature. Some studies found that gender did not influence driving behaviour at lane changing scenarios (Li et al. 2015) and occurrence of work zone related crashes which require mandatory merging (Koilada et al. 2020). In contrast, some studies found that gender have a direct impact on a drivers merging related decision making (Yan et al. 2007; Weng and Meng 2011; Hang et al. 2018; Duan et al. 2020).

Age, driving experience and license type were expected to have some levels of correlation between the variables. However, a pairwise correlation test showed that no significant relationship was present between these variables. It could be assumed that the survey was completed by a significant number of international drivers living in Australia with limited driving experience in Australia but falls within a higher age group category. This assumption can also explain the absence of any significant relationship between driving experience and license type.

Apart from the demographic factors, this study has evaluated the driver merging preference under two traffic volume levels. The results show that under high traffic volume drivers will merge to the exit lane earlier than under low traffic volume. A potential reason for such behaviour could be related to the difficulty of finding a suitable gap under high traffic volume condition. A simulation study (Mo et al. 2020) reported that merging in advance under high traffic volume is more efficient that late merge at off-ramp areas. In addition, Weng et al. (2015) reported that drivers tend to make risky manoeuvres with increased elapsed time after their decision point of a merging manoeuvre. As such, the probability of crashes could increase for drivers who are unable to complete their merging manoeuvre at their preferred merging locations.

While this study presents new knowledge on drivers preferred merging locations at freeway exits, it has some potential limitations which could be addressed in future studies. Use on a stated preference survey method in the study allowed gathering information on drivers' preferences, but this data was not possible to be compared with actual driving behaviour. Further studies need to be done using video recordings to understand the difference between driver preference and actual behaviour at off-ramp merging and to identify the other traffic related factors influencing driver merging behaviour. Future studies should also look at a larger number of traffic volume conditions to understand how the preferred merging locations vary with traffic conditions, as well as consider alternative model structures for the dataset including a random parameter model by treating the response variable as a nominal variable.

6. Conclusion

A multi-level mixed effect ordered probit model was formulated and calibrated to analyse drivers' preferred merging locations at freeway exits and the influential factors of driver preferences. The model was calibrated using data from a survey of 502 drivers in Australia.

Results showed that drivers preferred to merge early to exit lanes in high traffic volume conditions. Experienced drivers tended to prefer merging early and drivers with probationary and learner driver licenses preferred to merge late than other drivers. The gender and age of drivers did not show any statistically significant relationships with their preferred merging locations.

Findings of this study provide a base for future studies to understand drivers' observed merging behaviour and compare those with the findings of this study on the preferred merging locations at freeway exits. The findings can also be useful in developing simulation models of merging events at freeway exits and making freeway operations more efficient and safer.

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