A NEW MEASURE QUANTIFYING DRIVERS' DECISION MAKING BEHAVIOR WHILE FACING AMBER LIGHT

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ABSTRACT

For years, great attention has been drawn to the Dilemma Zone (DZ) problem as it has been questioned as one of the causes to the high traffic accident records at signalized junctions. This problem has far been investigated in engineering perspectives, but few attempt to investigate influences of drivers' decision making behavior. Since Zegeer and Dean (1978), Logistic regression model has commonly been adopted to simulate drivers' STOP/GO decision and figure out DZ boundary; Discrete choice model, for instance Logit model which has similar underlying nature as the Logistic regression model has however few been used. The un-popularity of the Logit model might be because it requires individual attributes for establishing utility functions of STOP and GO decisions; only field observed data cannot be used for this purpose. Therefore, a new measure termed *generalized distance* was proposed. The proposed measure is of two folds: (1) it is used to quantify and assess drivers' decision making behavior; and (2) it can be used to establish utility functions of STOP and GO decisions and thus Logit model was adopted in this study. The results reveal that, during the observation period, drivers were more likely to GO at amber; and, interestingly, drivers who maneuvered over speed limit were more likely to STOP. The findings of this study also suggest that drivers' decision making behavior should first be assessed as to decide appropriate road safety interventions for the reported problem.

Keywords: Dilemma Zone; signalized junction; decision making behavior

INTRODUCTION

Traffic signal controlled design is commonly adopted at intersections with high traffic demand and popularly used in urban areas due to complex traffic patterns. This design is expected to have systematic control on traffic coming across the intersecting area, thus optimizing road networks efficiency and preventing road users from traffic accidents due to conflicts. As far as signalized intersections being widely used, the comparatively high traffic accident records appear to reflect that traffic signal control may not function well in safety respect as anticipated. The inefficiency in preventing road users from traffic accidents has been well studied with two main conclusions: First, drivers' disobedience. Drivers have been reported to violate traffic regulations including speeding and red-light running leading to the high accident records at signalized junctions (e.g. Retting and Greene, 1997; Lum and Wong, 2003; Retting et al., 2008; Fitzsimmons et al., 2009; Archer and Young, 2009); Second, imperfect traffic signal design. When designing traffic signal time, particularly amber time, deterministic average values of drivers' reaction response time and acceleration rate are used. For those drivers who are relatively incapable of having rapid reaction or aggressive in driving, the assumed values adopted in the design might not cover their needs and thus they are more likely to subject to more risky traffic conditions at amber (e.g. Gazis et al., 1960; Shinar and Compton, 2004; Papaioannou, 2007). To deal with the first problem, traffic administrators normally take actions on raising fine levels and either increasing demerit points or decreasing merit points to strictly penalize drivers who disobey traffic regulations. In addition, the government would launch road safety campaigns to educate drivers and the public as to promote road safety and achieve annual accidents reduction targets. In regard to the second problem, due to the diversity of drivers' driving behavior and skills, it is hard to have definite solution that suit for the need of every driver. This would probably be the reason why traffic accident problem at signalized junctions has not yet been solved.

In the past decades, Gazis et al.'s (1960) suggested that the improperly timed amber duration problem leads to the high traffic accident records at signalized junctions. They explained that, at the instance of amber onset, drivers can neither safely stop at the stop line nor completely pass through the intersection before the red light commences. This expression has been commonly known as Dilemma Zone (DZ) problem. Gazis, Herman and Maradudin thus set up formulation based on drivers' approaching speed, reaction response time and acceleration rate to determine minimum amber duration in safety respect. They claimed that the DZ problem could be eliminated if amber time is comply with the minimum requirement governed by this formulation which has late been named as GHM model. On the basis of the GHM model, great efforts have initially been paid onto relieving drivers' dilemma by extending amber duration. The late review has however reported that providing sufficiently long amber time cannot essentially solve the problem, the crucial factor is that drivers should approach signalized junctions with speed level not higher than the threshold value adopted in the signal design, i.e. design speed limit (Liu et al., 1996). Despite that, the model may not be generalizable to fulfil drivers' needs as deterministic average values of drivers' acceleration rate and reaction response time are adopted in the model. These parameters may not sufficiently good to represent the diversity of driving behaviour on roads (Liu et al., 1996); and it is a doubt that whether or not drivers become more likely to GO under extended amber duration, leading to another traffic accident problem. In response to the limited coverage of diversified driving behavior using deterministic approach, Zegeer and Deen

(1978) proposed a probabilistic model to formulate DZ problem; unlike the GHM model, this model is used to figure out the boundary that drivers are likely to face difficulty in making STOP/GO decision. The length of this boundary can also be used as an indicator to assess the degree of seriousness of DZ problem, but not for finding minimum amber duration. For clarity, Zegeer and Deen's (1978) model has late been named as Type II DZ and the GHM model has been named as Type I DZ (Parsonson et al., 1974).

