The Dilemma at Signalized Intersection Dilemma Zone

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الخلاصة:

عندما يقترب السائقون من تقاطع عند ظهور الضوء الاصفر يجب ان يقرروا التوقف او عبور التقاطع. هناك صعوبة في هذا القرار عندما تكون العربة ضمن المنطقة المعضلة وقد يحدث احيانا تصادم جراء التوقف المفاجيء. المنطقة الحرجة هي المساحة التي لا تستطيع العربة فيها التوقف او العبور بامان قبل ظهور اللون الاحمر. هذا البحث يدرس تصرف السائقين عند ظهور اللون الاصفر في التقاطعات.

تم اختيار تقاطع يعمل بالاشارة الضوئية في مدينة دمشق لجمع البيانات. تم جمع البيانات بواسطة التصوير الفديوي. جمعت البيانات ولخصت وعولجت وحللت باستخدام برامج طورت لهذا الغرض. الدراسة اجريت على 226 سائق عند ظهور اللون الاصفر ووجد ان 42.55 % منهم تعرضوا للمنطقة المعضلة وان 51.5% من هذه النسبة تعرضوا لعملية تسريع 42.5% منهم تعرضوا لتوقف مفاجيء بينما وجدت الدراسة 6.25% منهم تجاوزوا التقاطع عند ظهور اللون الاحمر.

Abstract

When drivers are approaching a signalized intersection at the onset of a yellow change interval, they must decide whether to stop or cross the intersection. This can be a difficult decision when the vehicle is located within the dilemma zone and the result is sometimes a rear-end crash due to a sudden stop. Dilemma zone is defined as an area close to an intersection in which a vehicle can neither stop safely before the intersection nor clear the intersection without speeding before the red signal comes on. This research studies the driver behavior during the amber onset in the signalized intersection.

One signalized intersection was selected in Damascus city to collect data for this purpose. Data was collected using video recording technique. Data were abstracted, processed and analyzed using programs developed for this purpose. The study examined 226 drivers on the amber onset, 42.47% of them were found to be conflicted by the dilemma zone phenomenon. 51.25% of them conflicted with accelerating, 42.5% who stopped abruptly, and 6.25% who passed during the red signal.

Key words: dilemma zone, amber onset, clearing distance, stopping distance

Introduction

Road accidents have killed millions of people since 1900, and the number of deaths and injuries increase in proportion to the number of drivers, and the total number of miles driven in a given area. The intersections are one of the areas contributing to high percentage of accident occurrences. The problem with signalized intersections is associated with the decision to be made by the drivers whether to stop or to proceed at the onset of amber signal. Inappropriate decisions of drivers in responding to onset of amber are commonly will associated to crashes.

The main purpose of the yellow indication after the green is to alert motorists to the fact that the green is about to change to red and to allow vehicles already in the intersection to cross it. Bad choice of yellow interval may lead to the creation of a dilemma zone, which may be defined as an area close to an intersection in which a vehicle can neither stop safely before the intersection nor clear the intersection without speeding before the red signal comes on. The required yellow interval is the time period that guarantees that an approaching vehicle can either stop safely or proceed through the intersection without speeding.

A risk of accident may be expected if a driver takes too long time to react with the instantaneous changes in traffic situations, and if the decision made was incorrect even though the time taken to decide was short. Therefore, it is important to consider human factor in the design of a traffic signal system at an intersection. This research represents an aspect to study the driver behavior at the onset of amber period in a signalized intersection.

Research Problem

The area close to a signalized intersection, called dilemma zone, poses a high accident potential for the driver in stopping safely during the yellow interval or in proceeding through the intersection before the beginning of red. Generally, the location of the driver on the intersection approach and the speed of the vehicle influence the driver's decision to stop or proceed when he sees the green signal changing to yellow (FHWA 2005).

The clearing distance is the distance the vehicle travels between the time the signal changes to yellow to the time the signal changes to red. The stopping distance is the distance traveled by the vehicle between the time the signal changes to yellow to the time when the vehicle actually comes to rest. If the stopping distance is greater than the clearing distance, and the vehicle is placed in between them, a dilemma zone is formed.

