



A Car Lane-Changing Model under Bus Priority-Lane Effects

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Abstract

Car lane-changing behaviour has been well investigated at merging locations or weaving sections where the lane-changes are usually due to different origin-destination trip purposes. However, the lane-changing behaviour under the effects of bus priority-lanes in urban streets has not been received much attention. This kind of behaviour is found to initially depend on the existence of oncoming buses in priority-lanes in urban streets. In this paper, a car lane-changing model under bus priority-lane effects in urban streets is proposed. This model comprises three steps: looking-back threshold determination, gap acceptance model and execution model. The model's parameters are estimated jointly by using the Maximum Likelihood Method. The research results show that the car lane-changing behaviour under bus-priority-lane effects in urban streets is considered compulsory behaviour. The behaviour has specific characteristics with smaller critical gaps compared with those at other normal lane cases and can be modelled by the proposed model.

Keywords: Bus priority-lane, car lane-changing model, gap acceptance model.

1. Introduction

In terms of bus priority schemes, it is easy to find out many definitions for bus lanes from literature reviews. Indeed, with-flow bus lanes, contra-flow bus lanes, bus ways are defined as link based measures to give priority to buses (Kevin, G., 2009). Specifically, with-flow bus lane is defined as a roadside reserved traffic lane for the use of buses and may accommodate bicycles (DETR, London, 1997). Meanwhile, contra-flow bus lane is a lane where buses are allowed to travel against the main direction of traffic flow. Being segregated from general traffic, bus-ways are designed for the exclusive uses of buses. This bus lane type can protect buses from congestion and make the trip faster as well. In a more detailed aspect, HCM (2000) categorizes bus lanes into three types. For type 1, bus lanes have no use of adjacent lane. In type 2, bus lanes have partial use of the adjacent lane, which is shared with other traffic. Lastly for type 3, bus lanes are provided for exclusive use of two lanes by buses. It can be seen that, the

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category was based on the degree of exclusivity of bus lane. The greater the degree of exclusivity of bus lane and the greater the number of lanes available for buses to manoeuvre, the greater the bus lane capacity. Similarly, a report released by National Capital Region Transportation Planning Board, Washington (2011) divided bus lane types into exclusive lane, restricted lane and unrestricted lane. In which, exclusive lane is reserved solely for use by buses and other government vehicles such as emergency vehicles. Restricted lane is reserved for buses and high Occupancy vehicles. Unrestricted lane is a lane in which buses operate in mixed traffic with no special provisions to improve operations. However, in Japan, the category of bus lanes is divided into three types, including ordinary lane type (in which buses travel in mixed traffic flow), exclusive bus lane type and bus priority-lane type as illustrated in Figure 1. The bus priority-lane is a special bus lane and be concerned in this research.

The bus priority-lanes have been deployed in urban streets of Japan for years. This is a bus lane type that has performed as a countermeasure for congestion (Kunihiro et al., 2007). The bus priority-lane is defined as a lane in which buses have priority in travelling. Once an oncoming bus comes in the priority-lane, passenger cars travelling in this lane have to change lane to give space for the oncoming bus (Koyama Kotsu, 2001; The MCB Butler Installation Safety, 2008). It can be said that, this lane-changing behaviour occurs under the effects of oncoming buses in the priority-lane. The lane-changing cars recognise the priority of the buses in lane usage and must change lane. Due to this flexibility of passenger cars in lane usage, bus priority-lanes can improve the bus level of service and lessen negative impacts on passenger cars simultaneously (Tu et al., 2012). Related to the paper's title, two groups of previous papers are briefly reviewed in this section. One group concerns with lane-changing models and the other is about bus lane studies.

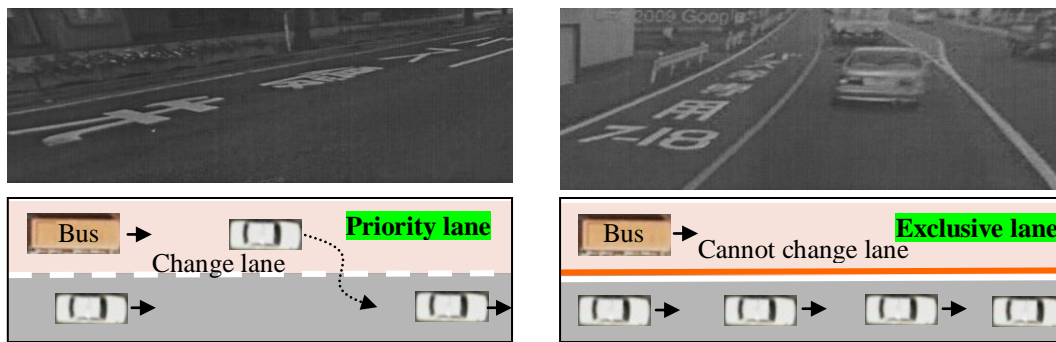


Figure 1: Bus priority-lane (left) and exclusive bus lane (right)

