Dilemma Zone Conflicts at Isolated Intersections Controlled with Fixed–time and Vehicle Actuated Traffic Signal Systems

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Abstract—Installation of traffic signal control system at relatively high traffic volume intersections is expected to safeguard drivers at such intersections by providing a clear definition of right–of–way to drivers. However, a particular operational issue is the existence of dilemma zone conflicts if the type traffic signal system installed is not properly selected and designed. The problem is critical for isolated intersections on relatively high speed road sections. This paper describes result of a study carried out to investigate the existence of dilemma zone conflicts at isolated intersections installed with various types of traffic signal control systems. Three indicators of dilemma zone conflicts considered in the analysis are (i) stop abruptly; (ii) accelerate through amber period; and (iii) red–light running. Data pertaining to the analysis of dilemma zone conflicts was collected at eight isolated intersections with different types of traffic signal control systems using a video–recording technique. The data includes vehicles’ approaching speed, distance from the stop line at the onset of amber, the decision made by the drivers at onset of amber as well as the types of vehicles driven. The result shows that relatively large proportion of drivers did not willing to stop at onset of amber signal. A vehicle–actuated traffic signal system appears to perform better compared to other types of system in terms of reduction in dilemma zone conflicts at isolated signalized intersections.

Index Term—Driver’s decision, amber period, dilemma zone, red–light running

I. INTRODUCTION
Traffic signal–control system is one of the common methods used to control and regulate traffic movements at intersections at which the hourly traffic volumes or the peak–hour traffic volumes is reasonably high. However, such a traffic control system may expose the drivers and other users to risk of accidents because it involves decision making by a driver whether to stop or to proceed at an onset of amber period. Malaysian road accident statistics in 2003 showed that about 22% of total accidents were at intersections [1] and Mohd Faizul Mohd Ali Hanapiah [2] reported that about 94% of total accidents are due to human factors. In general, a driver is exposed to the risk of accident if he/she takes too long time to react with the instantaneous changes in traffic situations. On the other hand, he/she is also exposed to the same risk of accident if the decision made was incorrectly made although the time taken to decide was short.

Two common types of traffic signal system is the fixed–time system and vehicle–actuated system. The current practice of many municipal–councils is to install a fixed–time system with a countdown timer which will act as an advanced warning system to the drivers. Other common form of a warning system is the flashing green leading to amber. It is believed that the use of additional features such as a countdown timer system would improve the level of safety and traffic operations at intersections installed with a fixed–time traffic signal control system.

This paper discusses the result of a study carried out to evaluate the effects of several types and features of traffic signal system on dilemma zone conflicts at onset of amber period. Three types of dilemma zone conflicts are abrupt stop, accelerate through amber, and running the red light [3, 4].

II. BACKGROUND
One of the many aspects considered in defining the causes of accidents at a signalized intersection is the driver’s confusion about what action to take when the signal changed from green to amber. A driver of this state of mind is probably occupying an area known as the dilemma zone near the intersection. A dilemma zone is defined as 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. Any decision made by the driver may lead to an accident or near–accident. Martin et al. [4] suggested that a driver may be considered was in a dilemma zone if he was running the red light, or coming to an abrupt stop, or accelerating through amber.

A study by Gazis et al. in 1960 [5] suggested that the formation of dilemma zones is caused by poorly designed amber periods. Therefore, to eliminate dilemma zones, the amber period should be long enough so that a driver can stop at the intersection if he/she has enough stopping distance (\(d_o\)) in front of him/her at the onset of the amber signal. If the driver decides to clear the intersection at a legal speed limit for a reason that it is not safe for him to stop, there must be enough clearing distance (\(d_c\)) in front of him when he perceives the amber signal. Mathematically, the stopping distance and clearing distance are given by (1) and (2), respectively.

\[
\text{Stopping distance, } d_o = v\delta + \frac{v^2}{2a} \tag{1}
\]

\[
\text{Clearing distance, } d_c = v\tau - (w + L) \tag{2}
\]

Where \(v\) is the speed of the approaching vehicle, \(\delta\) is the perception–reaction time of the driver, \(a\) is the maximum speed.
comfortable deceleration rate of the vehicle, \( \tau \) is the length of the amber signal, \( w \) is the width of the intersection, and \( L \) is the length of the vehicle.