In this situation, neither the distance to the intersection is adequate for stopping nor is the signal interval adequate for clearing the intersection. The driver is in a potentially hazardous situation whereby, if he tries to cross the intersection at the onset of red interval, he may end up in an angle accident with the cross street traffic or if he accelerates through yellow, he may end up in a rear-end collision. The uncertain situation in a dilemma zone can potentially lead to rear-end or right angle collisions (FHWA 2005).

Research objectives

The main objective of this study is focused on driver's decision at the onset of amber period at signalized intersection either proceed to clear the intersection or stop safely before the stop line. The other objective is to study the existence of dilemma zone and its types in the selected intersection.

Literature Review

Traffic signal controlled system

A traffic light, or traffic signal, is a signaling device positioned at a road intersection, pedestrian crossing, or other location in order to indicate when it is safe to drive, ride, or walk using a universal color code. The function of a traffic signal system is to regulate or rotate the right of way and makes orderly traffic movement hence reduces conflict point as much as possible. It promotes safe and efficient traffic flow at busy intersections. But there are disadvantages of traffic signals too, it includes result of rear-end collision, increase total delay and if signal is not working can lead to serious traffic difficulties especially during peak hour (Gillian Lissem 2008).

In most countries, the sequence of signal indications is red, green, and amber. An amber or yellow light warns that the signal is about to change to red. In this interval, drivers should continue moving and clear the junction safely if they are in the intersection but if they are not, they can come to a safe stop. However, this system is not fully perfect as many road crashes occur, especially during the signal change interval from amber and following all-red periods (Retting et al. 1999).

If a traffic signal is the most appropriate choice of traffic control for the intersection, it is important to ensure that the driver can see the traffic signal far enough away from the intersection so that driver can stop safely upon viewing the yellow and red display (Institute of Transportation Engineers, 1999).

Safety at Signalized Intersection

Major challenges in road design include more traffic congestion, the impacts of population growth, increased speeds, a higher degree of risk-taking among road users, increasing complexities between road users and pedestrians and modern urban design and planning issues. Therefore, traffic engineers need to ensure that roads are able to accommodate as much traffic as possible due to safety and environmental constraint (Gillian Lissem 2008).

Safety at signalized intersections depends on the geometric design, the traffic volumes at the approaches, the phasing and time setting of the traffic signal and the course of human behaviors of both drivers and pedestrians. Further, the combinations of good geometric design and good traffic control will make the intersections operate efficiently and safe (Gillian Lissem 2008).

Dilemma zone at signalized intersection

One of the main contributors to signal-related accidents is the existence of a dilemma zone at signalized intersections. Thus, understanding the dynamic nature of intersection dilemma zones so as to design counter measures has emerged as one of the imperative research issues in the traffic safety community (Hicks, and Tabacek 2006). As defined in the ITE handbook (1999), a dilemma zone is a range, in which a vehicle approaching the intersection during the yellow phase can neither safely clear the intersection, nor stop comfortably at the stop-line. Figure (1) illustrates this phenomenon.