There have been many research studies about bus lanes and lane-changing models as well. However, a car lane-changing model under bus priority-lane effects has not been received much attention. Indeed, many previous papers proposed successfully lane-changing models for various vehicle types such as cars (Kazi, 1999), motorcycles (Minh et al., 2012) in different travel facilities such as urban street (Varun, 2007), freeway (Charisma, 2005). The lane-changing behaviour was studied just at merging locations (at ramps) or weaving sections with a typical lane-changing process including lane selection model, gap acceptance model and execution model (Charisma et al., 2007). In other words, most of the lane-changing models were built under the effects of different Origin-Destination (OD) pairs or different cost perceptions. Meanwhile, the lane-

changing behaviour in the case of having bus priority-lanes is quite different from that in previous studies. The effects of oncoming buses in priority-lanes cause the lane-changing manoeuvre of passenger cars unexpectedly as well as take shape new features of the lane-changing behaviour.

For studies on bus lanes, many bus lane types (TRB, (2000)) including queue jump lane, with-flow bus lane, confront bus lane, exclusive bus lane, etc. have been main objects in many research studies from the beginning. However, studies concerning bus priority-lane effects have been received less attention. In the early time, the assignment of special lanes to bus was studied with investigations on the changes in bus travel time and bus speed (Cox, 1975). Several papers tried to develop a decision model (Huanyu et al., 2003) for bus lanes, setup methodologies and criteria of exclusive bus lanes (SEO et al., 2005), or investigate the change in travel times when adding lanes to traffic networks (Joy et al., 1998; Venkatachalam, T. A. and Perumal, V., 2008). Effects on bus travels and general vehicle travels were considered not only for with-flow bus lanes (Shalaby, S. A. and Soberman, M. D., 1994) but also for exclusive bus lanes (Lin et al., 2010). These effects were studied not only on hypothetical traffic networks (Huanyu et al., 2003), but also on real traffic networks (Amer, 1999; Hyung, 2003; Tanaboriboon, Y. and Toonim, S., 1983). From the literature review, it is easily seen that exclusive bus lane was the major topic in most of the research studies. Recently, Kunihiro et al., (2007) have examined the effectiveness of bus priority-lane in Shizuoka, Japan. The conclusion was merely based on empirical data analysis. Tu et al. (2012) has tried to comparatively analyse three popular bus lanes, including bus priority-lanes in Japan. Their research ended at analysing the advantages of bus priority-lanes in the aspect of city planning for bus operations. The development of proper models for bus priority-lanes has not been received much attention commensurate with its advantages. Therefore, developing a car lane-changing model under bus priority-lane effects is necessary to get a comprehensive understanding about the benefits when bringing it into practice.

This paper consists of 6 main parts; each part deals with its relevant aspects. This research's overview is presented in this section, Section 1 – Introduction, and then followed by Section 2 – Research objectives, in which the main targets are presented and elaborated. Section 3 describes in detail the methodology used in this paper. The result of the estimation is illustrated in Section 4 to show how large the influence of each factor in the proposed model. Section 5 shows a comparison between critical gaps in the proposed model and those in previous studies. Finally, the paper ends with several conclusions and recommendations presented in Section 6.

2. Research objectives

The paper aims at two objectives. The first objective is the development of a car lane-changing model under bus priority-lane effects in urban streets. This model comprises three steps: looking-back threshold determination, gap acceptance model and execution model with parameters being estimated by using maximum likelihood method. In terms of critical gap comparison, the second objective of this paper is a comparison of the lane-changing behaviour under bus priority-lane effects in the proposed model to that at merging or weaving locations in previous studies. The comparison aims at clarifying the special lane-changing behaviour in the studied situation in particular as well as providing a more comprehensive view on the behaviour of changing lane in general.

3. Methodology

3.1 Research assumptions

Some assumptions are used in the model:

The proposed model is applied to traffic cases in Japan with the most left lane being considered the bus priority-lane. The effects of oncoming buses are supposed to influence mostly on non-turning-left cars that are currently travelling in the priority-lane. Under bus priority-lane effects, an affected passenger car will change into adjacent lane to give the priority-lane to the oncoming buses. Passenger cars which are going to turn left or currently travelling in the other lanes are supposed to be not affected by the coming buses. The lane-changing behaviour of these cars as well as the behaviour of changing lane that is not caused by the bus effects is beyond the scope of this research.