By definition, a segment of dilemma zone approaching the stop-line is said to exist when \( d_o > d_c \). The length of the segment is \( d_c - d_o \), as shown in Fig. 1. A vehicle travelling at a legal speed limit in this dilemma zone cannot stop at the stop line safely and comfortably, and cannot clear the intersection safely and legally at the onset of amber signal.

![Fig. 1. Formation of dilemma zone when \( d_o > d_c \).](image)

It is quite obvious that the fundamental aspect to consider in addressing the dilemma zone problems is associated with the selection of an appropriate duration of amber period. In fact, most related studies reported are more focused on the methods to eliminate dilemma zones at signalized intersections by means of providing adequate length of amber period before the green phase changes to red or by installing advance warning systems.

Bonesson et al. [6] is reported to conclude that one of many factors that influence red–light running is the actuated control and coordination system. According to Bonesson et al., at an actuated control system, drivers expect the signal to remain green as they pass through the intersection because they often travel in platoons through several interconnected signals. In such a situation, drivers usually expect the amber period to be long enough so that they can pass through the intersection and stay with the platoon.

It must be pointed out that Bonesson et al. only addressed a component of dilemma zone conflicts, i.e. red–light running at intersections with actuated and coordinated traffic signal control system. Drivers might response and behave differently at isolated signalized intersections especially in suburban areas. In fact, Martin et al. [4] emphasized that the problem of dilemma zones become more pronounced at isolated intersections when drivers have no prior knowledge of the state of the traffic signal. Therefore, it is essential to assess the performance of some common types of traffic signal system installed as an isolated system in terms of effects on both the red–light running and the dilemma zone conflicts.

### III. METHODOLOGY

#### A. Studied Parameters and Sites

As described earlier, a driver may be considered was in a dilemma zone if he was running the red light, or coming to an abrupt stop, or accelerating through amber. Therefore, the evaluation of dilemma zones in this study is based on these characteristics of drivers as well as the approach speed of vehicles. A vehicle is considered as stopping abruptly if it decelerated at a rate of greater than 3.41 m/s²[4]. A red light running case is only considered for a vehicle travelling at a legal speed perceives red phase after it has crossed the stop line.

Eight isolated intersections installed with different features of traffic signal systems were selected. The intersections are selected from different suburban areas to ensure that the drivers are sampled from different groups of driver’s population. Each intersection is relatively further away from its neighboring intersections such that the movements of the vehicles are not influenced by the intersections in the upstream and downstream of the intersection studied. The intersections are summarized in Table I. The analysis is based on the data collected for off-peak hour traffic to minimize the influence of congestion on driver’s decision and behavior. The visibility at all intersections is good.

#### B. Data Collection and Analysis

Data pertaining to the analysis of the approach speeds, acceleration and deceleration rates, driver’s decision, etc. at the onset of amber was collected using a video recording technique. Fig. 2 illustrates the positioning of two video–cameras used to record traffic movements on one of the approach roads at one of the intersections. The layout of one of the intersections studied is shown in Fig. 3. The observation of the behavior of each driver was made when the vehicle was about 150m from the stop line.

The parameters abstracted 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 abstraction process was carried out using an event–recorder computer program. The analysis of the data was carried out using SPSS computer program.
TABLE I
General characteristics of the intersections studied

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Intersection name</th>
<th>No. of Arms</th>
<th>Type of signal system</th>
<th>Posted Speed Limit (km/h)</th>
<th>Cycle time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Permatang/Setia Tropika</td>
<td>4</td>
<td>Fixed-time</td>
<td>70</td>
<td>120</td>
</tr>
<tr>
<td>B</td>
<td>Tun Aminah Rd/Dato’ Sulaiman</td>
<td>4</td>
<td>Fixed-time</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td>C</td>
<td>Seri Melaka Rd</td>
<td>4</td>
<td>Fixed–time with digital countdown</td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td>D</td>
<td>Teberau Rd</td>
<td>4</td>
<td>Fixed–time with digital countdown</td>
<td>70</td>
<td>142</td>
</tr>
<tr>
<td>E</td>
<td>Johor Jaya Rd</td>
<td>3</td>
<td>Fixed–time with digital countdown</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td>F</td>
<td>Saleng/Kulai Rd</td>
<td>3</td>
<td>Fixed–time with 9.0 sec Flashing green leading to amber</td>
<td>70</td>
<td>160</td>
</tr>
<tr>
<td>G</td>
<td>Tun Aminah Rd/Dato’ Sulaiman</td>
<td>4</td>
<td>Vehicle–actuated</td>
<td>60</td>
<td>Varies</td>
</tr>
<tr>
<td>H</td>
<td>Pontian Rd/Tembaga Rd</td>
<td>3</td>
<td>Vehicle–actuated</td>
<td>70</td>
<td>Varies</td>
</tr>
</tbody>
</table>