For years, two models have been extensively used for different purposes: Type I DZ (i.e. the GHM model) is fundamentally used for determining minimum amber duration; Type II DZ is commonly used for assessing the degree of seriousness of DZ problem and efficiency of remedial measures for tackling DZ problem: shorter the DZ boundary, lesser the seriousness. In addition, as the Type II DZ is obtained by binary regression model (i.e. Logistic regression model), the calibrated model can be used for predicting drivers' STOP/GO decision, facilitating signal time extensions for vehicles falling within DZ boundary as to avoid conflicts. Because of this, effects of different traffic conditions as well as spatial and temporal characteristics on DZ boundary have been widely investigated as to enhance prediction accuracy. Correlation between DZ boundary and vehicle type, platooning condition, arrival type as well as time-of-day has been found (e.g. Wei et al., 2009; Gates and Noyce, 2010; Li et al., 2010; Wei and Li, 2009). With these multi-parametric prediction models, traffic operators could be able to provide signal extensions for driver who is predicted to decide to GO in the condition that the driver cannot completely clear the intersection before red light commences, i.e. the driver would probably run red-light. This measure might however be inefficient because prediction may not often 100% correct and drivers may subject to another dilemma under dynamically extended traffic signal. In particular, for drivers who routinely drive across the same junction, s/he would probably know when the green signal yields and how long the amber signal lasts for. S/he would thus make decision based to its familiarity and experiences. Therefore, drivers might feel hesitate that the signal time is randomly changing and thus they cannot make their own decisions based on their experiences and familiarities with the junction, if the junction is ameliorated by signal extension measures. Attributes regarding engineering design including traffic signal time and design speed limit have also been considered in the literature with the conclusions that DZ problem is likely to exist if, particularly, vehicles approaching speed is over the design speed limit used for the determination of amber duration (Shinar and Compton, 2004; Papaioannou, 2007). That's mean if drivers obey traffic regulations, DZ problem should theoretically not exist; but, in reality, even though drivers manoeuvre below design speed limit, their diversified abilities in driving might have influences on DZ problem occurrence. This is because not all the drivers are able to react as rapid as expected and thus their longer reaction time would lead to DZ problem (El-Shawarby et al., 2010). It leaves another issue that DZ problem could be derived from drivers' inabilities, but not improperly timed amber duration or drivers' speeding violence.

While discussing drivers' abilities, reaction response time is one of the popular surrogate measures that has been widely used in the literature. This is because, theoretically, drivers' reaction time is an imperative attribute used for the determination of minimum amber duration as defined in the GHM model. In general practice, the value of reaction response time is obtained from the cut-off of tail of the distribution curve of drivers' reaction time under the population. In case of drivers who are aged over 60, they may require longer reaction time to make STOP/GO decision in response to amber as they are less reactive than young drivers. Their slow-reactions might not be covered by the assumed value adopted in the model, thus they would probably be more likely to suffer from DZ problem. In fact, a study was conducted investigating drivers' reaction response time under controlled traffic conditions, concluding that female and older drivers (age over 60) require longer reaction time than other drivers supporting the above discussion (Massie et al., 1995; Lourens et al., 1999; Gates et al., 2007; Liu, 2009; El-Shawarby et al., 2010). In addition, presence of variations of drivers' reaction response time was reported at junctions with different gradients and vehicle platooning conditions. More specifically, drivers' reaction response time is longer when following a vehicle running yellow compared to being the leading vehicle (El-Shawarby et al., 2010). Other factors including time-of-day, vehicle types and approaching speed were also reported to have significant influence on drivers' reaction response time at amber (Gates and Noyce, 2010). Apart from drivers' performances under general situations, effects of different weather conditions on DZ boundary have been examined. Sharma et al. (2010) reported that drivers manoeuvred differently under wet pavement due to raining and snowing, but the changes in DZ boundary from dry to wet pavement condition is not comparable to the degradation of pavement frictions. This indicates that drivers that were observed in the study did not properly respond to inclement weather condition, even though they did adjust their manoeuvres.