The looking-back threshold of a vehicle's driver is defined as the longest distance between that vehicle and the nearest behind bus in the priority-lane. This distance is considered at the moment that the vehicle starts to turn on the winker before changing the lane. The looking-back threshold is assumed to follow the normal distribution. A car is considered under the bus effects when the distance back to the behind bus (d) (as shown in Figure 4) is shorter than the looking-back threshold of that car's driver.

3.2 Car lane-changing model

The lane-changing philosophy of a passenger car under bus priority-lane effects is proposed in this part. Firstly, based on the looking-back threshold, a car recognises oncoming buses in the priority-lane (step 1). If the current lane is the priority-lane, the car will find its satisfying lead gap and lag gap (step 2) and then make a decision of changes (step 3). If all the above conditions are satisfied, a manoeuvre from the priority-lane to its adjacent lane will occur to give space for the coming bus. However, as a real behaviour at the studied sites, the above lane-changing philosophy is not applied to left-turning cars which have no choice to change lane because of safety and lane-usage's regulations. The details of the structure are shown as in Figure 2.

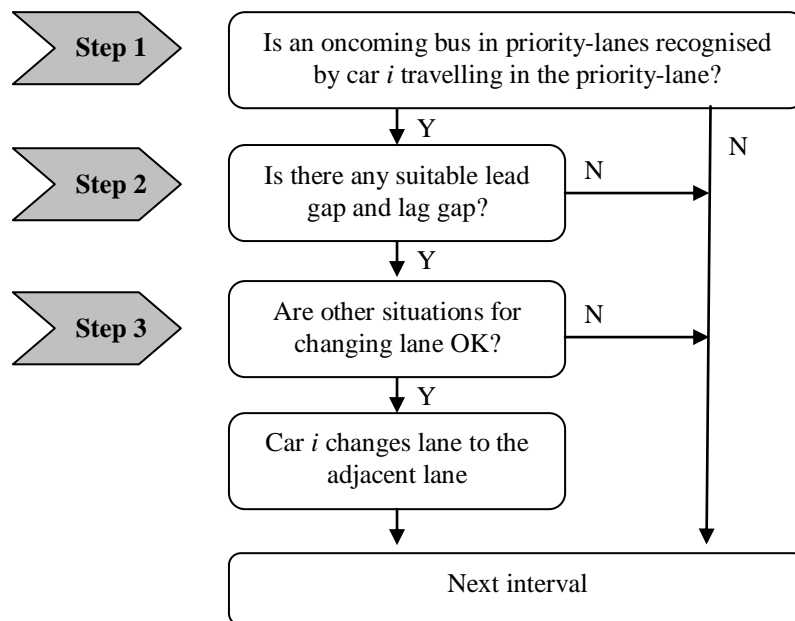


Figure 2: The structure of a car lane-changing process caused by bus effects

3.2.1 Looking-back threshold determination (step 1)

This step is suggested to determine the looking-back threshold of a vehicle's driver. This value is assumed to be different for different drivers and follow the normal distribution. While driving, approximately 90 percent of the information drivers use is visual (Roger et al., 2004). According to the Universal Traffic Management Society of Japan (UTMS), information displayed on warning display board helps passenger cars recognise oncoming buses. However, in reality, vehicle's drivers have to recognise oncoming buses through the rear-view mirrors on their cars. The probability for a car n at time t to recognise oncoming buses is defined as follows:

$$P(r_{t,n}) = \begin{cases} 1 & , \text{ If } d \text{ is less than looking-back threshold} \\ 0 & , \text{ Otherwise} \end{cases} \quad (1)$$

The looking-back threshold is determined based on the recorded videos and field observation (detailed in Figure 5, Figure 6). With Kolmogorov-Smirnov Test (test statistic $Z=1.017$; Most Extreme difference $D=0.069$; and $P\text{-value}=0.252 > 0.05$), the threshold distribution can be considered a normal distribution as shown in Figure 3.