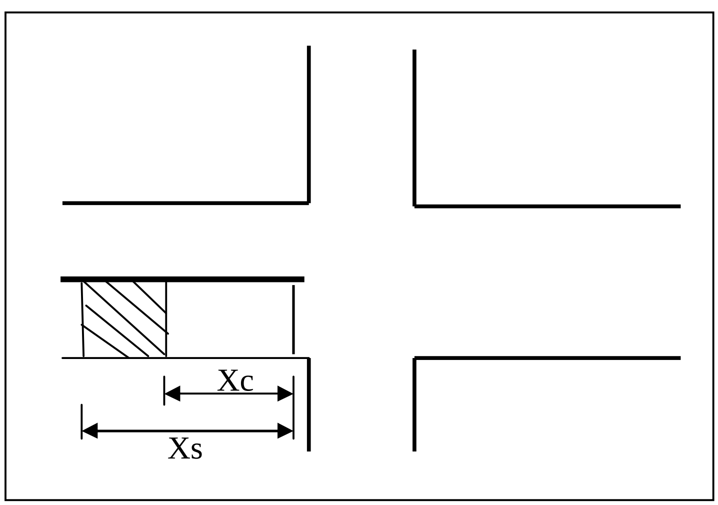

Fig. (1): The dilemma zone

The length of the dilemma zone is dynamic and increases with the increment of approaching speeds, which can be calculated by Equation (1), So, the speeding drivers are most likely involved in the dilemma zone problem.

$$\mathbf{Xs - Xc = V(tr - YT + V/2a)} \qquad \text{...............(1)}$$

Where,

Xs = the minimum distance to safely stop at the intersection (m), and calculated by the equation, Xs = V (tr + V/2a), which is equal to the stopping sight distance.

Xc = the maximum distance to safely cross the intersection (m), and calculated by the equation, Xc = V*YT – (W+L)

V = vehicle speed limit(m/s).

tr = reaction time (assumed 1 sec.).

YT = the yellow change interval, sec.

W = intersection width (m), L = vehicle length (m).

a = deceleration rate (m/s^2).

Note that both the length and the location of a dilemma zone may vary with the speed of the approaching vehicles, driver reaction times, and vehicle acceleration - deceleration rates.

In review of the literature, it is evident that the first intersection dilemma zone model, also termed as “Type-I Dilemma” was developed by Gazis, Herman, and Maraduin. They also indicated that incompatibility frequently exists between a driver’s desire to comply with the yellow-light-phase indication and driver encountered constraints. Olson and Rothery conducted field observations at five intersections and found that drivers tend to take advantage of the long yellow-light phase and view it as an extension of the green phase (Hicks, and Tabacek 2006).

The other dilemma, termed as “Type-II Dilemma” was proposed to accommodate the problem of indecision when both stopping and passing maneuvers can be executed. It defines the dilemma zone as the range in which 10 to 90 percent drivers decide to stop (Urbanik, and Koonce 2005). (Zeeger et al.) also proposed a measuring method termed as "option zone" in which 90% vehicles stop and 10% go under the condition of stochastic traffic distribution.

Transportation researchers in recent years began to realize that both the location and length of dilemma zones are dynamic in nature, and may vary with the complex interactions between the response of drivers, yellow phase duration, vehicle mechanical performances, intersection geometric features, and average traffic flow characteristics. For instance, Moon and Coleman proposed a strategy to minimize the gate delay by adjusting rail-gate closing actions, based on the length and locations of dilemma zones on highway-rail intersections (Hicks, and Tabacek 2006).

For signalized intersections, several improvements of the dilemma zone protection system have been proposed. Instead of using an assumed desired speed, those approaches use the measured speed of a vehicle to determine its individual dilemma zone.

However, those improvements did not fully address the probabilistic nature of the dilemma zone due to the measure error and driver preferences. A recent study by (Tarko, et al 2006) proposed a framework to deal with the probabilistic dilemma zone problem by introducing the dilemma zone likelihood function as well as a method to optimize the green extension time. (Xiang, et al. 2005) performed an extensive numerical investigation of the dilemma zone dynamics under different driving populations and vehicle characteristics. Based on the survey results, they also classified driver behavior into several distinct patterns, and identified the potential key factors that may affect a driver's decision-making process during the yellow phase. However, due to the constraints of the sample size and the measurement method, their results are informative, but not sufficient for computing the dilemma zone distribution under different driving populations.

Amber signal timing

The amber phase is defined and designed for the purpose of allowing the decision making process to occur in safe conditions. Although there is no universal practice for selecting the duration of the amber period, many state and local transportation agencies follow guidelines published by the Institute of Transportation Engineers (ITE, 1999) that consider site-specific criteria including traffic speeds, deceleration and acceleration rate, condition of pavement and intersection geometry.

