

Driver's Decision Model at an Onset of Amber Period at Signalised Intersections

Othman Che Puan^{a,*}, Muttaka Na'iyah Ibrahim^a, Nur Syahriza Muhammad Nor^a, Era Triana^a

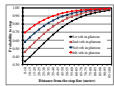
^a Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia

*Corresponding author: othmancp@utm.my

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Graphical abstract



Abstract

Driving is a complex task and, probably, the most dangerous activity on roadways because it involves instantaneous decision making by drivers. A traffic signal-controlled intersection is one of road facilities which require drivers to make an instantaneous decision at the onset of amber period. This paper describes the application of a regression approach to evaluate the factors that influence the decision made by a driver whether to proceed or to stop at the stop line at the onset of amber period at signalised intersections. More than 2,700 drivers approaching the stop-line at the onset of amber period at six intersections installed with a fixed-time traffic signal-control system were observed. Two video cameras were used to record the movements of vehicles approaching the intersection from a distance of about 150 metres. The data was abstracted from the video recordings using a computer event recorder program. The parameters considered in the analysis include vehicles' approaching speed, distance from the stop line at the onset of amber, the position in the platoon as well as the types of vehicles driven. The result of the analysis shows that about 13.43% of the drivers tend to accelerate to clear the intersection at the onset of amber period and about 26.32% of the drivers ended up with running the red light. A binary logistic model to explain the possible decision made by a driver for a given set of conditions was developed. The analysis shows that the probability of drivers' decision either to stop or proceed at an onset of amber period is influenced by his/her distance from the stop line and his/her position in the platoon.

Keywords: Driver's decision, amber period, binary logistic model, red light running

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1.0 INTRODUCTION

Intersections are one of the areas contributing to high percentage of accident occurrences. Malaysian road accident statistics in 2003 showed that more than 20% of total accidents were at intersections [1, 2]. Traffic signal-control system is the most common method used to control and regulate traffic movements at intersections. However, such a system may expose drivers and other users to risk of accidents because it involves decision making by a driver whether to stop or cross the intersection at an onset of amber phase. Making a wrong decision on either to stop or proceed, will lead to a red light running violation or a sudden stop at the intersection [3]. This could lead to rear-end collision or other forms of accidents.

In Malaysia, red light running practice by drivers was demonstrated as one of the reasons for the high number of accidents and fatalities at intersections [4] which had been on the increase in the past several years [5] of which human factor was reported responsible for; accounting for about 94% of the total accidents [6]. Kulanthayan *et al.* [7] reported that traffic light running violations are influenced by factors such as time of the

week (weekdays or weekend), type of vehicle, location and type of traffic light (normal or countdown timer).

In general, a driver is exposed to the risk of accident if he takes too long time to react with the instantaneous changes in traffic situations. On the other hand, he is also exposed to the same risk of accident if his decision was wrongly made. This paper discusses the result of a study carried out to evaluate the factors influencing driver's decision at the onset of amber signal at intersection and the form of a decision model developed in this investigation.

2.0 BACKGROUND

Decision making in response to the onset of an amber phase at signalised intersection is one of the most critical situations of driving. Driver's wrong decision could result in red light running violation or traffic conflict with the leading vehicle whose driver decided to stop at the onset of amber [3]. The driver's decision making is usually affected by multitude of traffic, situational, and behavioural factors. These include, among others, attitude, emotional state, crossing ability before red signal, consequence of stopping or not, interactive behaviour with other drivers, approach

speed and distance to stop-line [8]. Drivers are expected to consider certain factors when approaching an intersection [9]; included among the factors are:

- Monitoring and adjusting speed;
- Maintaining lane width;
- Being aware of other vehicles;
- Attending to signals or signs;
- Scanning for pedestrians, bicyclists, people in the wheelchairs and blind or visually-impaired people;
- Decelerating for a stop;
- Searching for path guidance; and
- Selecting proper lane.

Previous studies [10, 11] discussed the various factors affecting driver’s decision on whether to stop or proceed through the intersection upon seeing the onset of the amber. They reported that drivers are less likely to stop under the following situations:

- having a short travel time to the intersection;
- driving at higher speeds;
- travelling in platoons;
- on steep downgrades;
- facing relatively long amber indications; and
- being closely followed.