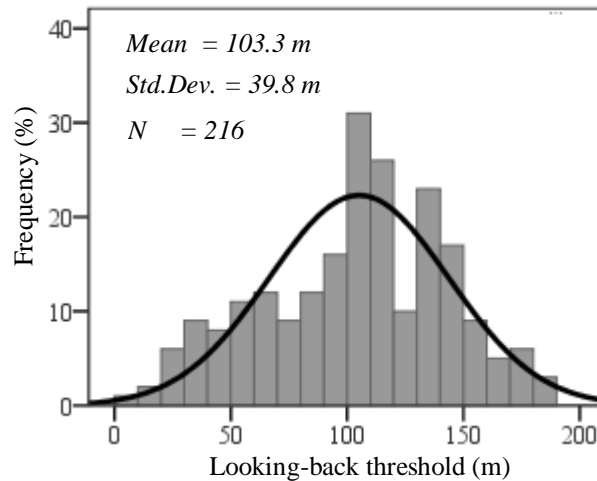


Figure 3: Looking-back threshold distribution

3.2.2 Gap acceptance model (step 2)

Like many previous papers about lane-changing models (Charisma et al., 2007; Kazi, I. A., 1999; Minh et al., 2012), this study also uses the concepts of lead gap and lag gap in the gap acceptance model. The gaps between the subject vehicle and the lead vehicle, the lag vehicle in the adjacent lane are defined as the lead gap and the lag gap, respectively. The displays are illustrated in Figure 4.

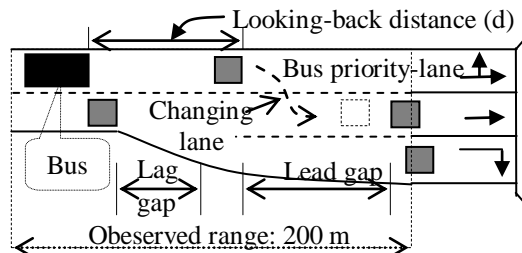


Figure 4: Lead gap and lag gap at the studied site

The minimum acceptable space gaps are defined as critical gaps. These gaps are used to evaluate the current gaps and assumed to follow lognormal distributions:

$$\ln(G_n^{cr,lead}(t)) = \beta^{cr,lead} X_n^{cr,lead}(t) + \varepsilon_n^{lead}(t) \quad (2)$$

$$\ln(G_n^{cr,lag}(t)) = \beta^{cr,lag} X_n^{cr,lag}(t) + \varepsilon_n^{lag}(t) \quad (3)$$

where

$G_n^{cr,lead}(t)$, $G_n^{cr,lag}(t)$ are critical lead, lag gaps, respectively for vehicle n at time t (m);

$X_n^{cr,lead}(t)$, $X_n^{cr,lag}(t)$ are the vectors of the explanatory variables of the lead gap and lag gap, respectively;

$\beta^{cr,lead}$, $\beta^{cr,lag}$ are the vectors of the unknown parameters of the lead gap and lag gap, respectively;

$\varepsilon_n^{lead}(t)$, $\varepsilon_n^{lag}(t)$ are the random terms associated with the lead gap and lag gap, respectively, and assumed to follow the normal distribution.

$$\varepsilon_n^{lead}(t) \sim N(0, (\sigma^{lead})^2)$$

$$\varepsilon_n^{lag}(t) \sim N(0, (\sigma^{lag})^2)$$

where

$(\sigma^{lead})^2$ and $(\sigma^{lag})^2$ are the variances of the error terms in gap acceptance models.

The lead gap and lag gap will be compared with the critical lead gap and critical lag gap, respectively. If the available gaps are larger than the corresponding critical gaps, these available gaps are acceptable and the passenger cars have chance of changing lane. Otherwise, the passenger cars will stay in the priority-lane and wait for next chances. The probability of the gap acceptance for a car n at time t is given by:

$$\begin{aligned} P(Acc | r)_{i,n} &= \Pr(Lead_gap \geq Crit_lead)_{i,n} \cdot \Pr(Lag_gap \geq Crit_lag)_{i,n} = \\ &= \Phi \left(\frac{\ln(G_n^{lead,i}(t)) - G_n^{cr,lead,i}(t)}{\sigma^{lead}} \right) \cdot \Phi \left(\frac{\ln(G_n^{lag,i}(t)) - G_n^{cr,lag,i}(t)}{\sigma^{lag}} \right) \end{aligned} \quad (4)$$

where $\phi(\cdot)$, $\Pr(\cdot)$ are cumulative function of a standard normal random variable and the probability function, respectively.

3.2.3 Execution model (step 3)

Even when a passenger car can find acceptable gaps for changing lanes, this car does not change lanes in some cases due to some reasons. The reasons may include the current speed states, the driver's awareness about advantageous traffic situations at that moment (such as no traffic queue ahead, or just turning-on green signal), or even because of the poor awareness of drivers, etc. The decision of lane-changing execution can be modelled as a binary logit model with the probability function defined by

$$P_e(j_t | v_n) = \begin{cases} \frac{1}{1 + \exp(-(\beta X + \alpha v_n))} & , \text{ if lead gap and lag gap are satisfied} \\ 0 & , \text{ Otherwise} \end{cases} \quad (5)$$

where: j is the lane-changing action, and X are explanatory variables. Driver specific random term v_n that is constant for a given driver is assumed to follow the normal distribution. The final lane-changing action of passenger cars to give space to oncoming buses in the priority-lane is observed.