As far as studies concerning DZ problem discussed above, that driving behavior (e.g. speed choice and STOP/GO propensity) and drivers' capabilities (e.g. reaction response time, driving skills and experiences) could be imperative to the occurrence of DZ problem has however few been studies. It seems that there is a need to have an in-depth investigation of how road users respond to the current traffic signal system, then to provide corresponding remedial measures to tackle the reported problem. A review of literature shows that several studies attempted to look into the correlation between drivers' decision making behavior and DZ problem. To name a few, Elmitiny et al. (2010) attempted to find out the most influencing attribute of drivers' STOP/GO decision as well as red-light violation using Classification and Regression Trees (CART). They concluded that vehicle distance from stop line surpasses approaching speed when deciding STOP/GO decision while facing amber and the occurrence of red-light violation; and Papaioannou (2007) who is probably the first one examining the implication of speeding on DZ problem. Its study qualitatively classifies drivers into three categories including conservative, normal and aggressive based on drivers' approaching speed and decision at amber. The results reveal that drivers classified as "aggressive", i.e. manoeuvring over speed limit or making improper decision with respect to their traffic conditions were more likely to be caught in DZ boundary. These two studies qualitatively investigate the correlation between driving behavior and DZ problem, but yet, to date, no study attempts to quantitatively assess drivers' decision making behavior. The study presented in this paper aims to bridge this gap by proposing a new measure termed *generalized distance*. It uses to quantify and assess drivers' decision making behavior, simultaneously taking into account approaching speed and vehicle distance from stop line at amber. The results of the calibrated Discrete choice model (i.e. Logit model) is anticipated to provide indicators to reveal drivers' propensity in making STOP/GO decision and level of influences of the interaction of approaching speed and vehicles distance from stop line on their STOP/GO decisions compared to other factors such as vehicle type, platooning condition and presence of pedestrian(s) waiting to cross the junction.

METHODOLOGY

Studied junction

A signalized T-junction of two through lanes and one right turning lane with design speed limit 50kph was selected for observing drivers' STOP/GO decision making behavior at amber. The junction is situated in a highly populated residential urban area in Kowloon peninsula in Hong Kong, it serves vehicular and pedestrian interesting traffic between Lei Yue Mun Road and Ko Chiu Road by means of traffic signal control with Annual Average Daily Traffic (AADT) 9060 vehs/day. 510 pedestrians were recorded to walk across the crossing facility in 385 signal cycles. In the vicinity of this junction, there are eight 40 storey residential buildings, one primary and five secondary schools, as well as a football playground. A roundabout and a signalized T-junction is 600m and 400m apart at the upstream direction as well as an offline bus stop for public buses and public light buses is 50m apart at the downstream direction. The probability that vehicles face amber while approaching is very much dependent on signal time coordination within that area. Green time, Amber time and cycle length of the studied junction is 70, 3 and 130 seconds, respectively; the visibility for drivers going straight is about 80m. It should be noticed that the 3 seconds amber period is consistently adopted at signalized junctions in Hong Kong and comply with the requirement as stated in Transport Planning & Design Manual (TDPM) established by Transport Department Hong Kong SAR. During the observation period, averagely 19 vehicles were observed to face amber in every 10 signal cycles. This comparatively high figure is good for survey purpose, as other signalized junctions which are of relatively high accident records, were observed to have less than 5 vehicles facing amber in every 10 signal cycles and thus they are not considered in this study. According to the Transport Department, the studied junction was labelled as "Blacksite" in year 2010 quarter 3 (i.e. at the time closes to the observation period), meaning that 2 or more fatal accidents happened in the past 5 years or 9 or more injury accidents happened in the past 12 months. Albeit this junction is labelled as of comparatively high risk in terms of number of injuries and casualties due to traffic accidents, no speeding camera, red-light running camera or signal count-down devices was installed.

Data Collection

As in the literature, video based observation method was used to record drivers' decision making behavior at amber. To avoid interferences on drivers' manoeuvres, equipment used for video recording were mounted on podium level of a residential building along the studied approach at approximately 60m apart at upstream direction. Since vehicle approaching speed and distance from stop line at amber was extracted by replaying video thereafter, benchmarks in every 5m interval along the road kerb of the studied approach were placed for the ease of data extraction. Figure 1 depicts the view of studied junction from video camera with 5m interval lines overlaid on it. Throughout the observation period, 20 hours video was filmed during weekdays at day-time and night-time, 511 drivers were recorded as facing amber. Parameters describing vehicles' conditions at amber including approaching speed, vehicle distance from stop line, vehicle type, platooning condition and STOP/GO decision were obtained. These records provide focus data for this study, of which 275 drivers opted to GO and 236 drivers opted to STOP with grand mean approaching speed at 45kph. It is important to highlight that 190 drivers were observed manoeuvring over speed limit (50kph) of which 119 opted to GO.