Many studies on drivers’ behaviour relating to signal change at intersections showed that the probability of driver to stop or cross the intersection at the onset of amber was modelled using binary logistic regression technique [12-17]. One of these studies [15] developed a binary choice model which relates the probability of a stopping at the stop-line or crossing it as a function of approach speed, distance from intersection, gender, age group and the existence or not of a dilemma zone (an area approaching the stop line within which a driver finds himself is too close to stop safely and yet too far away to pass completely through the intersection at a legal speed before the red phase commences). Findings from the study revealed that a substantial proportion of drivers facing the amber signal were caught in a dilemma zone due to high approaching speeds and exercise an aggressive behaviour.

Numerous studies reported that an area within the upstream of intersections at the onset of amber phase is associated with larger variability in drivers’ stop-go decisions [18-21].

3.0 METHODOLOGY

Six isolated intersections installed with a fixed-time traffic signal system drawn from Johor and Melaka States, Malaysia were used for the data sampling. The intersections used are summarised in Table 1. The layout of one of the intersections studied is as shown in Figure 1.

The selection of the intersections and the data collection period are based on the following considerations:

- The intersections were sampled from different suburban areas to ensure that sampled drivers were from different groups of population;
- Each intersection was chosen relatively further away from its neighbouring intersections to ensure that drivers’ behaviour and decisions are not influenced by the intersections in the upstream and downstream of the intersection studied;

Table 1 List of Intersections Studied

| Site | Location | No. of Arms | Posted Speed Limit (km/h) | Cycle Time (sec) |
|------|-----------------------------------|-------------|---------------------------|------------------|
| A | Permatang/Setia Tropika | 4 | 70 | 120 |
| B | Persiaran Utama/Persiaran Utama 1 | 4 | 60 | 120 |
| C | Seri Melaka | 4 | 90 | 120 |
| D | Jalan Teberau | 4 | 70 | 142 |
| E | Jalan Johor Jaya | 3 | 60 | 120 |
| F | Jalan Kulai/Saleng | 3 | 70 | 160 |



Figure 1 Layout one of the intersections studied (Site B)

- The surveys were carried out under good weather conditions to minimise the effect of weather on drivers’ behaviour;
- The analysis were based on the data collected during off-peak hour traffic to minimize the influence of congestion on driver’s decision and behaviour; and
- Sites with relatively good visibility were chosen to ensure that drivers have a good vision of the traffic signal indicators.

Data pertaining to the analysis of the factors that influence the decision of the drivers at the onset of amber was collected using a video recording technique. The advantages of using a video recording technique for traffic data collection has been described by various researchers [22, 23]. The observation of each driver’s behaviour was made when the vehicle was about 150m from the stop line. Parameters extracted from video playbacks are vehicle’s approaching speed, position of vehicle in the platoon, types of vehicle driven and distance from the stop line. Data extraction process was carried out using an event-recorder computer program. The analysis of the data was carried out using SPSS computer program.

The number of drivers observed for the analysis was estimated based on Equation (1) [15, 24]. In this study, only drivers approaching the stop line at onset of amber period and during the entire amber period were considered.

$$N = \frac{K_a^2 pq}{E^2} \tag{1}$$

where, N is the sample size, p is the proportion of vehicles facing an amber signal that passed, q is the proportion of vehicles facing an amber signal that stopped, K is the standard deviation corresponding to the desired level of confidence, α , and E is the permitted error in the proportion estimate. In this study, $p = q = 0.5$, $K = 1.96$ and $E = 0.05$. Therefore, the minimum number of drivers arriving at the stop line observed at each intersection was approximated as 384. The observation at each intersection was conducted for several days in order to obtain the required sample size.

4.0 RESULTS AND ANALYSIS

4.1 Drivers' Decision on Approaching an Amber Period

A total of 2,793 drivers were observed at six intersections. It must be pointed here again that only drivers approaching the stop line during the amber period were considered in the study. The frequencies of drivers decided not to stop at the onset of amber period and run the red light at each intersection are tabulated in Table 2.