The probability of such an action consists of three parts: the looking-back threshold probability, the probability of gap acceptance and the probability of execution decision. The joint probability of this combination for a car n at time t is defined by

$$P(J)_{t,n} = P(r_{t,n}) \cdot P(Acc | r)_{t,n} \cdot P_e(j_t | v_n) \quad (6)$$

Assuming the independence of the lane-changing observations of different passenger cars, likelihood function is expressed as follows:

$$L = \prod_{n=1}^N P(J)_{t,n} \quad (7)$$

where N is the number of observations

In summary, the structure of the car lane-changing model proposed in the paper is different from that of previous studies. In this study, the step of looking-back threshold plays a key role for the following lane-changing process to happen. Meanwhile, in the car lane-changing models of previous studies, lane selection model plays an important step. Because of bus effects, the passenger cars travelling in the bus priority-lane perceive the priority of bus in lane usages. They have only one choice that is moving out of the priority-lane to escape the situation. However, the driver's perception finally decides the completion of the lane changes.

3.3 Data collection

Bus priority-lanes have been deployed in Niigata prefecture, Japan for years. The bus priority-lanes on route No.7 connecting Niigata station to the office areas in the northern help improve the transportation system. Data was collected in normal conditions about time, weathers at several points on this route. The recorded cameras are set at the studied site as shown in Figure 5.



Figure 5: The studied site in Niigata, Japan

The total recorded time was 40 hours, including peak hours and off-peak hours. The research used two ways to collect data simultaneously, namely direct observation and recorded video. For direct observation, observers would take note the moment as well as special signals at which lane-changing wipers are on, or the moment that buses come, etc. For video record, the researchers used cameras mounted on high positions to observe lane-changing manoeuvre along urban streets. In the transportation lab, a video based software (Minh, 2007; Minh et al., 2012) was used to analyse traffic data needed for model calibration and validation. The data collected includes lead gaps, lag gaps, speeds, the distance back to oncoming buses at which the passenger car turning on the winker before changing lane out of the priority-lane, etc.

According to Minh (2007), a Coordinate Transformation Technique was introduced to transform screen coordinates to roadway coordinates. This technique was utilized the principles of projective geometry that is derived from one of two fundamental operations in photogrammetry projection. The fundamental principle of the general concept of projection is the theory of cross ratio. After estimating related coefficients in the simultaneous equations of a so-called base points, the coordinate between screen and roadway is matched. Therefore, all screen and roadway coordinates were determined. The information of lead distances, lag distances, vehicle speeds are easy to get by tracking point on the screen and output to excel file. For the accuracy of the data, only “candidate” cars were chosen to measure the speeds and distances. Figure 6 shows the interface of SEV software used to collect data at the studied site. The real distances between base points are directly measured at the site to input real coordination to the SEV software. The interface is as follows:

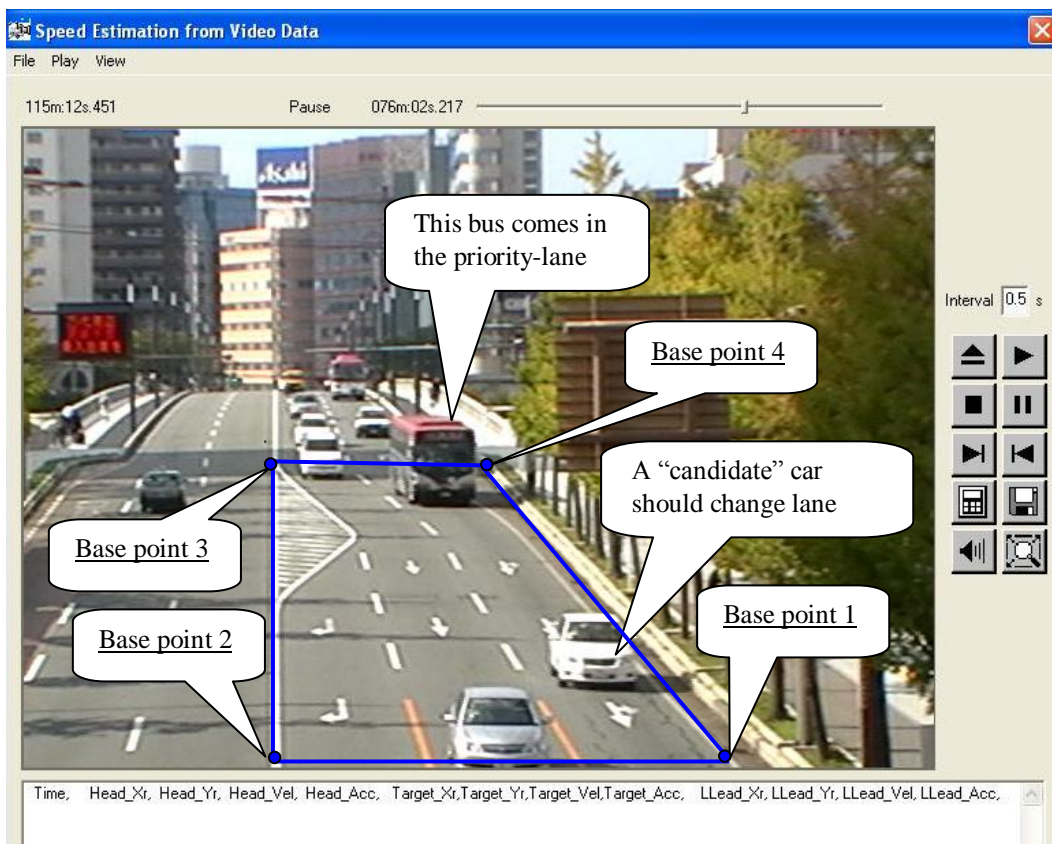


Figure 6: A snapshot of using SEV to collect data

4. Results and analysis

The model is calibrated by maximum likelihood estimation using Newton Raphson method in the statistical estimation software GAUSS. The parameters of lag critical gap, lead critical gap and binary decision as well as their test values can be estimated by programming in the statistical software. The ρ^2 index tests are conducted to evaluate the model performance. The estimated results are illustrated in Table 1.

Table 1: Estimated parameters

Variable	Estimation	t-value
Lag Critical Gap		
Constant	1.587	10.92
$\max(\Delta V_n^{lag}, 0)$ (m/sec)	0.079	3.32
σ^{lag}	0.251	1.99
Lead Critical Gap		
Constant	-0.187	-0.17
σ^{lead}	1.359	1.60
Execution		
Constant	3.158	4.37
$V_n^{subject}$, (m/sec)	-0.202	-3.91
Number of cases = 216		
$L(0) = -148.33, L(\beta) = -116.63, \rho^2 = 0.214$		
$L(c) = -129.60, \rho^2 = 0.100$		

where

$$\max(\Delta V_n^{lag}, 0) = \max(V_n^{lag} - V_n^{subject}, 0) \quad (8)$$

$V_n^{subject}$, V_n^{lag} are speeds of subject vehicle n and the corresponding lag vehicle n , respectively.

The test statistic is $-2(L(\beta)-L(0))=63.40$, which is used to test the null hypothesis, in which all of the parameters are zero. The critical value of the chi-square distribution with 7 degrees of freedom at the 1% level of significance is 18.48. Therefore, the null hypothesis can be rejected at 0.01 level of significance. For the null hypothesis test $-2(L(\beta)-L(c))=25.93$, in which all the parameters other than the alternative-specific constant are zero, the critical value is 9.21, indicating that the null hypothesis can be rejected at 0.01 level of significance.

Like many previous models about lane changes, the positive sign of maximum relative lag speed variable in the lag critical gap function is as expected. Indeed, a large lag gap is required when the speed of lag vehicles is considerably larger than that of the subject vehicle. Despite the low t-values in the lead critical gap results, the lead gaps are necessary for a safe lane change. Unlike most of the traditional results about lead critical gaps, the lead critical gap is independent from the relative lead speed in this study. It reflects that the lane-changing behaviour in the studied situation is compulsory. As soon as a passenger car recognises oncoming buses, it would rather pay attention to the speed of the lag vehicle than concern that of the lead vehicle in finding acceptable gaps. Regardless of how small the lead vehicle's speed is, the passenger car can find a minimum possible lead gap. In addition, the negative sign of the subject speed variable in the function of execution model means that the passenger cars trend to decide

changing lane with low travel speeds. This is reasonable for safety purposes. The simulation results show that the proposed model could produce properly the number of lane changes at the studied location.