The Manual on Uniform Traffic Control Devices (MUTCD 2004) indicates that amber intervals should range from approximately 3 to 6 seconds. The reason for that longer interval is to reserve for approaches with higher traffic speeds. Because drivers generally cannot predict the onset or duration of an amber signal, the likelihood that a driver will stop on a red signal is related to vehicle speed and distance from the intersection when the signal changes to amber.

There are factors to be considered in determining a suitable amber interval for a signalized intersection includes (Gillian Lissem 2008):
i) Deceleration rate or acceleration rate.
ii) Condition of pavement (wet or dry) where the coefficient of friction is required.
iii) The gradient of the lane.
iv) Lane width.
v) The vehicles approaching speed.

Stopping sight distance

A driver is in a dilemma zone when he sees the yellow traffic light but is both too far away from the intersection to cross and too close to the intersection to stop, the consequence is that he will either run the red light or must brake abruptly. This is a potential cause for traffic accidents in the intersections. Given the speed v (in mph) that the vehicle is at the beginning of the yellow light, there is a standard formula for computing the stopping sight distance SSD. This is the sum of the reaction distance and the braking distance (Prahlad and Cheng 2001).

$$\mathbf{SSD = t^{*}V_o + V_o^2/2a\,(g+f) \quad \ldots\ldots(2)}$$

Where:

SSD, is the stopping sight distance (m).
t, is the perception reaction time (s).
V_o, is the vehicle approaching speed.
a, is the deceleration / acceleration rate (m/s^2).
g, is the grade coefficient, and
f, is the coefficient of friction.

If SSD is longer than the distance from the vehicle to the intersection when the traffic signal turns yellow, the driver does not have enough distance to stop the vehicle. If it is also the case that the vehicle cannot reach the intersection in the current speed (this happens when the clearing distance, or the distance the vehicle travels before the signal turns red, is shorter than the distance to the intersection), the driver is in a dilemma zone and in danger of causing an accident. The speed and distance to the intersection at the time when the traffic signal turns yellow are assumed to be the only factors that determine whether the driver will be in a dilemma zone.

Data Collection

Observations were made at a signalized intersection in Syria-Damascus city named Al-Jalaa club intersection, located on Al Maza Jabal street behind Al-Jalaa sport club. Data for this intersection was collected by the researcher on January of 2009 year. The timing diagram showing the intersection signal indications is illustrated in Figure (2). The geometric layout of this intersection is shown in the Figure (3).