Table 2 Drivers' Decisions at Studied Intersections

| Site No. | Sample Size (N) | Accelerate through Amber | Red-light Running | Total Drivers Decided Not to Stop |
|----------|-----------------|--------------------------|-------------------|-----------------------------------|
| A | 412 | 16 (3.88%) | 124 (30.10%) | 140 (33.98%) |
| B | 420 | 154 (36.67%) | 174 (41.43%) | 328 (78.10%) |
| C | 552 | 20 (3.62%) | 196 (35.51%) | 216 (39.13%) |
| D | 424 | 136 (32.08%) | 0 (0%) | 136 (32.08%) |
| E | 407 | 69 (16.95%) | 65 (15.97%) | 134 (32.92%) |
| F | 578 | 36 (6.23%) | 176 (30.45%) | 212 (36.68%) |
| Total | 2793 | 431 (15.43%) | 735 (26.32%) | 1166 (41.75%) |

In general, about 41.75% of the drivers sampled at six intersections decided not to stop at onset of amber period. About 15.43% of them managed to accelerate and clear the intersections before the red light commences. However, about 26.32% of the total drivers observed ended up with running the red light. A study across some States in USA [25] reported about 55.8% of observed drivers were red light runners. However, finding from another recent study conducted in central Florida [3] reported 227 drivers out of 1292 observed population as red light runners; this represents an approximate of 18%. The proportion of red light running violation (26.32%) from the observed drivers in this study is seems to fall within the values in the existing literature. Variations in the reported figures from the various studies could be due to differences in drivers' behaviour from the countries where the studies were conducted.

4.2 Formulation of a Binary Logistic Model

There are many factors that could contribute to the decision making by drivers. In this study, only factors such as vehicle's approaching speed (SPD), type of vehicle driven (VEH), vehicle position in the platoon (POS) and distance from the stop line (DIST) when amber light appears were considered. Gender and age of the driver were not considered in the analysis because of the difficulty in obtaining the data accurately.

The first part of the modelling approach is the development of a linear function of the independent variables. The method of maximum likelihood (β) was used to estimate the parameters of the logistic response function. This method is well suited a problem associated with a response being binary [26]. A general form of the model is as given in Equation (2).

$$z_i = a_0 + a_1VEH_i + a_2POS_i + a_3SPD_i + a_4DIST_i \quad (2)$$

Where z_i is a linear function of the independent variables and a_i is the estimated regression coefficient.

In the modelling process, the distance of the vehicle from the stop line (DIST) is expressed in terms of group of distances. The distances observed were divided into 19 groups, i.e., distance between 0–10m as group 1, 10–15m as group 2, 15–20m as group 3, 20–25m as group 4, 25–30m as group 5, 30–35m as group 6, 35–40m as group 7, 40–45m as group 8, 45–50m as group 9, 50–55m as group 10, 55–60m as group 11, and so forth.

Vehicle position is based on its position in a queuing system, i.e. '1' for the leader, '2' for the second vehicle in the platoon, '3' for the third and so forth. The movement of a platoon of vehicles is considered end when green period ends. The following vehicle that continues to clear the intersection or to stop at the stop line is regarded as the leader of the next platoon if exist.

Vehicles were classified as 1 for passenger cars, 2 for trucks, 3 for buses, 4 for heavy trucks, and 5 for motorcycles. Speed was divided into 7 groups, i.e., speed between 30–40 as group 1, 40–50 as group 2, 50–60 as group 3, 60–70 as group 4, 70–80 as group 5, 80–90 as group 6, and 90–100 as group 7.

The preliminary statistical assessment on the influence of each variable on the linear function, z , indicates that the type of vehicle driven and the approach speed have a p-value of much greater than 0.05 and, therefore, can be excluded from the model. The statistical measures of other variables are summarised in Table 3.

Table 3 Summary of Statistical Analysis of Model Variables and Parameter Estimation

| Variables | A | S.E | Wald | p-value | Exp (β) |
|-----------|-------|-------|--------|---------|-----------------|
| Constant | -1.40 | 0.591 | 4.065 | 0.042 | 0.280 |
| POS | 0.50 | 0.180 | 4.882 | 0.030 | 1.65 |
| DIST | 0.23 | 0.052 | 16.622 | 0.000 | 1.35 |

As can be seen from Table 3, both variables POS and DIST have a p-values of less than 0.05 which may be inferred that the two variables (position of vehicle in the platoon (POS) and distance from the stop line (DIST)), are the significant factors to influence the decision of a driver at the onset of amber period. This leads to the form of linear function describing driver's decision as shown in Equation (3).

$$z_i = -1.40 + 0.50POS_i + 0.23DIST_i \quad (3)$$

All variables are as defined earlier.