5. Critical gap comparison

In this section, the research would like to show a comparison between critical gaps in the proposed model and that of previous studies. As shown in Figure 7, the behaviour of a passenger i changes lane under priority-lane effects in this paper may differ from that in previous studies. In most of the previous studies on car-lane-changing behaviour, the behaviour was considered at merging or weaving locations. The motive of the lane changes is to change the trip direction. There was no any concern with the effect of priority-lane like being investigated in this study. Therefore, the behaviour on critical gap recognitions under priority-lane effects is not the same to that under the conditions of no priority-lane effects. The research conducts the comparison for critical lead gap and critical lag gap in every detail as following parts.

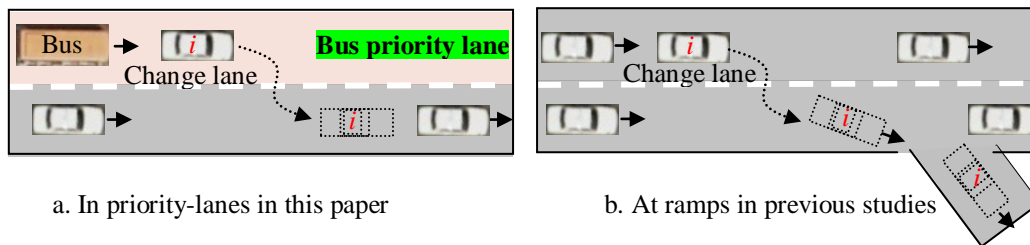


Figure 7: Studied cases for lane-changing behaviour.

5.1 Critical lead gap

Compared with the lane-changing behaviour at traditional merging locations (ramps, weaving sections, etc.) in normal lane cases of some previous studies (Kazi I.A., 1999; Charisma F.C., 2005), the critical gaps in this study have several specific characteristics. Indeed, the relationship between critical lead gap and relative lead speed is shown as in Figure 8.

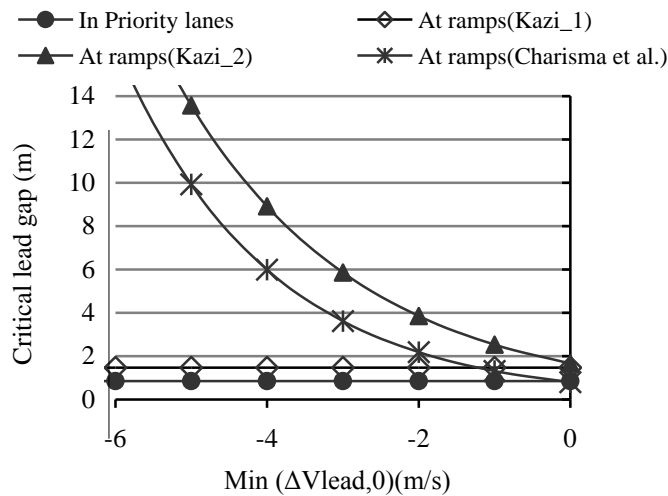


Figure 8: Critical lead gap comparison

where

$$\text{Min}(\Delta V_{lead}, 0) = \min(V_n^{lead} - V_n^{subject}, 0) \quad (9)$$

$V_n^{subject}, V_n^{lead}$ are speeds of subject vehicle n and the corresponding lead vehicle n , respectively.

Traditionally, the critical lead gaps at merging locations in most of the previous studies have strong relationships with relative lead speed differences (stars and triangles marked curves). The smaller the minimum relative lead speed is, the larger the critical lead gaps are needed. However, the critical lead gap in the priority-lane case (circles marked line) is a constant with respect to the relative difference in lead speeds. It reflects the compulsory lane-changing manoeuvre when prioritized buses come. How different the speeds between the subject vehicle and the lead vehicle are, the subject vehicles can find a minimum critical gap in the cases of priority effects. Except smaller values in terms of average critical gap, the critical lead gap in the studied case looks similar to that of in the compulsory model (squares marked line) developed by Kazi I.A., (1999). But, the motivations of finding gap are under different locations (ramps, weaving sections versus urban segments) and different lane-changing purposes (OD trips or perceived costs versus bus effects). The smaller values of critical lead gaps in this study tell somewhat the passivity of passenger cars when buses come.

5.2 Critical lag gap

Similarly, with respect to relative lag speed, the curve of critical lag gap in the studied case is generally smaller than that of other studies as shown in Figure 9.