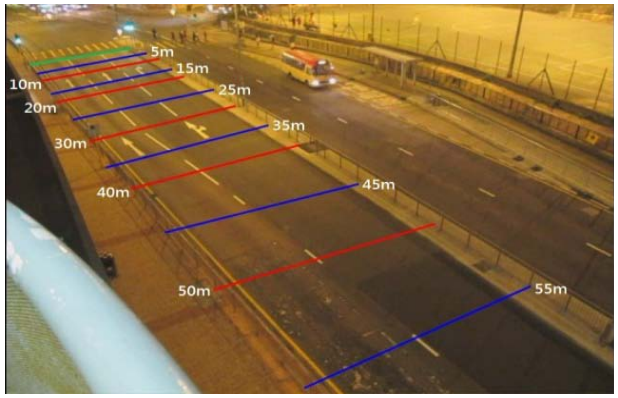

Figure 1 Elevated view of the studied signalized junction from video camera

Formulation of the new proposed measure

As aforementioned, a new measure is proposed, namely *generalized distance* hereinafter, used to quantify and assess drivers' decision making behavior at signalized junctions at amber. This new measure is formulated based on the GHM model (Gazis et al., 1960), i.e. the deterministic Type I DZ approach. It can be used to form individual attributes for STOP and GO decisions, termed gen_dist_{stop} and gen_dist_{go}. For drivers opt to STOP, gen_dist_{stop} is defined as vehicle distance from stop line minus the minimum safe stopping distance at amber onset; for drivers opt to GO, gen_dist_{go} is defined as the maximum safe passing distance minus vehicle distance from stop line at amber onset. Detail formulations of these two parameters are shown as follows:

$$gen\_dist_{stop} = D - x_c = D - \left(v_o \delta_{stop} + v_o^2 / 2a_{stop} \right) \tag{1}$$

and

$$gen\_dist_{go} = x_o - D = \left[v_o \tau + 0.5 a_{go} (\tau - \delta_{go})^2 \right] - D \tag{2}$$

where

τ :	amber time of studied signalized junction, i.e. 3 seconds.
v_o :	vehicle approaching speed (m/s).
x_o, x_c, D :	maximum safe passing distance, minimum safe stopping distance and vehicle distance from stop line at amber onset (m).
$\delta_{stop}, \delta_{go}$:	driver's reaction time to make STOP/GO decision while facing amber, 1 second reaction time was adopted (e.g. Bonsall et al., 2005; Papaioannou, 2007).
a_{stop}, a_{go} :	maximum deceleration rate for stopping 5-0.213v_o (m/s^2) and maximum acceleration rate for passing 5 (m/s^2). These two values are suggested by Gazis et al. (1960) and adopted in Traffic Detector Handbook (2006) as well as Wei et al.'s (2009) and Li et al.'s (2010) studies.

The numerical example below shows how gen_dist_{stop} and gen_dist_{go} apply to quantify drivers' decision making behaviour at signalized junctions at amber. Assuming a vehicle is 20m apart from stop line with approaching speed 45kph at the time when amber commences, gen_dist_{stop} and gen_dist_{go} are determined as follows:

$$gen\_dist_{stop} = 20 - \left\{(45/3.6)*1 + (45/3.6)^2 / 2 / \left[5 - 0.213*(45/3.6)\right]\right\} = -25.9m$$

and

$$gen\_dist_{go} = \left[(45/3.6)*3 + 0.5*5*(3-1)^2\right] - 20 = 27.5m$$

The positive value of gen_dist_{go} indicates that GO is an appropriate decision at that situation while gen_dist_{stop} is found to be negative and thus STOP is an inappropriate decision. In addition the positive and negative signs, larger the value of *gen_dist*, lesser the risk of having accidents. However, under some special situations, positive values are reported in both gen_dist_{stop} and gen_dist_{go} indicating the presence of option zone (OZ) at amber onset (Saito et al., 1990). If so, the driver can choose comfortably stop at the stop line or safely clear the junction with gentle manoeuvre.

Logit model for drivers' STOP/GO decision

According to the large body of literature, binary choice regression model, i.e. Logistic regression model was generally adopted to establish the relation between STOP/GO decision, approaching speed and vehicle distance from stop line at amber. Only Logistic regression model has been widely used in previous studies; discrete choice models for instance Logit model, which is of similar underlying nature as Logistic regression model, has however not yet been used. The unpopular usage of the Logit model might be due to its disaggregated nature. As if Logit model used for DZ problem, similar to the modal choice model that individual attributes such as travel time and fare for different mode choices, individual attributes for STOP and GO decisions are required. The data collected on sites can however not be used for this purpose. Thus, a new measure is proposed in this study, in which the new measure can be used to establish individual attributes for the two choices STOP and GO decisions. The Logit model was thereby adopted in this study attempting to model drivers' STOP/GO decision making behavior. The probability that individual driver opts to STOP and GO are shown as follows:

$$P_{stop} = \frac{e^{U_{stop}}}{e^{U_{stop}} + e^{U_{go}}} \tag{3}$$

$$P_{go} = 1 - P_{stop} = \frac{e^{U_{go}}}{e^{U_{stop}} + e^{U_{go}}} \tag{4}$$

When establishing utility functions of STOP and GO decisions, gen_dist_{stop}, gen_dist_{go} and variants that describe the situation of subject vehicle at the instance of amber onset were formulated as follows:

$$U_{go} = \beta_{go} \times \ln\left(gen\_dist_{go}\right)/8 + \beta_{Dec} \times Req\_dec + \beta_{Speeding} \times Speeding + \beta_{Plat} \times Platoon + \beta_{Ped} \times Pedestrian \tag{5}$$

$$U_{stop} = C + \beta_{stop} \times \ln\left(gen\_dist_{stop}\right)/8 + \beta_{Dist\_if} \times Dist\_if + \beta_{Veh} \times Veh\_type + \beta_{Light} \times Lighting \tag{6}$$

where

Req_dec: equals to 1 if, at the time when amber commences, required deceleration rate to completely stop at the stop line is lesser than -2m/s^2 and 0 otherwise.

$Speeding$: equals to 1 if vehicle approaching speed at amber onset is greater than design speed limit of the studied junction, i.e. 50kph and 0 otherwise.

$Dist\_if$: equals to 1 if vehicle distance from stop line at amber onset is greater than 40m (i.e. approximately 3 seconds amber boundary at operating speed 50kph) and 0 otherwise.

$Lighting$: equals to 1 if natural light is daylight and 0 otherwise.

$Pedestrian$: equals to 1 if there is pedestrian(s) waiting to cross the junction and 0 otherwise.

$Platoon$: three dummy variables representing vehicle platooning conditions include leading, following, individual and adjacent (i.e. another vehicle at nearby traffic lanes within 2 seconds headways).

Veh_type: four dummy variables representing vehicle type including public bus, public light bus, private car, taxi and goods vehicle.

C: alternative specific constant.

Logarithm transform to the base *e* of *gen_dist* is used because the rate of change of influence on drivers' STOP/GO decision is expected to decrease gradually with the increase of *gen_dist*; and the value is further scaled down by 8 in the model as to avoid numerical problems during the estimation because other attributes have a level of magnitude of about 1.0.

Table 1 shows descriptive statistics of data collected at the studied junction and variants adopted in the Logit model.

Table 1 Descriptive statistics of data and variants adopted in the Logit model

Factors			Count
Decision	GO		275
	STOP		236
Speed (kph)		Mean = 45.6 kph Std = 14.57kph	
Speeding	1		190
	0		321
Distance (m)		Mean = 26.9 m Std = 14.67 m	
Dist_if	1		146
	0		365
Ln(gen_dist) (m)	GO	Mean = 2.478 m Std = 1.577 m	
	STOP	Mean = -2.129 m Std = 2.787 m	
Veh_type	Private car		104
	Public bus		54
	Public light bus		107
	Taxi		66
	Goods vehicle		180
Platoon	Leading		79
	Following		81
	Individual		262
	Adjacent		89
Req_dec	1		68
	0		443
Pedestrian	1		407
	0		104

RESULTS AND DISCUSSIONS

Results of the calibrated Logit model as shown in Table 2 reveal that drivers that were observed in the studied signalized junction were more likely to make GO decision at amber, as coefficient β_{go} is found to be four times more than β_{stop} (i.e. one unit change of gen_dist_{go} has relatively large influence than gen_dist_{stop} on drivers' decision making at amber). However, it should be noticed that this 1 unit change in *gen_dist* in the model does not mean 1 meter change in *gen_dist*. This is because the proposed measure *gen_dist* for STOP and GO decisions were logarithm transformed to the base *e* and scaled down by 8 prior to the calibration as shown in eqs. (5) and (6). Albeit drivers were reported as bias to GO at amber, there is insufficient evidence to conclude that drivers' bias to GO at the studied junction has detrimental effects on road safety. In case the studied junction is integrated with other signalized junctions within the district as to provide good progression quality for drivers, making GO decision at amber would probably be appropriately safe as they are expected to. The impact of integrated traffic signal control system on DZ problem would be one of the key research areas in the near future, as closely packed signalized junctions are very common in urban area in which the implication has not yet been explored. Nevertheless, due to the lack of information regarding progression quality of studied junction, sound conclusion cannot be made here.