As described earlier, a driver only has two choices at the onset of amber period, i.e., either to stop or to proceed. Mathematically, these choices of driver's decision can be modelled using a binary logistic regression approach as shown in Equation (4) [26].

$$y_i = P\{y_i\} + \varepsilon_i \quad (4)$$

Where y_i are independent Bernoulli random variables with expected values $P\{y_i\}$, P is the probability for a driver to stop and ε_i is an error term.

Since the driver's decision is considered as the binary response, the outcomes of y_i are coded as '1' or '0' as indicated in Equation (5). In the analysis, ε_i is assumed to be normally distributed with mean equals to zero. Therefore, the logistic regression model to describe the driver's response is simplified as shown in Equation (6).

$$y_i = \begin{cases} 1 & \text{if decision to stop} \\ 0 & \text{if decision to proceed} \end{cases} \quad (5)$$

$$y_i = P\{y_i\} = P(y_i = 1|z_i) = \frac{e^{z_i}}{1 + e^{z_i}} \quad (6)$$

Substituting Equation (3) into Equation 6, the model to explain the probability for a driver to stop having a specific position in the queue and distance from the stop line can be written as in Equation (7).

$$y_i = P(y_i = 1|z_i) = \frac{e^{(-1.40+0.50POS_i+0.23DIST_i)}}{1 + e^{(-1.40+0.50POS_i+0.23DIST_i)}} \quad (7)$$

All variables are as defined earlier.

To illustrate the interpretation of the model given in Equation (7), a graph showing the probability of a driver to stop at an onset amber period for four leading vehicles in a platoon is plotted as shown in Figure 3.

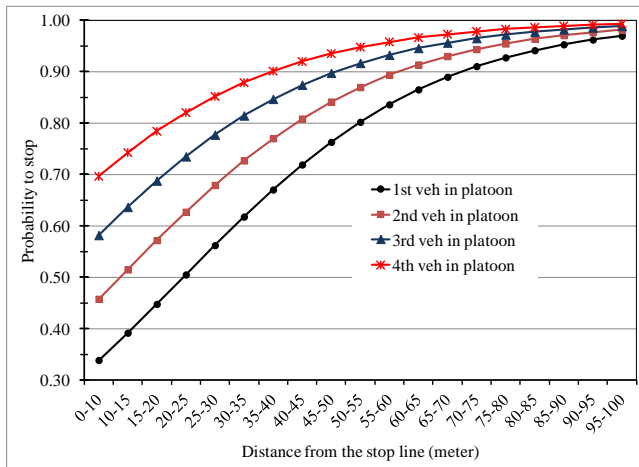


Figure 3 Probability of a Driver Stopping for a Given Distance from Stop Line and Position in Platoon

It may be inferred from Figure 3 that the probability of a leading vehicle to stop increases as its distance is further away from the stop line. The probability of the following vehicles in a platoon to stop derived above is, however, based on the

assumption that they can only have a choice to proceed if their respective leading vehicles have decided not to stop.

5.0 CONCLUDING REMARKS

This study examined the application of logistic regression modeling approach to evaluate the factors influencing driver's decision at signalised intersection at the onset of amber light on either to stop or crosses to clear the intersection. The most important findings from this investigation are summarised as follows:

- An analysis of the results revealed that about 13.4% of the drivers tend to accelerate to clear the intersection at the onset of amber period and 26.3% of the drivers ended up as red light runners.
- The probability of a driver to stop or proceed to clear the intersection at the onset of amber light at signalised intersections may be described in form of binary logistic model.
- Driver's distance from the stop line and vehicle's position in platoon were found to be the major factors influencing the driver's decision at the onset of amber light. However, if the subject driver is not the platoon leader, his decision to proceed to clear the intersection is influenced by the leading vehicle's driver decision.
- Findings from this study also suggest that there is a possibility that the red light runners are due to the existence of dilemma zone at the signalised intersection. Thus, the design of a traffic signal control system to regulate traffic movements at an intersection needs to re-evaluate the implication of such a zone in order to reduce the red light running violations and hence improve the level of safety at intersections.

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