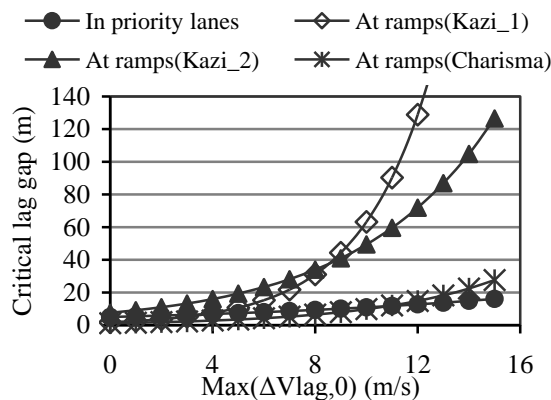


Figure 9: Critical lag gap comparison

The critical lag gap in the priority-lane effects slightly depends on the relative lag speed between the subject car and the lag car in the adjacent lane. Meanwhile, the curves in the other cases show a strong relationship between critical gaps and relative lag speed, especially the case study at ramps in the research of Kazi, I. A., (1999). The less dependence on the relative lag speed in this study is somewhat caused by the existence of buses in the priority-lane. After recognizing an oncoming bus in priority-lane, car's drivers perceive the priority of the bus and try to find suitable gaps to change lane. The critical gaps in this situation are not as usual even with a big relative lag speed difference. This reflects the lane changes in this situation is a compulsory lane changes. However, because of the compulsoriness in changing lane, the safety level should be an important point to consider. The consideration is for not only city planers on deploying

bus priority-lanes but also for car's drivers on adjustment the speeds before changing lanes.

6 Conclusion and recommendation

6.1 Conclusion

The research proposes a car lane-changing model under bus priority-lane effects in urban streets. Unlike any previous car lane-changing model, this model consists of three steps: looking-back threshold determination, gap acceptance model and execution model. These three steps are represented for the philosophy of a lane-changing manoeuvre of passenger cars under the influence of oncoming buses. Once a passenger car recognises oncoming buses travelling in the priority-lane, this passenger car will evaluate the acceptable lead and lag gaps. If the acceptance model is satisfied, the car will revise the execution decision and decide that whether the lane-changing manoeuvre should be completely executed.

To calibrate the model and analyse the special lane-changing behaviour under bus priority-lane effects as well, the research conducts two periods of calculation. The first period concerns with using actual data to calibrate the model parameters by applying the method of Maximum Likelihood estimation. The estimation results with satisfying statistic tests are as expected. The positive sign of maximum relative lag speed variable in the lag critical gap function is reasonable. It means that a large lag gap is required when the speed of lag vehicles is considerably larger than that of the subject vehicle. The lead critical gap is independent from the relative lead speed in this study. It reflects that the lane-changing behaviour under bus priority-lane effects is compulsory. As soon as a passenger car recognises oncoming buses, it would rather pay attention to the speed of the lag vehicle than concern that of the lead vehicle in finding acceptable gaps. The second period is to compare the differences in perception behaviour of lane-changing cars under priority-lane effects and under no such effects. This comparison was conducted in terms of critical lead gap and critical lag gap. The results show that the lane-changing behaviour under bus lane effects has specific characteristics with smaller critical gaps when compared with that of the cases of no bus lane effects. The less sensitive relationship between critical gaps and its corresponding relative speed is the consequence of the existence of buses in priority-lane. The interference makes car drivers understand the priority of the buses in lane usages and change lane to give space to the buses. Because of the priority recognition in this situation, the research would like to send a message on warnings of traffic accident to car drivers and city planners. Although the lane-changing behaviour could help the bus service more convenient, it may obstruct the traffic in the other lanes by interference or accidents. Therefore, a safe lane change requires a full control of the car's speed as well as careful observation. City planners should consider more about the maximum permitted speed or other safety requirements before deploying bus priority-lanes in urban streets.

6.2 Recommendation

The data about lane-changing manoeuvre, lane-changing gaps as well as traffic characteristics were collected by setting videos at high positions to record the traffic stream along the street. The longitudinal observation field of the recorded videos was not large enough, around 200m long, causing the loss of data outside the observation field, making difficulties in upgrading the model. Moreover, the lane changes which are assumed to be not caused by the effects of bus priority-lanes in this paper have not been

investigated much. A further research study with advanced methods of data collection should consider more detailed the behaviour of car drivers when buses come. In addition, the priority effects on trucks or turning left cars were also not considered in this research. It should be considered more in further studies.

Looking-back threshold determination is an important part in the proposed model to recognise oncoming buses. However, the development of the looking-back model in this research remains several weak points. The looking-back threshold depends on not only driver characteristics but also the vehicle types, surrounding geometry, etc. Thus, this model should be received more comprehensive investigation. Moreover, the aspect of state dependency among sub-models over time as well as other influent factors such as the distances between oncoming buses and subject vehicles, the effects of the distance from the subject vehicles to intersections, lane flow density, geometry feature, etc also need more concern in future works.

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