Table 2 Results of calibrated Logit model for STOP/GO decision

	Coefficient	**Value**	**Std err**	**t-test**	**p-value**
U_{go}	β_{go}	4.32	1.15	3.75	0.00
	β_{Dec}	1.38	0.333	4.13	0.00
	$\beta_{Individual}$	-0.504	0.252	-2.00	0.05
	β_{Ped}	-0.671	0.283	-2.37	0.02
U_{stop}	β_{stop}	0.972	0.552	1.76	0.08
	β_{Dist_if}	2.18	0.332	6.57	0.00
	β_{Bus}	0.878	0.431	2.04	0.04
	$\beta_{GoodsVeh}$	0.852	0.302	2.82	0.00
	$\beta_{Private\ Car}$	0.876	0.343	2.55	0.01

Goodness-of-fit test
Number of observations: 511
Initial log-likelihood: -354.198
Final log-likelihood: -203.949
Rho-square: 0.424
Adjusted rho-square: 0.399

Note: parameters that were found to be insignificant at 10% significance level are not shown in the table

Regarding other parameters formulated in the utility functions of STOP and GO decisions, the results as shown in Table 2 indicate that, at the time when drivers are required to make STOP/GO decision (i.e. amber onset), drivers were more considerate towards if they were too far away from the stop line than their favorability of making STOP decision, as *Dist_if* was found to be significant at 5% significance level and the coefficient β_{dist_if} is reported as two times larger than β_{stop}. The reported relatively large influence of parameter *Dist_if* on drivers' decision making might be reasonable because, at that demanding fast-reactive situation after amber onset, it would be easier for drivers to assess the appropriateness in making STOP/GO decision merely based on vehicle distance from stop line than combined consideration of distance and speed; the result is indeed consistent with Elmitiny et al.'s (2010) findings that distance is the first prioritized attribute while making decision at amber. In fact, at certain distance away from stop line (e.g. over 40m), drivers would generally bias to STOP unless some drivers who are aggressive in driving and thus refuse to STOP. The value 40m, which is approximately 3 seconds travel time to stop line at design speed limit, adopted in this model could be argumentative, as drivers may not know amber time is 3 seconds. Even if drivers know amber time is 3 seconds, they may not know where the 3 seconds travel time boundary is when driving. The use of 40m is taken as an approximation of a cut-off line that drivers would probably have different decision making behavior. Similar to *Dist_if*, parameter *Req_dec* was also found to be significant at 5% significance level, but the positive sign of coefficient β_{Dec} reveals that drivers were more likely to make GO decision once they find that hard deceleration is required if choosing STOP. The result further supports the above discussion that even though drivers may not that intelligent to assess their favorability of STOP/GO decision, they would be able to assess if rough maneuver (e.g. hard deceleration) is required in making such a decision. Thus, drivers would prefer to make a decision that requires a comparatively gentle maneuver as to avoid conflicts. In this case, the deceleration rate -2m/s^2 obtained from the formula 5-0.213v_o with speed 50kph (i.e. design speed limit of the studied junction) is also taken as an approximation of a cut-off line that drivers would probably have different decision making behavior. The effects of *Dist_if* and *Req_dec* on drivers' decision making appear to show that driving comfort and possible consequences with respect to their decisions could be drivers' first prioritized consideration while making STOP/GO decision (Elmitiny et al., 2010). In other words, drivers would be aware that if they opt to GO but cannot clear the junction within amber, they might subject to a risk of having head-on/angled collision with vehicles from another leg of junction; and if they opt to STOP but hard deceleration is required as to completely stop at the stop line, they might subject to a risk of having rear-end collisions with the following vehicle. Nevertheless, the cut-off value of these two parameters *Dist_if* and *Req_dec* should subject to further scientific investigations, for instance employing driving simulators to figure out the actual boundary that drivers have significant different decision making behavior as Inman (2010) did. Despite the above reported phenomenon that drivers were considerate towards their driving comfort while making STOP/GO decision, drivers were inconsiderate towards if their approaching speed were over speed limit, as the parameter *Speeding* was found to be insignificant in the model. This contradicts to Papaioannou's (2007) findings that drivers maneuvered over design speed limit were more likely to make GO decision at amber. In this junction, drivers did not take speeding violence as one of the imperative considerations while making decision at amber might be because drivers would like to take vehicle distance from stop line as the main rule to decide STOP/GO as reported above, speed is just a secondary measure or even totally disregard. Notwithstanding, it is ensure that the insignificance influence of *Speeding* would not be derived from the deviation of vehicle distance from stop line between vehicles with operating speed below and over speed limit, as insignificant mean difference under these two groups was revealed.