Note: Sites B and G are the same site. The site was originally installed with a vehicle–actuated traffic control system.

IV. RESULT AND DISCUSSIONS
A. Dilemma Zone Conflicts
Table II summarizes the distributions of dilemma zone (DZ) conflict indicators at each intersection studied. Effects of the number of intersection’s arms, number of traffic phases and length of cycle time are not considered in the analysis because of sampling problem. The duration of amber period

\[
N = \frac{pqK^2}{E^2}
\]  

(3)

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 confidence level, and \(E\) is the permitted error in the proportion estimate. In this study \(p = q = 0.5\), \(K = 1.96\) and \(E = 0.10\). As shown in Table II, the actual sample size obtained for each site, i.e. the number of drivers arrived at an intersection at onset of amber period, is greater than the value calculated using (3).

Fig. 2. Arrangement of the video cameras during field data recording

Fig. 3. Layout one of the intersections studied

The minimum number of drivers observed for the analysis is based on (3)[7, 8].
provided at each intersection is compared against the theoretical or required duration to assess its influence on DZ conflicts. The theoretical amber period required is based on the formula suggested by Malaysian Public Work Department [9] with a comfortable deceleration rate of 3.41 m/s². As indicated in Column 3 of Table II, except for Site D where the length of the amber period provided was about 104% of the theoretical value, the amber period at other intersections were in the range of 64%--79% of the respective theoretical values.

In general, the percentage of the drivers facing dilemma zone conflicts at two intersections controlled by a vehicle–actuated system is lower (i.e. 15.82%--31.53%) than the percentage of drivers facing DZ conflicts at intersections controlled by other types of traffic signal systems (i.e. which is greater than 35%).

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Type of traffic signal</th>
<th>Amber period provided (% of the theoretical value)</th>
<th>Sample size (N)</th>
<th>Abrupt stop</th>
<th>Accelerate through amber</th>
<th>Running red light</th>
<th>Total DZ Conflicts</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Fixed–time</td>
<td>64%</td>
<td>412</td>
<td>6</td>
<td>16</td>
<td>124</td>
<td>146</td>
</tr>
<tr>
<td>B</td>
<td>Fixed–time</td>
<td>75%</td>
<td>212</td>
<td>0</td>
<td>78</td>
<td>88</td>
<td>166</td>
</tr>
<tr>
<td>C</td>
<td>Fixed–time with digital countdown</td>
<td>40%</td>
<td>552</td>
<td>34</td>
<td>20</td>
<td>196</td>
<td>250</td>
</tr>
<tr>
<td>D</td>
<td>Fixed–time with digital countdown</td>
<td>104%</td>
<td>424</td>
<td>16</td>
<td>136</td>
<td>0</td>
<td>152</td>
</tr>
<tr>
<td>E</td>
<td>Fixed–time with digital countdown</td>
<td>70%</td>
<td>165</td>
<td>1</td>
<td>28</td>
<td>26</td>
<td>55</td>
</tr>
<tr>
<td>F</td>
<td>Fixed–time with 9.0 see flashing green leading to amber</td>
<td>69%</td>
<td>578</td>
<td>33</td>
<td>36</td>
<td>176</td>
<td>245</td>
</tr>
<tr>
<td>G</td>
<td>Vehicle actuated system</td>
<td>75%</td>
<td>406</td>
<td>5</td>
<td>83</td>
<td>40</td>
<td>128</td>
</tr>
<tr>
<td>H</td>
<td>Vehicle actuated system</td>
<td>79%</td>
<td>455</td>
<td>0</td>
<td>61</td>
<td>11</td>
<td>72</td>
</tr>
</tbody>
</table>

Table II: Frequency of DZ conflicts at each intersection.