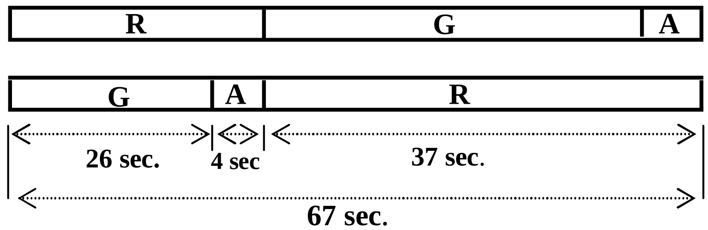

Fig. (2): The intersection two phase signal timing

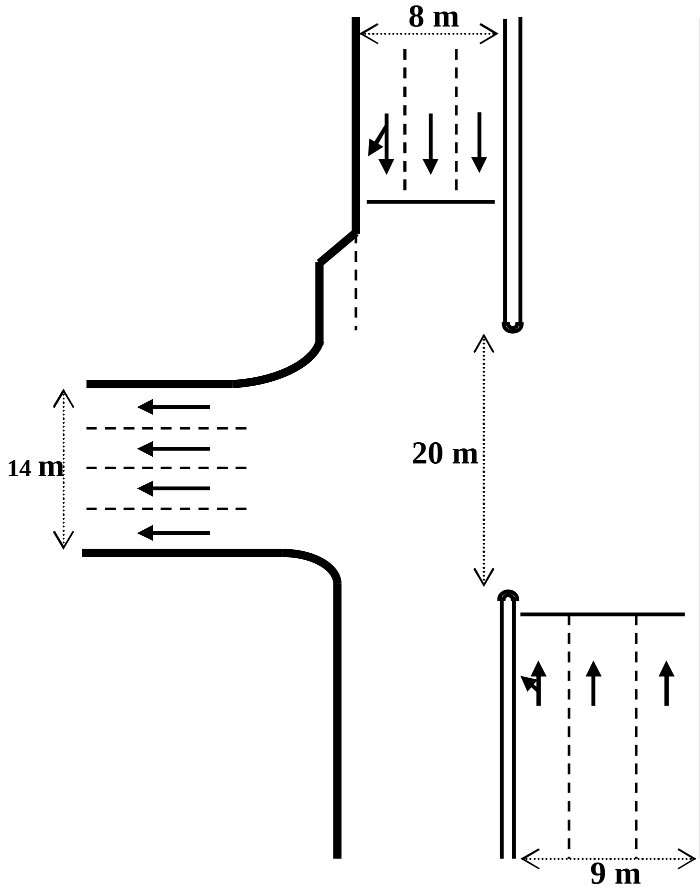

Fig. (3): The intersection geometric layout

Field data was collected using video recording technique. The camera is mounted on tripod and placed at high location, not far from the selected signalized junctions. The view must include the stop line and extend back along the approach for a distance equal to that needed for the desired detection layout. The purpose is to obtain clear view of the junctions without distracting the movement of traffic. This set-up is chosen in order to get well-arranged data collection. Sessions for a period of one hour for each approach were recorded (the selected intersection consists of two signalized approaches). Recording sessions were conducted during an off peak daytime and under dry condition.

Data abstraction, processing

The recorded data were reduced into sessions of thirty minutes period because this session is sufficient to provide a statistically meaningful sample size, and to avoid the large fluctuations that may occur in traffic flow. The film was played back several times to observe the required information.

The process of abstracted data achieved with the aid of a computer program named (EVENT) developed by Dr Ali.K. AlNeami. The program produces time accuracy values recorded for the successive events. Traffic flow, traffic composition, time headways for successive vehicles may be concluded from the program output files. The abstracted data were processed to determine the required data necessary for this research.

Analysis and results

The main item to focus on is the number of drivers who made decision either to stop or clear the intersection safely at onset of amber. Several parameters are considered has significant effects to driver’s decision. The parameters consist of vehicle speed, types of vehicle, stopping distance from the stop line. The following sections will describe the analysis of these parameters:

Vehicle speed

Speeds of approach vehicles were measured using the floating car technique. The researcher used his own car as a test car. The test car is travelling at the average speed of all vehicles. The test car is trying to pass the same number of vehicles that overtake it. There is a probability that the test car will not be travelling at the average speed, therefore, this process was made ten times for each approach. The test car speed is recorded for each trial. The average value is then computed which is found to be **(40 km/h)** while the maximum and minimum speed value were **50 km/h**, and **25 km/h** respectively. The average value will be taken as the approaching speed for the intersection to be used later to forecast the existence of dilemma zone.

Vehicle types

The traffic composition of the observed flow in the selected intersection is shown in the Table (1) below:

Table (1):- Intersection traffic flow composition

Vehicle type	Passenger car	Mini buses	Small pickups
% from traffic	95	3	2

The traffic composition may considered as 100% of passenger cars because both the mini buses and the small pickups are of four wheels and they are similar to the passenger car in the size and performance.

Stopping sight distance or the minimum distance to stop safely (x_s)

The standard formula for computing the stopping sight distance SSD or the minimum safely stopping distance is (1),

$$\mathbf{Xs = V\ (\ tr + V/2a)} \quad \ldots\ldots\ldots\ldots..(3)$$

The parameters for equation (3) was defined hereinbefore.