In addition, influence of vehicle type on drivers' STOP/GO decision at amber that has commonly been examined in the literature was also considered in the Logit model in this study (e.g. Wei et al., 2009; Elmitiny el al., 2010; Gates and Noyce, 2010; Li et al., 2010; Gates and Noyce, 2010). The results reveal that three groups of drivers including public bus, goods vehicle and private car drivers were found to be significant at 5% significance level, while public light bus and taxi drivers do not. The three corresponding coefficients β_{Bus} , $\beta_{GoodsVeh}$ and $\beta_{Private\,Car}$ were reported of similar magnitude indicating the level of influences on drivers' decision making are not significantly different. This is however inconsistent with the previous studies that different vehicle types are of different decision making behavior at the same junction, albeit the deviations are reflected by the DZ boundary differences but not the coefficients of Logit model as discussed above (Wei et al., 2009; Gates and Noyce, 2010; Li et al., 2010). Other than the differences among vehicle types, vehicle platooning condition was also taken into account in this model. Interestingly, only vehicles that were individually approaching the junction were found to be significant in the model. Under this Individual situation, drivers were more likely to make GO decision, further supporting the previous discussion on the new proposed measure that drivers that were observed in this junction were bias to GO at amber. As far as DZ problem has been widely investigated, influence of pedestrian(s) waiting to cross the intersection has few been considered in the literature (Gates et al., 2007). This study took the advantage of the studied junction, considering the existence of pedestrian(s) waiting to cross the intersection in the model. It was found that drivers were more likely to STOP while there is pedestrian(s) waiting to cross. The result is in agreement with Gates et al. (2007), giving a good sign to traffic operators that, in addition to drivers' own satisfactions, drivers were considerate towards pedestrians while making STOP/GO decision at amber.

Table 3 Results of calibrated Logit model for lookup chart

	Coefficient	Value	Std err	t-test	p-value
U_{stop}	C	6.80	0.708	9.60	0.00
	β_{stop}	-2.10	0.587	-3.57	0.00
U_{go}	β_{go}	21.7	2.20	9.86	0.00

Goodness-of-fit test
Number of observations: 511
Initial log-likelihood: -354.198
Final log-likelihood: -210.916
Rho-square: 0.405
Adjusted rho-square: 0.396

Analogous to the previous studies, DZ boundary of the studied junction was figured out as shown in Figure 3; but in this study, Logit model instead of Logistic regression model was adopted considering the alternative specific constant C as well as the proposed new measures gen_dist_{go} and gen_dist_{stop} only (e.g. Gates et al., 2007; Wei et al., 2009; Gates and Noyce, 2010; Li et al., 2010). From the figure, it can be seen that, according to the 10-90% rule as defined by Zegeer and Deen (1978), DZ boundary is about 33 to 47m from stop line with approaching speed 50kph. Interpreting this area into estimated travel time to intersection (TTI) at speed level 50kph, the boundary is approximately 2.3 to 3.4 seconds TTI from stop line. This area is somewhat in line with the commonly reported Type II DZ boundary in the literature (e.g. Zegeer and Deen, 1978; Gates et al., 2007; Wei et al., 2009; Gates and Noyce, 2010; Li et al., 2010). Other than the boundary, it should be highlighted that the curve obtained by the calibrated Logit model is asymmetrical with a long tail below the probability level 0.2, while the curve obtained by the commonly used Logistc regression model is a symmetrical logistic curve. This long tail appears to reflect that drivers do not have noticeable changes between STOP and GO decision at the area close to the stop line. This flattening trend has yet been discussed in the literature would be because Logistic regression model has widely be used, and thus symmetrical curve should normally be reported. The implicit change between STOP and GO decisions at the area close to the stop line might be realistic as if drivers are originally decide to GO at 10m apart with approaching speed 40kph, an extra 5 to 10m distance from stop line with the same operating speed would probably not influence their own intentions. If so, it might be questionable that the symmetrical curve obtained by Logistic regression model is unsatisfactory to reflect drivers' STOP/GO decision behavior under this special circumstance.