At this juncture, it is difficult to conclude whether the variations in the types of DZ conflict faced by the drivers are due to the type of traffic signal installed or due to inadequate duration of amber period provided. The data does not show any specific trend in terms of the effect of percentage of amber period provided on the percentage of drivers facing the DZ conflicts at onset of amber. However, it may be inferred from Table II that an intersection controlled by a vehicle–actuated traffic signal system appears to perform better in terms of reduction in the number of drivers facing the dilemma zone conflicts compared with other types of traffic signal systems studied.

A χ² test for categorical variables analysis was used to compare the variations of DZ conflicts at all intersections statistically. The calculated χ² values, i.e. χ²(\text{obs}) for the comparison between sites are tabulated in Table II.

Each value of χ²(\text{obs}) in Table III is compared against the χ²(\text{critical}) at a significant level of 0.05, i.e. χ²(1,0.05). In this case, χ²(1,0.05) is equal to 3.84. The χ²(\text{obs})>χ²(\text{critical}) indicates that the variation in the number of drivers facing the dilemma zone conflicts at the corresponding intersections is significantly different. The difference could be inferred as a result of the different types of traffic signal system used at the respective intersections or as a result of the variation in the length of amber period provided compared with the actual length required for the intersection.

B. Red–Light Running

The variations of the frequency of the red–light running due to dilemma zone conflicts between intersections are also compared statistically. The summary of χ² values based on the categorical variables analysis is tabulated in Table IV. The analysis indicates that frequency of red–light running at intersections installed with a vehicle–actuated system is significantly different from that of the other types of traffic signal systems. This is indicated by the χ²(\text{obs})>χ²(\text{critical}).

As can be seen in the previous Table II, the percentage of red–light running at vehicle–actuated signalized intersections, i.e. Site G and H, is much lower than at the other intersections except for Site D.
The percentage of red–light running at Site D, which is controlled by a fixed–time signal with a digital countdown timer, is very much lower than at other sites. It must be pointed out that the duration of the amber period provided at this site is longer than the theoretical value (i.e. about 104%). This result tends to agree with T.H. Law et al. [10] who suggested that the longer amber period reduces the red–light runners. However, it appears to increase the number of drivers who will accelerate through amber period.

There is no specific inference can be made regarding the percentage of red–light running at intersections controlled with the traditional fixed–time system and at intersections controlled with countdown timer. M. R. Ibrahim et al. [11] found that the rate of red–light running at countdown traffic signal intersections is higher than those at intersection without countdown timer. It is possible that their findings were based on the study carried out for urban areas where the behavior of the motorists is most likely to be influenced by high volumes of traffic flow and the presence of neighboring intersections.

In general, the interpretation of $\chi^2$ values in Table III and 4 supports the inference that the overall performance of a vehicle–actuated traffic signal system for isolated intersection in terms of DZ reduction is better compared with other types of traffic signal systems. It is worth to note from Tables II –IV that the installation of a traditional fixed–time system (i.e. Site B) to replace the vehicle–actuated system at Site G has increase the red–light running from 9.85% to 41.51% at the intersection. The total DZ conflicts at that intersection increased from 31.53% to 78.30%.

### IV. CONCLUDING REMARK

The findings that can be summarized from this study are:

a. Relatively large proportion of drivers tends not to stop at onset of amber at the studied intersections.
b. Effect of shorter length of amber period on red–light running is not clear but the duration of amber period longer than the required length appears to reduce the red–light running significantly.

c. Provision of additional features such as digital countdown timer or flashing green leading to amber period without adequate length of amber period does not seem to reduce the DZ problems.

d. At isolated signalized intersections, a vehicle–actuated system appears to perform better in terms of reduction in DZ problems.

ACKNOWLEDGMENT
The financial grant received from the Malaysian Ministry of Science, Technology and Innovation (MOSTI) to carry out this research is gratefully acknowledged.

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