For the average approaching speed 40 km/h (11.11m/s) and the acceleration rate is 3.28 m/sec^2 as discussed in the literature, the resulted Xs is 30 m. While the maximum safely crossing distance is equal to

$$V*YT = 11.11 * 4 = 44.44 \text{ m}$$

This value implicitly includes the intersection width (22 m) and the average vehicle length is 5 m. these values will be subtracted to represent the Xc value shown in Figure (1), while the 30m represents the stopping distance which is the Xs value illustrated in the same figure. The interpolation between these two figures represents the dilemma zone area length which is (30-17.5=12.5 meter).

Number of vehicle caught in amber onset

After the processing of the extracted data was done, it was concluded that **226** vehicles were observed at the onset of amber at the two approaches of the selected intersection. As the amber signal appears, drivers will have to decide to proceed or to stop. In this observation, about 56.25% of drivers decided to proceed through amber while 37.5% of drivers were decided to stop at onset of amber and 6.25% of drivers decided to proceed through red signal. Table (2) shows these results. Figures (4), (5) indicate the observed vehicles during the amber onset in the selected signalized intersection.

Table (2): Percentage of vehicles in amber onset

Vehicles no.	% proceed at amber	% stop	% proceed at red
226	56.25	37.5	6.25

Fig. (4): Observed accelerating dilemma zone

Fig. (5): Observed uncomfortable decelerating dilemma zone

Number of vehicle caught in dilemma zone

An analysis of the processed data also involved the determination of existence of dilemma zone conflict. dilemma zone may detected due to three conditions. Firstly, driver detected in dilemma zone conflict when he/she accelerate through amber. Secondly, dilemma zone conflict also occurs when drivers who stop without comfortable deceleration rate. According to Arahan Teknik Jalan (Gillian Lissem 2008), a comfortable deceleration rate is 3.28 m/s^2. Thirdly, a driver who ran red light is also in dilemma zone conflict.

Acceleration or deceleration rate may be detected only when the approach speed and the speed at the area of stop line for each vehicle observed in the onset of amber are calculated. This is difficult to perform during this research study.

The alternative method is to playback the recorded sessions several times in order to detect the accelerated vehicles or the sudden breaking and deceleration for each vehicle observed during the amber period. It was found that **96** drivers detected in dilemma zone conflict due to three dilemma zone conditions, **51.25%** of them conflict with accelerating, **42.5%** who stop without comfortable deceleration, and **6.25%** who proceed during the red onset. Table (3) indicates these results.

Table (3): Percentages of dilemma zone conflict

Drivers no.	% proceed at amber	% stop abruptly	% proceed at red
96	51.25	42.25	6.25

The results for dilemma zone detection at this selected signalized intersection is different from previous study conducted. According to a research done by Jill Fluer Benson (2006), the major dilemma zone conflict comes from accelerating during amber with 35.22 percent followed by running red light with 18.7 percent and lastly stopping abruptly with 7.83 percent. This difference is mainly due to the driver behavior and their traffic education and partly to the implementation of authority laws.

Conclusions and recommendations

Conclusions

The study indicated that the three types of conflicts namely, running red light, stopping abruptly and accelerating through yellow can be successfully used to identify vehicles that experience dilemma zone problems at signalized intersections. It revealed that the accelerating through yellow was the major conflict for all intersections, followed by stopping abruptly and running red respectively.

The concluded statistical numbers are shown in the followings:

1- The observed sample size for the drivers was (226) and 37.5% of the drivers that observed during the amber period were stopped while 56.25% were proceeded at the amber onset and 6.25% were passed the intersection at the red onset, that is the majority of driver are conservatives and trying to obey the traffic restrictions.

2- 42.47% of the detected drivers in the amber onset were conflicted by the dilemma zone phenomenon. **51.25%** of them conflict with accelerating, **42.5%** who stop without comfortable deceleration, and **6.25%** who proceed during the red.

Recommendations

1- The amber length for the selected intersection is four seconds. It is clear from the concluded results and the geometric layout of the intersection that this length is sufficient, so it is recommended to redesign the cycle time for the intersection to take in the consideration the driver behavior and existing traffic demand.

2- To complete the issue of the existing of dilemma zones in the signalized intersections in Damascus city, it is recommended to study a various number of intersections.

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