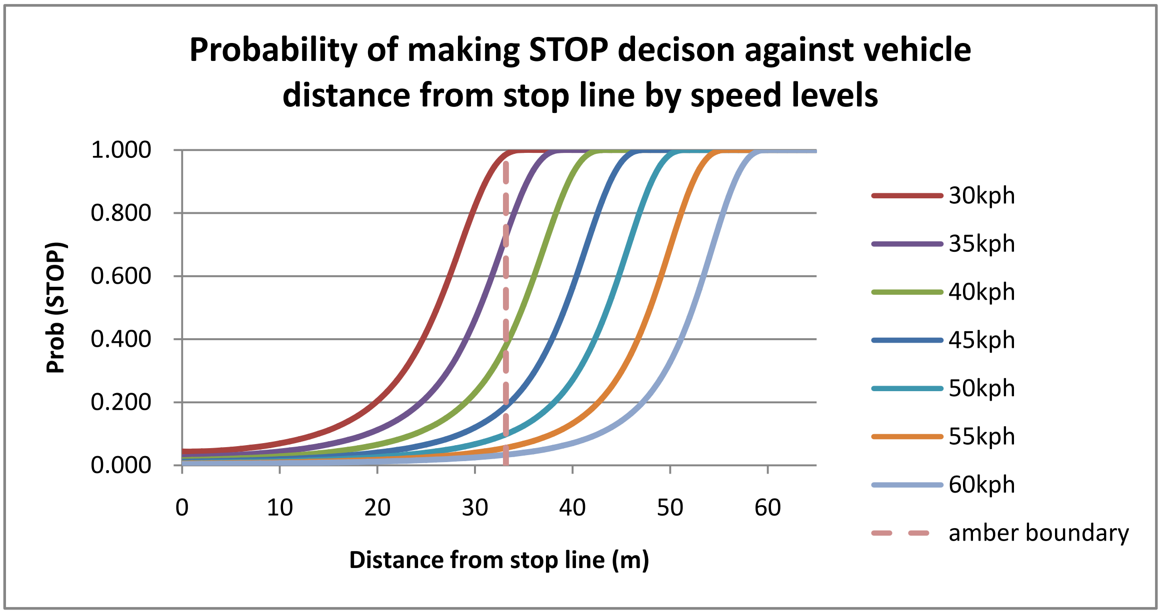

Figure 3 Probability of making GO decision against vehicle distance from stop line (m) by different speed levels (kph)

Further to using this chart to figure out DZ boundary, the chart could be used as an indicator to evaluate junction safety level in DZ respect. Figure 3 depicts the probability of drivers making STOP decision at varied speed levels with reference to the 3 seconds amber boundary. At the intersecting point between the 50kph curve and the 3 seconds amber boundary line, drivers are predicted to have about 10% chance to STOP at amber, but however drivers at that situation are expected to over 50% chance to STOP. This is because, as originally designed, drivers would not be able to clear the intersection within amber time, unless they maneuver over design speed limit or running red-light. This inconsistence appears to give an alert to road operators that road users' decision making behaviors at amber are not in line with the junction signal design, and thus road safety problem would probably exist if appropriate interventions are not deployed. In response to the above problem, possible remedial measures for the studied junction based on the results obtained in this study are suggested as follows: (1) drivers should avoid maneuver at/over design speed limit if they are likely to face amber while approaching the studied junction. With respect to this, traffic engineers could consider implement warning sign at upstream locations as to remind drivers to slow down at the situation that drivers are likely to face amber. Referring to the results of the two calibrated models in this study, placing the warning sign that is visible to drivers which are at least 40m apart from stop line, advising drivers to maneuver at about 35-40 kph, as drivers are predicted to have about 40-50% chance to STOP; and (2) in case the above situation is found, an additional effort is required to evaluate if this bias to GO at amber is attributed to the unsatisfactory traffic signal coordination within the district. This is because drivers that are more likely to GO at amber might be due to unfavorable progression quality of the signalized junctions within that area, but not derived from drivers' aggressive driving behavior.

CONCLUSIONS

In this study, a new measure termed *generalized distance* is proposed to quantify and assess drivers' decision making behaviour at signalized junctions. Unlike the previous studies, Logit model was employed to establish the relation between drivers' STOP/GO decision, approaching speed, vehicle distance from stop line and other variants describing the situation at the time when amber commences. In the first calibrated Logit model, the results reveal that drivers were more likely to GO at amber, but there is insufficient evidence to conclude whether this bias to GO has detrimental effects on road safety at the studied junction. Interestingly, drivers who manoeuvred over speed limit were found less likely to GO at amber compared to those driving below speed limit. In regard to the second model, only alternative specific constant C, gen_dist_{go} and gen_dist_{stop} were taken into account. Two charts were developed to (1) figure out the DZ boundary of the studied junction based on the 10-90% rule defined by Zegeer and Dean (1978); and (2) depicts the potential safety problem of this junction that drivers were bias to GO, even at a situation that drivers should have over 50% chance to STOP. From administration perspectives, the developed chart could also be used as an indicator to evaluate junction safety level in DZ respect by examining the deviation between the 3 seconds amber boundary line and the 50kph probability curve at the 0.5 probability level. For further studies concerning DZ problem, it is suggested to first assess drivers' decision making behavior, then to design corresponding remedial measures for that specific problem. This is because remedial measures for drivers having bias to GO and STOP might be significantly different. For instance, the signalized junction considered in this study, drivers were found more likely to GO at amber. Subsequent efforts should thus be paid onto whether this bias to GO is attributed to comparatively high approaching speed, poor traffic signal coordination or drivers' aggressiveness, but not just implement general safety measures that were found to be efficient in other places (e.g. traffic signal countdown devices), as drivers might become even more likely to GO at amber under the operation of signal countdown devices, further erode safety level of the ameliorated junction.

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